NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

**OFFICE OF THE
GENERAL COUNSEL**

Case #06-281?

October 18, 2006

Ms. Marcia Hofmann
Staff Attorney
Electronic Frontier Foundation
1875 Connecticut Avenue, NW, Suite 650
Washington, DC 20009

Dear Ms. Hofmann:

This is in response to your September 19, 2006 Faxed Freedom of Information Act (FOIA) request for copies of the NSF funded grants numbered 0219893 and 0524540.

Records responsive to your request are enclosed. There are no reports under the grant numbered 0524540. Personal information (individual salaries, bios, pending and non-Federal grants) has been withheld wherever it appears under the privacy protection of Exemption 6 of the FOIA. Reviewer identifying information in the proposal jacket is withheld under exemptions 5 and 6 of the Freedom of Information Act (5 U.S.C 552(b)) that protect from disclosure the predecisional, deliberative process and personal information and exemption (k)(5) of the Privacy Act (5 U.S.C. 552a). Further, reviewer's comments/rankings are exempt from disclosure under the provisions of Exemption (b)(5) of the FOIA. Your right of administrative appeal is set forth in Section 612.9 of the NSF FOIA regulation (copy enclosed).

There is no fee for FOIA services in this instance in accordance with 5 U.S.C. 552 (a)(4)(A)(i) et seq.

Sincerely,

Leslie A. Jensen
FOIA/Privacy Act Officer

Enclosures

§612.9 Appeals.

(a) Appeals of denials. You may appeal a denial of your request to the General Counsel, National Science Foundation, 4201 Wilson Boulevard, Suite 1265, Arlington, VA 22230. You must make your appeal in writing and it must be received by the Office of the General Counsel within ten days of the receipt of the denial (weekends, legal holidays, and the date of receipt excluded). Clearly mark your appeal letter and the envelope "Freedom of Information Act Appeal." Your appeal letter must include a copy of your written request and the denial together with any written argument you wish to submit.

(b) Responses to appeals. A written decision on your appeal will be made by the General Counsel. A decision affirming an adverse determination in whole or in part will contain a statement of the reason(s) for the affirmance, including any FOIA exemption(s) applied, and will inform you of the FOIA provisions for court review of the decision. If the adverse determination is reversed or modified on appeal, in whole or in part, you will be notified in a written decision and your request will be reprocessed in accordance with that appeal decision.

(c) When appeal is required. If you wish to seek review by a court of any denial, you must first appeal it under this section.

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2		FOR NSF USE ONLY	
NSF 01-149 02/07/02		NSF PROPOSAL NUMBER	
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **CCF - ITR SMALL GRANTS**		**0219893**	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **Purdue University**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Purdue University** **Young Hall** **West Lafayette, IN. 479072108**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0018259000**	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions)   ☐ FOR-PROFIT ORGANIZATION   ☐ SMALL BUSINESS   ☐ MINORITY BUSINESS   ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT   **ITR: Printer Characterization and Signature-Embedding for Security and Forinzic Applications**

REQUESTED AMOUNT $ **499,999**	PROPOSED DURATION (1-60 MONTHS) **36** months	REQUESTED STARTING DATE **08/15/02**	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)

☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)

☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)

☐ HISTORIC PLACES (GPG II.C.9)

☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)

☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date _____

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 Exemption Subsection _____ or IRB App. Date _____

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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT **Electrical Engineering**	PI/PD POSTAL ADDRESS
PI/PD FAX NUMBER **765-494-9893**	**West Lafayette, IN 47907** **United States**

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Jan P Allebach**	**PH.D**	**1976**	**765-494-3535**	**jan.p.allebach.1@purdue.edu**
CO-PI/PD **George T.-C. T Chiu**	**PhD**	**1994**	**765-494-2688**	**gchiu@purdue.edu**
CO-PI/PD **Edward J Delp**	**PhD**	**1979**	**765-494-1740**	**ace@ecn.purdue.edu**
CO-PI/PD				
CO-PI/PD				

     Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 02-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix A of the Grant Proposal Guide.

Debarment and Suspension Certification   (If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?   Yes ☐   No ☒

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Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE	DATE
NAME **Diane E Troyer**		**Electronic Signature**	**Feb 7 2002 4:13PM**
TELEPHONE NUMBER **765-494-1052**	ELECTRONIC MAIL ADDRESS **dtroyer@purdue.edu**		FAX NUMBER **765-494-1360**

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

Project Summary

Printed material is a direct accessory to many criminal and terrorist acts. Examples include forgery or alteration of documents used for purposes of identity, security, or recording transactions. In addition, printed material may be used in the course of conducting illicit or terrorist activities. Examples include instruction manuals, team rosters, meeting notes, and correspondence. In both cases, the ability to identify the device or type of device used to print the material in question would provide a valuable aid for law enforcement and intelligence agencies.

Proposed Strategy We propose to develop two strategies for printer identification. The first strategy is passive. It involves characterizing the printer and finding intrinsic features in the printed output that are characteristic of that particular printer, model, or manufacturer's products. We call this the intrinsic signature. Developing the intrinsic signature requires an understanding and modeling of the printer mechanism, and the development of image analysis tools that are used for printer characterization during the signature development phase, and then later, for the actual detection of the signature in printed pages with arbitrary content.

The intrinsic signature is detected by scanning the printed pages with a high resolution drum scanner, and applying low-level image analysis routines to extract features. These features are processed with a soft classifier to yield likelihoods at each level of a decision tree that the document was printed with a device belonging to each particular class. At the highest level of the decision tree, likelihoods are provided for which of the two possible dominant printing technologies - electrophotography (EP) (commonly referred to as a laser printer) and inkjet (IJ) was used. At the next level, likelihoods are generated for the candidate printer manufacturers, and so on. As we proceed down through the tree, we generate liklihoods regarding information that is more and more specific to the particular printer in question.

The second strategy is active. Here we embed an extrinsic signature in every printed page. This signature is generated by modulating the process parameters in the printer mechanism to encode identifying information, such as the printer serial number and date of printing, in every printed page. To detect the extrinsic signature, we again scan the printed pages, and process them using image analysis techniques; but in this case, our goal is to decode the signature to extract the information embedded in it. Development of the methodology for extrinsic signature embedding will build directly on our work with intrinsic signatures. We will use our knowledge of the printer mechanism models and the results of the printer characterization to determine the printer process parameters that can be modulated to encode the desired identifying information. The modulation of these parameters will require modification to the actual printer mechanism.

It is important to note that although both intrinsic and extrinsic signatures will be designed to work with arbitrary printed page content, the success of the detection, decision, and decoding processes for a particular printed page will depend on the amount of page coverage by printer marks. With their extensive research experience in printing, image processing, and watermarking, the principal investigators are uniquely qualified to conduct the proposed research. An additional distinguishing feature of the proposed effort will be the development of an undergraduate project course that will be associated with the research. In this course, students will learn about printing technologies and the application of electrical and mechanical engineering theory from their core courses to analysis and modeling of printing system. They will also learn about image processing and decision theory; and they will see how all these tools can be applied to the solution of practical real-world problems.

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C   Project Description (Including Results from Prior   15   _____
    NSF Support) (not to exceed 15 pages) (Exceed only if allowed by a
    specific program announcement/solicitation or if approved in
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E   Biographical Sketches (Not to exceed 2 pages each)   6   _____

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J   Appendix (List below.)   _____   _____
    (Include only if allowed by a specific program announcement/
    solicitation or if approved in advance by the appropriate NSF
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    Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated.
Complete both columns only if the proposal is numbered consecutively.

1 Overview

1.1 The Problem

Simply stated, we plan on investigating methods that will allow one to determine if a given document was printed on a particular digital printer. Our approach is unique in that we will use our extensive experience in characterizing the performance of inkjet and laser printers to develop techniques to essentially authenticate a printer and a document. We will also develop new methods to embed security features in all printers by exploiting how the printer actually places marks on the paper to form the printed document. This approach is far different than adding structures (e.g. watermarks) to a document before it is sent to the printer. Our approach will be more robust and tamperproof.

Our modern world order is characterized by a high degree of interdependence among individuals and organizations. This interdependence can only exist in an environment of trust and communication. Aside from providing the very glue that holds everything together, reliable communication of information promotes better understanding among different cultures and ultimately works toward the goal of world peace and a uniform standard of living. Among the various media for communication, the printed document occupies a central position. Print was the first means of broadcast communication. It offers unparalleled flexibility of use, is accessible to everyone, is highly stable, and has been robust to changes in technology across many centuries. In addition, print provides an aesthetic experience the visual and tactile components of which cannot be duplicated by a softcopy display.

With the rise of electronic technologies during the past four decades, forecasters and pundits have for some time been predicting the demise of paper. Contrary to their assertions, the use of paper has grown, not contracted during this time. For example, data from the American Forest and Paper Association shows that the U.S. consumption of document paper grew from about 450 lbs per capita in 1965 to about 700 lbs per capita in 1995 [1].

What has changed with the digital age is the way in which we use paper. While the invention of the printing press made it possible for everyone to receive broadcast information in print form, only a very limited set of individuals had the means to generate that information, i.e. to publish documents. Personal computers, desktop printers, and the internet have changed all that. They have enabled each and every one of us to be a publisher of printed content. Lyra Research predicts that U.S. digital print paper usage will continue to increase through the middle of the current decade by approximately 4% per year [1].

But these same technologies, which have so wonderfully democratized the creation and dissemination of information, are also very important to those individuals or organizations intent on criminal or terrorist acts. Printed media plays two roles in crime and terrorism. First, it often serves as a direct accessory to the crime, i.e. the criminal or terrorist entity may use electronic publishing capabilities to falsify printed material. Business documents, identity documents, financial security documents, and packaging for high-value or health and safety related products are all examples of printed material for which falsification may be of great benefit to a criminal or terrorist entity.

Secondly, criminal and terrorist individuals and organizations function just like any other individual or organization in many respects. In particular, these entities have communication needs that must be met in order to function efficiently and to achieve their goals. Printed media is one form of communication that is widely used for this purpose. Printed documents that might be employed by such an entity include organizational rosters, planning records, instruction manuals, and correspondence. All these documents provide a rich source of information to law enforcement and intelligence agencies charged with eliminating crime and terrorism.

Historically the police and other security services have used the ability to determine whether a document was typed on a particular typewriter as evidence that could be used in court. More recently an electronic version of this occurred when at 12:32 a.m. on April 27, 1986 an individual, identifying himself as "Captain Midnight," took over the Galaxy 1 satellite used by HBO and broadcast a text message for 4.5 minutes complaining about HBO's new pricing policy [2]. John R. MacDougall was later caught by the FBI and prosecuted. MacDougall was caught because someone noticed that the fonts used to construct the message were of a particular type used in a British video character generator. This enabled the FBI to find the satellite uplink station in Georgia used to temporally disable the HBO feed and then determine that MacDougall was on duty that night. Being able to characterize and identify printers will provide the same capability for printed materials as it was for video in the MacDougall case.

1.2 Opportunities

Printing is rapidly becoming an almost exclusively digital enterprise, except where very long runs (more than 500 to 1000 copies) are desired. Low-end digital printing devices include desktop laser and inkjet printers, digital copiers, fax machines, and multifunction devices. High-end digital printing systems include high-speed document printing systems and digital presses. With all these systems, every successive printed page can be different. For ease of communication in this proposal, we will simply refer to all fully digital printing devices as "printers".

Here at Purdue, two of the co-principal investigators on this proposal, Jan Allebach and George Chiu, have worked with a major printer manufacturer for over 10 years (both in the context of sponsored research and as employees with the company) to understand the causes of print quality artifacts that are due to the physical print mechanism, as opposed to the digital driver software and/or formatter hardware and firmware, and to devise means to reduce or eliminate these artifacts [3, 4, 5, 6, 7, 8]. From another perspective, that is pertinent to this proposal, these very print quality artifacts can be viewed as a signature that provides identifying information about the printer. The task of extracting this signature from the printed output requires image analysis at the front-end and decision-making capability at the back-end. The same image analysis capabilities that we have developed for characterizing printers in the context of artifact reduction [3, 4, 5, 6, 7, 8] will be germane to this task. At the back end, we will leverage the expertise of the third co-principal investigator Edward Delp in the area of optimal decision theory [9].

In order to eliminate artifacts due to the print mechanism, we have developed a variety of active strategies that modulate printer process parameters to cancel the sources of the artifacts [3, 4, 5, 6, 7, 8]. This modulation capability offers the potential to actively embed an *extrinsic signature* in the printer that would provide much more information, and be much more robust than the *intrinsic signature* alone. Such a signature is essentially a watermark. This is a major area of expertise of Edward Delp. He has done research in watermarking and secure communication for seven years [10]. In addition, he has co-chaired the annual IS&T/SPIE Conference on "Security and Watermarking of Multimedia Contents" for five years, and is a consultant to the industry leader in the area of watermarking. It is essential that an extrinsic signature embedded in printed material be imperceptible to the human viewer. We will draw upon Jan Allebach's expertise in print quality assessment and human visual system modeling [11, 12, 13, 14, 15, 16] to satisfy this objective.

For runs that are longer than 500 to 1000 copies, the preferred solution is still a conventional offset, lithographic, or intaglio press. These systems all use a physical printing plate to convey the printed information to the paper. Since the plate cannot be changed on the fly, successive impressions will be identical. While these systems are analog, digital systems are commonly used

to transfer the page image to the printing plate. This process of writing the plate is very much analogous to the process of printing a single page with a fully digital printing device, as discussed above. Thus, the solutions to be developed as part of this research will also have general applicability in the domain printing with conventional presses.

1.3 Proposed Research

We propose to address the problem of linking any printed material to the device that was used to generate it. We envision several scenarios, which may be divided into two classes that we describe as *passive* and *active* modes. In the passive mode, the document is printed with a legacy printer. In this case, we must identify the intrinsic printer signature in the printed document. Given just the document alone, we seek to determine as much as possible about the printer that was used to generate it. In increasing order of specificity, we would like to know the printing technology used, the manufacturer of the device, the product line of the device, and finally the model type. Given both a document and a printer, we would like to know whether or not this particular document was printed with this particular printer.

In the active mode, we modify the print mechanism to embed an extrinsic signature or watermark that will appear on the printed page. While not visible to the human eye, this watermark can be detected by scanning the page, and processing the resulting digital image. The signature could contain a variety of information, such as the serial number of the printer used to print the document, the identification of the user that generated the print job, and the time and date on which the page was printed. It is important to emphasize that the extrinsic signature will be generated by the actual print mechanism via analog modulation of one or more of the printer process parameters. Thus it will be very difficult to defeat, compared with a digital signature that is embedded in the document by the printer driver on the host or the formatter resident in the printer itself.

2 Background

2.1 Printing Technology

2.1.1 Printer Architecture: a Security Perspective

After preprocessing the image, e.g. scaling, color correction, and other operations, the final stage of image rendering contains two image processing steps [17]. One is *halftoning* where continuous tone image is converted into binary image. The other is *converting the halftoned binary image into hardware ready bits* that will be sent to the marking (printing) engine and printed. Depending on the specific implementation architecture, halftoning can occur in the print driver on the host computer or it can reside on the formatter board in the printer in the form of firmware code or an ASIC. The process of converting halftoned images to hardware ready bits is almost exclusively implemented in the printer in the form of firmware or ASIC.

Extrinsic signatures (watermarks) can be embedded to a document during either of the above mentioned image conversion processes or it can take place when the bits are being written onto the media (paper). From a security viewpoint, the closer the embedding process is to the host computer, the greater the threat of the signature being compromised. Since tools exist for hacking print drivers, implementing watermarking algorithms in the application or printer driver may not be secure. As the cost-of-entry increases dramatically as we move from compromising the printer firmware to modifying the marking process, it is desirable to shift the embedding process as close to the marking engine (printing process) as possible.
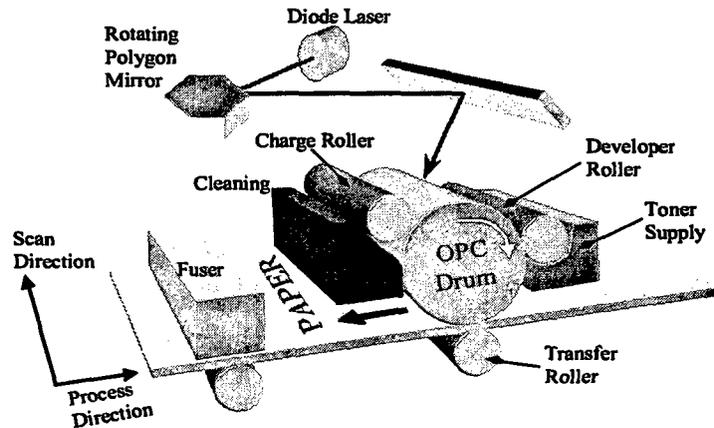
3

2.1.2 Electrophotography (EP)

Figure 1: Schematic of a typical monochrome electrophotographic process. For colors images, several process steps illustrated here will be repeated four times.

Electrophotography, also referred to as xerography, is the underlying marking technology for laser printers and document copiers. There are six processing steps in a typical EP process [18, 19]: charging, exposure, developing, transferring, fusing, and cleaning. Figure 1 shows a typical configuration of the EP process. An organic photoconductive (OPC) drum, also called a photoreceptor, rotating at a constant angular velocity is electro-statically charged through a charge roller. A latent image is then exposed onto the OPC drum by scanning a pulsed laser beam through a rapidly spinning polygon mirror. The latent image is developed by electrostatically adhering toner particles to the OPC drum. The developed image is then transferred onto the output media (paper) by moving the paper at the same linear speed as the OPC drum through a charged transfer roller. The toner image on the paper is then made permanent (fused to the paper) through heat and pressure in the fuser. The surface of the OPC drum is cleaned to remove any residual toner by a cleaning blade that scrapes across the OPC surface.

EP print artifacts can be attributed to the dot (pixel) placement error and the variation in the absorptance of each dot (dot gain). Dot gain is mainly affected by the quality and consistency of the exposure, development, transfer, and fusing steps. For example, laser intensity noise may cause nonuniform exposure of the OPC and lead to inconsistent dot gain that is manifest as streaking in uniform areas [20, 21]. The size and geometry of the toner particles and the electrostatic development and transfer process will also affect the amount of toner transferred on to the media and will impact dot gain. Dot placement accuracy is mainly affected by the motion quality of the rotating rollers, OPC drums and the polygon mirrors. As an example, periodic velocity fluctuation due to gear train tooth-to-tooth meshing imperfection, eccentricity, and load induced structure vibration will result in periodic dot placement error [22, 23]. Wobbling of the rotating polygon mirror will result in dot placement error in both the scan and process directions.

The periodic dot placement errors in the process direction (scan line spacing fluctuation) will result in banding artifact, which is the periodic fluctuation in absorptance, see Fig. 2(a). Figure 3 shows the waveforms and spectra of the projected absorptance and the corresponding scan line spacing scanned from the printout of a typical 600 dpi printer at 2000 dpi. In Figs. 3(a) and 3(b), we can observe corresponding peaks at the same spatial frequencies in scan line spacing and projected absorptance. The spatial frequency can be traced to the particular meshing character-

4

(a)
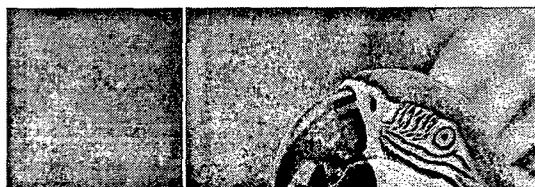
(b)

Figure 2: Banding artifact for a typical EP printer. The top image shows the banding artifact that is due to velocity fluctuation of the OPC drum. The bottom image is printed from the same printer as the top image, but with real-time banding compensation.
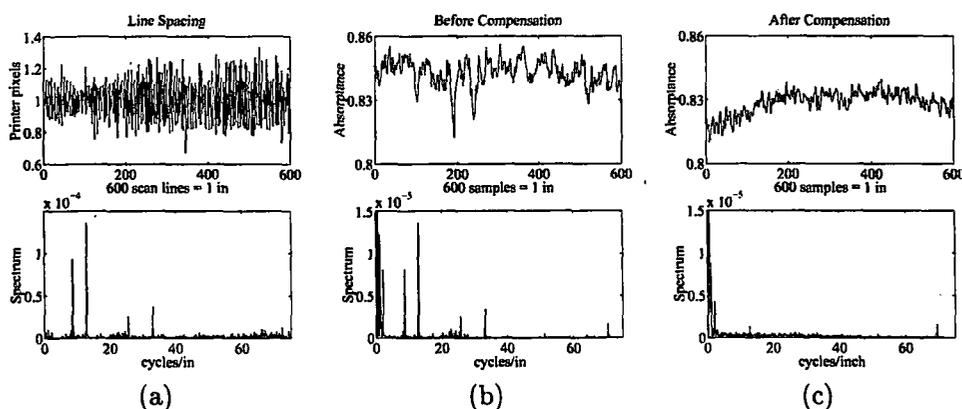

(a)   (b)   (c)

Figure 3: Waveforms and spectra of (a) scan line spacing, (b) horizontally projected absorptance before compensation, and (c) projected absorptance after compensation.

istics of specific pairs of gears in the EP process. *The distinct features of the banding artifact are unique to the print mechanism and can be interpreted as an example of the intrinsic signature that characterizes this particular printing mechanism.* Since 2000, we have developed three different hardware architectures for closed-loop banding reduction by using different actuators in the EP marking engine [3, 4, 5]. Figure 4 shows the block diagram of such a system. In this system, an optical encoder is mounted on the OPC drum axis to measure the speed of the OPC drum. A DSP system computes the pulse width modulated (PWM) desired laser exposure for each scan line based on the encoder output. The bottom image in Fig. 2(b) shows the compensated image. Figure 3(c) shows the measured absorptance of the compensated image. It can be seen that the major banding frequencies are suppressed. Since our hardware banding reduction systems can be used to suppress banding, they can also be used to embed extrinsic signatures.

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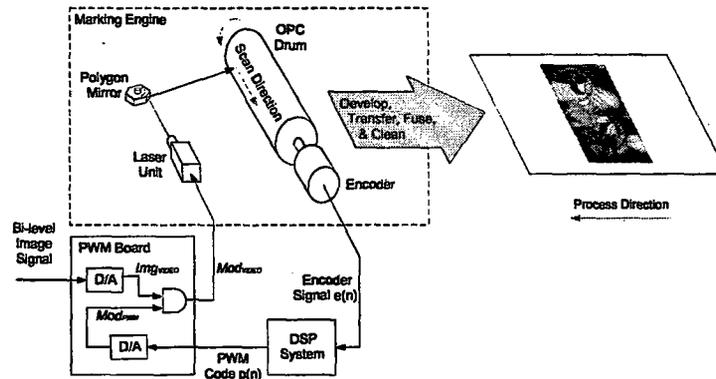
Figure 4: Block diagram of a closed-loop banding reduction system

2.1.3 InkJet (IJ)

The inkjet mechanism consists of three principle components: the print head, the carriage, and the paper advance mechanism. The print head consists of a nozzle plate containing several columns of nozzle openings and reservoirs for one or more of the different inks. The carriage moves the print head horizontally back and forth across the paper (scan direction). The paper advance mechanism picks up the paper from the input tray, advances it under the carriage (process direction), and ejects it into the output tray. Each column of multiple nozzles in the print head allows the simultaneous printing of several rows of pixels in a single pass of the print head across the paper. Two columns of nozzles may be offset vertically by half the distance between the nozzles and fed with the same color ink to yield a vertical spacing between rows of pixels that is smaller than the vertical distance between the nozzles.

Inkjet print artifacts are due to either irregularity in the size and shape of dots or dot placement errors. The cause of dot irregularity may be either ink coalescence or creation of satellites. Ink coalescence can take place when adjacent nozzles are fired simultaneously. Firing the nozzles at a high frequency may cause puddling around the nozzle opening that can create the satellites. Multiple-pass print modes are usually employed to avoid these printing artifacts [24]. In a multiple-pass mode, the print head visits each pixel more than once, and puts a drop there during a certain pass. Therefore, extra logic control is required to determine whether the pen should fire a drop at a given location on a given pass. Print masks are applied to provide this extra logic [24]. They are usually coded as an array of 0's and 1's. A 1 indicates firing the nozzle, if the halftone pixel at that point has value 1. A 0 means no firing regardless of the value of the corresponding halftone pixel. Figure 5 [24] shows an example for a two-pass print mode, with print mask width four and height eight. As this mask array is tiled over the media, the pen sweeps across the media and marks every other pixel location if the halftone pixel value there is 1, in a checkerboard pattern. Afterwards the media is advanced half the pen height and the printing resumes. All entries that were missed by M1 the first time are picked up by M2 during the second time when the pen visits. The print masks reflect hardware limitations on firing frequency, and avoid consecutive firing of the same nozzle.

Dot placement errors can be caused by errors in the paper advance, positioning errors in the positioning of the carriage, or misaligned nozzles in the print head. Figure 6 illustrates a typical nozzle geometry. The print head contains nozzles for three colorants, cyan, magenta, and yellow; and each colorant is assigned two columns of the nozzle. From the top view, we can see that the nozzle columns of each colorant are at the edge of the ink feed slot; and the nozzle plate bows down into the ink feed slot as it spans the void. The drop will travel roughly perpendicular to the nozzle
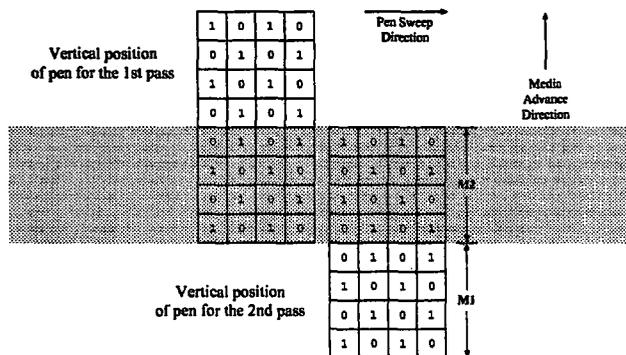
6

Figure 5: Illustration of the two passes used to print the pixels in the shaded region for an inkjet printer.

plate at the nozzle. However, since the nozzle columns are located on the curved part of the plate, the normals to the nozzle plate at each nozzle column have a slight inward tilt, causing the drop to travel slightly inward. This phenomenon is sometimes referred to as a toe-in or dimple effect.
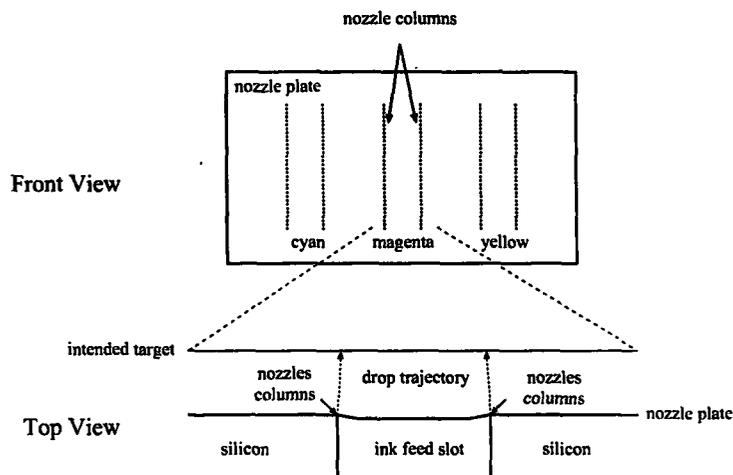

Figure 6: Structure of print head.

Any given printer can be operated in a number of different modes by varying the carriage velocity, whether or not printing occurs only during the left-to-right pass (uni-directional) or during both passes (bi-directional) of the carriage, the number of passes used to fully print a given horizontal swath of the paper, and the print mask. The combination of all these contributors to print quality artifacts can lead to a very complex intrinsic signature with many different identifiable features. However, one or two features will typically be much more prominent than the others. To illustrate, we consider the HP DeskJet 970Cx printer operating in a 600 dpi, 10 in/sec, uni-directional, multiple-pass print mode. By printing special test patterns, scanning the results, and applying image analysis techniques, we can obtain several different features of the printed dots [6].

Figure 7 shows the mean and standard deviation of the dot profiles, which are computed by aligning the centroids of each dot. The mean dot profile is about the size of the $X \times X$ pixel cells ($X = 1/600$ in) for this print mode. The mean dot profile is fairly flat within the cell, and
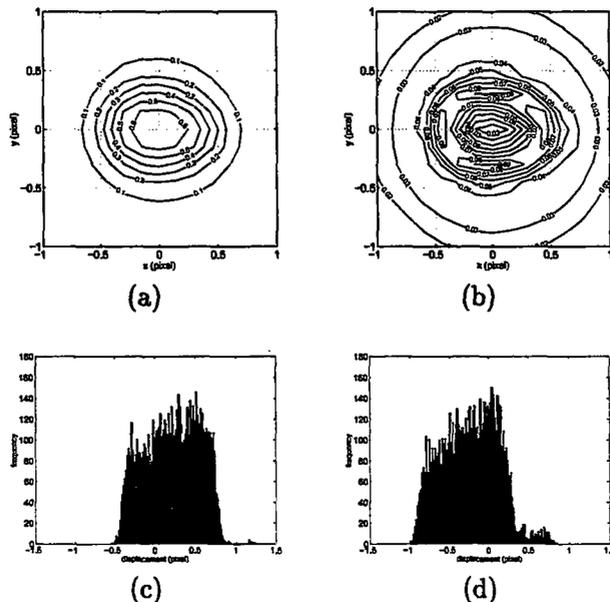
Figure 7: Measurement data for HP DeskJet 970Cx printer used in the 600 dpi, 10 in/sec, unidirectional print mode. Statistics of the dot profile: (a) mean and (b) standard deviation. Histogram of the horizontal dot displacements for (c) even lines and (d) odd lines.

rolls off quickly outside the cell. We refer to this as a "hard" dot. The fact that the variance is relatively low across the entire dot profile suggests that there is little variation in shape from dot to dot. Figures 7a and 7b show the histograms for the horizontal displacements of the dot centers from their nominal locations for even and odd rows, respectively. We see that dots are significantly displaced horizontally with different mean shifts for even and odd lines (approximately $X/4$ for even lines and $-X/4$ for odd lines). This is due to the combination of the toe-in effect mentioned above with the fact that even and odd lines are printed from nozzle columns located on opposite sides of the ink feed slot. This distinctive feature is an example of an intrinsic signature that characterizes this particular print mechanism and print mode. It results in the white veins that can be seen in the magnified dot textures from a halftone region, contained in Fig. 8a. At normal viewing distances, these veins result in an increased level of graininess in the printed image. In prior work [6], we incorporated a stochastic model within the digital halftoning algorithm to eliminate the veins, as shown in Fig. 8b. Here our goal will be to either passively detect this feature and others like it to identify the printer mechanism, or to actively modulate the feature, not to eliminate it as we did in [6], but rather to encode information in it, and to make it more robust.

2.1.4 Scanners

The most obvious counterfeiting opportunity occurs when a digital copier or multi-function product (MFP) is used to make copies of documents. A MFP is essentially a printer combined with a scanner. The scanning mechanism consists of three principle components: the light source, the CCD array and optics, and the scanner carriage motion system that either moves the media (in sheet feed scanners) or the CCD array (flatbed scanners). As the CCD array moves across the media (or vise versa), it is sampled at a rate that matches the velocity of the carriage motion to produce evenly spaced scan lines.
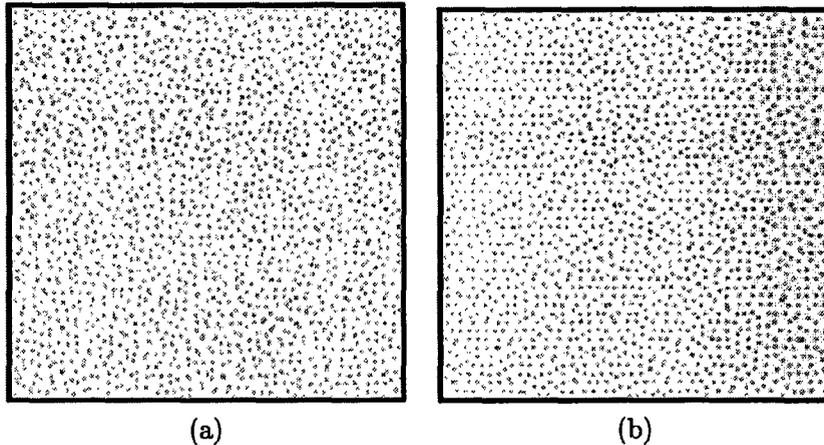
Figure 8: HP DeskJet 970Cx printer outputs (scanned at 4000 dpi) generated using direct binary search (DBS) halftoning algorithm [6] (a) without printer model and (b) with the stochastic dot model.

Scanning artifacts can be attributed to sensor noise or poor motion quality. The pattern noise of a CCD array (drop-outs) is an example of the sensor noise. Similar to the motion quality issue in EP printers, manufacturing and assembly tolerances will result in periodic velocity fluctuation in the scanner carriage motion. This will be manifest as periodic scanning artifacts at specific spatial frequencies. Through proper image analysis, these process/component induced artifacts can be extracted as distinct intrinsic characteristics of a specific scanner or scanner model.

Maintaining the consistency of the spectral characteristics of the light source is a quality control issue for scanners. By adjusting the spectral characteristics of the light source, we can manipulate the broad spectrum response to the material being scanned. By exploiting the properties of the human visual system, the light source can be used to modulate and embed an extrinsic signature in the scanned image.

2.2 Watermarking

In the last five years there has been an explosion in the use of digital multimedia elements: images, video, and audio. One difficulty is that a copy of a multimedia element is identical to the original and as such, an unlimited number of copies can easily be distributed and/or forged. This presents problems if the material is copyrighted. The protection and enforcement of intellectual property rights has become an important issue in the "digital world." Many approaches are available for protecting digital data; traditional methods include encryption, authentication, and time stamping. One of the newer approaches to help secure this type of data is the use of watermarking [10]. In watermarking, a controlled amount of distortion – the watermark – is inserted into an image. The watermark is not visible under normal viewing conditions and can be detected and used to determine ownership or whether an image has been tampered with. Watermarking belongs to a class of methods sometimes referred as data hiding, whereby an information signal is embedded in a multimedia element such that it cannot be seen. The embedded signal can contain information relative to the ownership of the data or can be, as in steganography [25], a message sent to a user whereby the multimedia element acts as a carrier of the message. Data hiding techniques can be modeled as a channel coding problem with side information [26]. The design parameters in any watermarking system are:
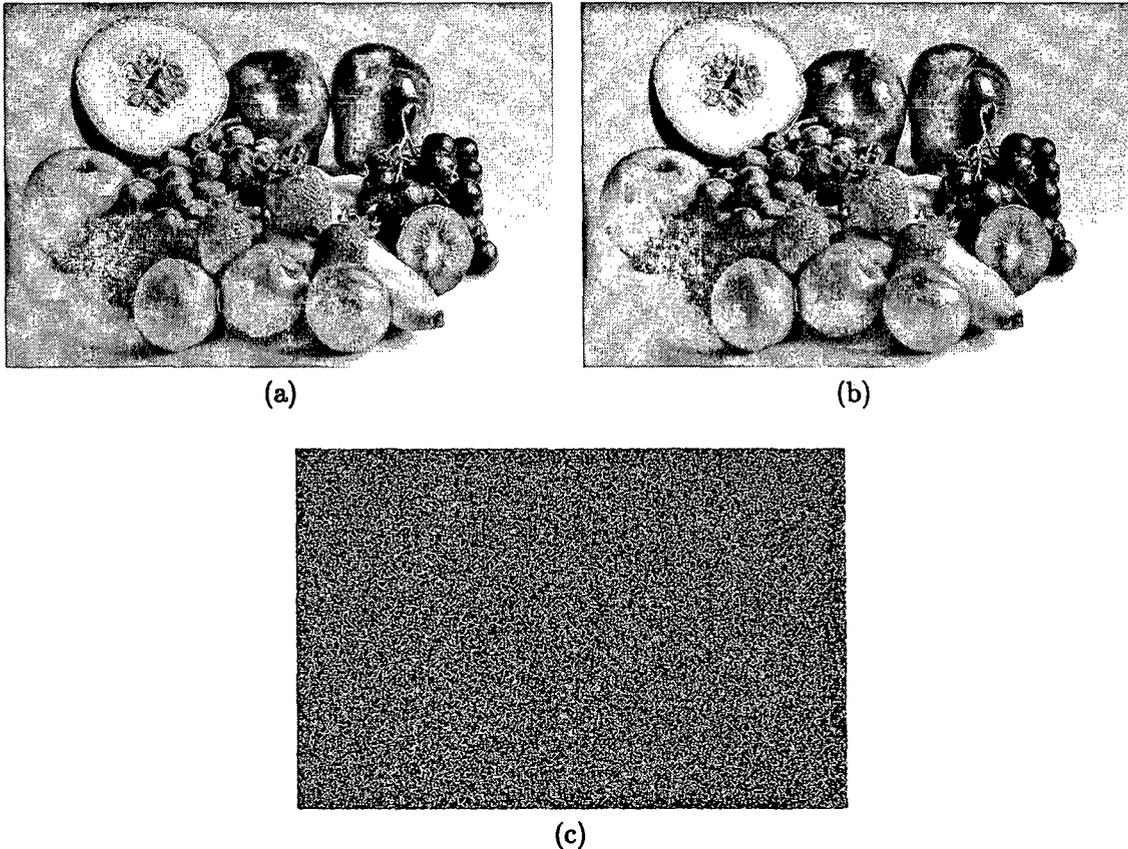
Figure 9: (a) Original Image. (b) Watermarked image using the semi fragile watermark described in [27]. (c) The watermark structure.

- Transparency - the watermark should not be visible under conditions of typical use.

- Robustness to attacks - the watermark should still be detected after the multimedia element has undergone linear or nonlinear operations such as filtering.

- Capacity - what is the maximum amount of data that can be embedded using the watermarking technique.

2.2.1 Our Previous Work

In the past six years we have examined several new watermarking techniques. Our work has concentrated in the areas of fragile and semi-fragile watermarking of digital images. More recently we have been examining issues relative to the design of robust video watermarking used in streaming over data networks.

Fragile watermarking is different from robust methods in that the watermark is designed to be easily destroyed. One applications of a fragile watermark is tamper detection where the goal is to determine if and where an image has been modified. We have developed two methods for fragile watermarking. In [27] we described a method that embeds the watermark in the spatial domain of an image in the low levels of the gray scale. We have shown that, based on the design parameters of the watermark and the embedder, this method can be used for fragile watermarks
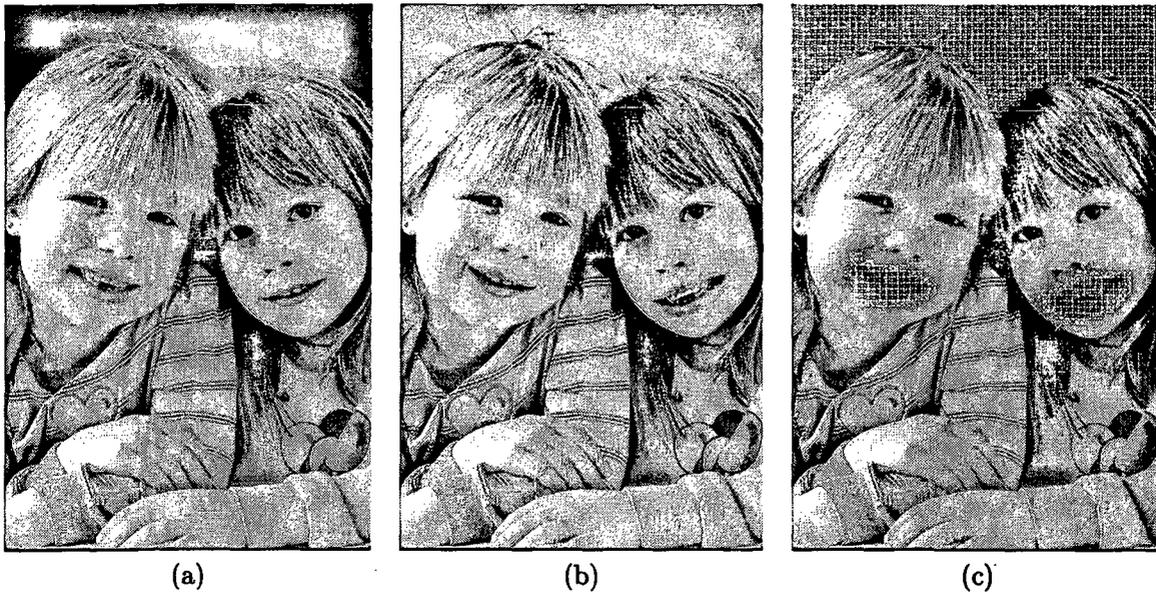
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Figure 10: (a) Original Image. (b) Tampered image: the lips on the children have been changed and the background altered. (c) The × indicates where the detector found tampered (not original) pixels.

or semi-fragile watermarks that can tolerate some changes. In Fig. 9, we show an example of this watermarking. In [28] we developed a new semi-fragile watermark that provided excellent spatial localization for determining how an image has been tampered with. Figure 10 shows the results of this watermarking.

In the past year, our work has concentrated on designing robust watermarking systems that can be used in video streaming. The problem in streaming applications is that the communications channel acts like an attacker in that packets can be lost, frames dropped, and delay and jitter can cause the watermark detector to become desynchronized [29]. In [30], we have developed a watermark protocol based on a finite state machine that allows the watermark detector to be continuously synchronized with the video sequence. We have shown that this approach is very robust to channel errors and can withstand many of the types of attacks that are typical for video watermarking. For example, we have shown that we can withstand an arbitrary number of frames being randomly inserted in our watermarked video sequence without losing synchronization.

2.2.2 Watermarking and Printing: Methods for Securing Documents

Most of the work in watermarking has concentrated on images, video, and audio. Much of the work relative to printing has been in the areas of watermarking halftone images [31, 32] or watermarking text documents [33, 34]. In the case of halftone images the goal is to insert a watermark in an image such that when it is printed using halftone techniques the watermark can be recovered. This is accomplished by modifying the halftone algorithm to effectively embed the watermark. In the case of text watermarking the slight shift in the spacing of the lines or fonts are used to embed a watermark structure. This type of approach is robust against copying and scanning. Other approaches have included using image watermarking techniques for protecting documents distributed over data networks, hashing the document to produce a unique digest, and using this to determine if the document has been altered [35].

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More recently, we have seen Digimarc with their Mediabridge technology [36] use watermarking techniques to protect printed material particularly from counterfeiting printed packaging material and advertising documents. Since the types of content printed are "image-like," image watermarking techniques are used.

None of the approaches described above effectively address the issue of authenticating a printer to a document because the methods used are proactive in that they assume the person that originates the document can be trusted, and that watermarking is used to secure the document after it leaves the control of the author.

3 Proposed Research

3.1 Printer Characterization

Printer characterization is essential to the development of both intrinsic and extrinsic signatures. There are two steps that must be completed:

Develop models for the print system. While in principle, one could identify features for an intrinsic signature while treating the printer as a black box, this is a bit like searching for a needle in a haystack. By developing models for the print system that account for mechanical, electro-optical, and materials properties that cause artifacts, we can much more effectively identify robust features for an intrinsic signature, since we will know what we are looking for. For embedding extrinsic features, such models are essential, since they tell us how to modulate the printing process parameters. We have already developed such models for a limited set of printers [3, 4, 5, 6, 7, 8]. For this project, we will need to generalize these models, and parameterize them for a larger set of different desktop printers.

Develop image analysis tools for printer characterization. These tools consist of specially designed test patterns and image processing algorithms that can extract the desired features from the printed test patterns after they have been scanned with a high resolution drum scanner. They are used to tie the internal printer models to the resulting artifacts on the printed page. We have already developed such tools for our prior work with printer characterization. We will again need to generalize these tools to a broader set of printers. An important part of this process is the characterization and calibration of the drum scanner used for the image capture. We must be able to reference the digital pixel values back to local colorant mass per unit area on the printed page. In addition, we must assure that the scanner is not introducing its own intrinsic signature to the scanned data, which we might mistakenly associate with the printer.

3.2 Intrinsic Signature Development

Based on the results of the printer characterization process, we will have identified for each printer or class of printers a small set of candidate features that could form an intrinsic signature, either singly or in combination. This work will be based on the specially designed test patterns discussed in the preceding section. However, we cannot expect that criminal or terrorist elements will be so cooperative as to include our test patterns in their documents to facilitate our determination of the printer used to generate those documents. Instead, we must be able to detect the intrinsic signature on a printed page containing arbitrary content. This poses a major challenge for our research. Clearly, we cannot expect to detect the intrinsic signature equally well on every printed page. In particular, the signature will be more difficult to detect on pages with very little colorant coverage.

So our task here will be to identify features on the printed page that can robustly be detected across a range of page content, and which, as much as possible, uniquely characterize the printer itself. The solution to this problem really involves three inter-related tasks. We must identify candidate features from the printer characterization studies discussed in the previous paragraph. Then we must develop low-level image analysis algorithms to detect these features on pages with arbitrary content. Finally, we must develop a decision architecture that, based upon the features extracted by the low-level image analysis algorithms, will seek to identify the printer. This decision process will generate a tree representing a hierarchical classification of the printer with a likelihood associated with each branch. At the top of the tree, we branch between the two printer technologies EP and IJ. At the next level, we branch between manufacturers. Near the bottom of the tree, we branch between specific models and at the very bottom, we branch between candidate serial numbers. As we progress downward through the tree, the predicted likelihoods will generally become less and less skewed, reflecting an increasing degree of uncertainty regarding the classification at that particular level of the tree.

We envision two different scenarios for using the intrinsic signature to identify information about the printer. Each of them will lead to a different degree of refinement in the decision tree structure. In the first scenario, we have only the printed material in question; and our task is to identify as much information as possible about the printer that generated that material. In this case, it is not likely that we could identify the serial number of that printer; but we may be able to identify the manufacturer and model. In the second scenario, we have the printed material, plus one or more suspected printers. In this case, we can actually perform a characterization, as discussed in Sec. 3.1, of each printer, then apply our image analysis and decision processes to the printed material in question, and simply restrict the decision output to a likelihood for each suspect printer, plus a null set representing the case in which the printed material was generated by a printer outside the set of suspects.

The final step in our research with intrinsic signatures will be to examine their resistance to attack. That is, how easily can the user defeat the intrinsic signature by making some modification to the print system. We will consider modifications that are appropriate to several different levels of user expertise relative to printer technology.

To conduct this research, we will make use of the range of EP printers presently in our research laboratory, as well as EP printers located in office areas and educational labs around campus. We will also purchase a select few low-end EP printers from manufacturers whose products cannot be found on our campus. There are relatively few IJ printers available on campus. However, these printers are sufficiently low in cost that we can afford to purchase quite a few of them for our characterization and signature development studies.

3.3 Extrinsic Signature Embedding

Our work with extrinsic signature embedding will build on all aspects of the work with printer characterization and intrinsic signature development. In this work, the printer characterization task will take on a new level of importance. For the intrinsic signature development, the printer model will only be used to guide the search for good features. For the extrinsic signature embedding, the printer model, especially the link between process parameters and features measured on the page, is critical to our ability to generate the extrinsic signal by modulating those very same parameters. Thus the extrinsic signature embedding work will make very direct and explicit use of the results of the printer characterization. As with the intrinsic signatures, we will seek features that are robust

across pages with different content. However, we no longer care that the signature be distinctive for the particular printer, since we can encode information in the extrinsic signature that will make it distinctive to that particular printer. So whereas the choice of an intrinsic signature may require a tradeoff between robustness and distinctness, here we can choose the most robust feature without regard for distinctness.

On the other hand, two new issues arise with extrinsic signature embedding that are not of concern with the intrinsic signature. First, we must be able to effectively modulate the feature on which the signature is based. Here *effectiveness* of the modulation is defined both in terms of the ease with which the controlling process parameters may be varied, and in terms of the reliability with which the extrinsic signature may be decoded from the scanned page. Some features that are distinctive to the printer may be very robust, but difficult to modulate effectively. Second, visibility of the extrinsic signature is a new issue that is not of concern with the intrinsic signature. The intrinsic signature may indeed be visible; but we did not put it there; so we assume that it is acceptable. With the embedding of an extrinsic signature, this is no longer the case. By increasing the level of modulation, which increases reliability of detection and thus capacity, we can drive the extrinsic signature to a point where it becomes unacceptably visible. As with traditional watermarking approaches, there will thus be a tradeoff between visibility and capacity of the watermark.

3.4 Signature Embedding, Capacity, and Attacks

Ideally, to uniquely identify each printer we expect that a 20 digit "serial number" will need to be embedded. We will assume this serial number can be represented by 20 bytes (160 bits). The signature detection process will inherently be imperfect due to the nature of how we do the embedding and to possible attacks. To ensure that the serial number can be extracted, we will expand the signature message using a rate error control code, this then requires 320 bits to be embedded. The signature may also be encrypted using a stream cipher.

The questions that need to be addressed by the proposed research are:
1. Can 320 bits be embedded by the printer mechanism in a way that does not effect the quality of the printed document? This is an inherent capacity vs. distortion tradeoff.
2. Will the printer be able to embed this entire signature for every document printed? Suppose a document with only a small number of marks is printed, is there a "marks" vs. capacity tradeoff?
3. What happens if only part of a document is printed? Will we be able to extract the signature?

We will need to design a codebook of signatures that address these issues. Our desire is to design a theoretical model to predict the capacity vs. quality vs. "number of marks" tradeoff.

We will also need to investigate attack scenarios:
1. Will an attacker be able to prevent the signature from being read by simply scanning and reprinting the document? What about other types of image processing operations?
2. Will an attacker be able to change the signature by essentially watermarking the input document in way that causes the signature be incorrectly embedded?

4 Integration with Education and Outreach

The proposed research will integrate with the existing science and engineering curriculum in the following way. To characterize all the legacy and future printers and copiers requires significant

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resources. However, the process is also an educational opportunity for students to learn from hands-on experience that integrates human perception, image analysis, image processing, and electro-mechanical system characterization and control. We will develop a dual-level interdisciplinary course that engages students from psychology, engineering, and technology to work in teams to validate and debug the process and procedures developed in the proposed research. Their feedback will provide valuable usability information and input to the on-going research. This course will be modeled after a similar project oriented course that is being offered by the principal investigators and six other faculty from three departments that involves bringing students from different engineering and science backgrounds together to develop a secure infrastructure for mobile printing at Purdue.

One unique aspect of the proposed research is that security, privacy and the ability to print high fidelity images is closely related to our everyday activities. People can easily relate to the need for security and privacy in printed materials. We will exploit this unique aspect in demonstrating the impact that science and technology have in improving the quality and security of everyday lives. Studies have shown that the decision to pursue higher education and careers in science and technology are being made between the 8th and 12th grade. The scope of the proposed research will provide an excellent vehicle to inspire high school students to consider a career in science and technology, and to pursue higher education. In particular, we will exploit this by giving tours and demonstrating the results of the proposed research to middle and high school students, especially in inner cities and rural areas with high concentration of under-represented minorities. In addition, we will actively recruit women and under-represented minority graduate and undergraduate students to participate in the research.

5 Impact

The proposed research is directed toward addressing a well-defined need to help combat terrorism and crime. It will provide the theory and tools needed by law enforcement agencies, intelligence organizations, and printer manufacturers to add a significant new level of accountability and tracking to the process of printing documents and other materials. The long term result will be a reduction in crime and better security in the face of terrorists threats. The proposed research will also provide an excellent educational opportunity, as well, and will increase the enrollment of under-represented minorities in secured engineering.

Existing NSF Project

Nonlinear Model Based Information Synthesis and Health Detection with Applications to Drive-by-Wire Engines, National Science Foundation, September 1, 2001-August 31, 2004, M. A. Franchek and G. T.-C. Chiu, $200,000. The project is on-going for 5 months. Preliminary results have demonstrated high correlation between the coefficient evolution of adaptive online models to specific fault detection and isolation.

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[35] G. W. Braudaway, F. Mintzer, J. M. Socolofsky, C. Tresser, and C. W. Wu, "Application of invisible image watermarks to produce remotely printed, duplication resistant, and demonstrably authentic documents," *Proceedings of the SPIE Conference on Security and Watermarking of Multimedia Contents*, vol. 4314, pp. 351–359, January 2001.

[36] A. M. Alattar, "Smart images using digimarc's watermarking technology," *Proceedings of the SPIE Conference on Security and Watermarking of Multimedia Contents*, vol. 3971, pp. 264–273, January 2000.

SUMMARY
PROPOSAL BUDGET

YEAR 1

	FOR NSF USE ONLY		
ORGANIZATION	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By	Funds granted by NSF (if different)
	CAL	ACAD	SU		
1. **Jan P Allebach - Professor**					
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**6,000**	
2. FOREIGN				**0**	

F. PARTICIPANT SUPPORT COSTS
1. STIPENDS $ **0**
2. TRAVEL **0**
3. SUBSISTENCE **0**
4. OTHER **0**

TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS	**0**	
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES	**2,400**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	**0**	
3. CONSULTANT SERVICES	**0**	
4. COMPUTER SERVICES	**0**	
5. SUBAWARDS	**0**	
6. OTHER	**12,786**	
TOTAL OTHER DIRECT COSTS	**15,186**	
H. TOTAL DIRECT COSTS (A THROUGH G)	**107,267**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)	**53,634**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**160,901**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)	**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	$ **160,901**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $		

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

	FOR NSF USE ONLY	
ORGANIZATION	**PROPOSAL NO.**	**DURATION (months)**
Purdue University		**Proposed** | **Granted**
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	**AWARD NO.**	
Jan P Allebach		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds	Funds granted by NSF (if different)
	CAL	ACAD	S		
1. **Jan P Allebach - Professor**					$
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE					
7 TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**6,000**	
2. FOREIGN				**0**	

F. PARTICIPANT SUPPORT COSTS		
1. STIPENDS $ **0**		
2. TRAVEL **0**		
3. SUBSISTENCE **0**		
4. OTHER **0**		
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS	**0**	
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES	**2,410**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	**0**	
3. CONSULTANT SERVICES	**0**	
4. COMPUTER SERVICES	**0**	
5. SUBAWARDS	**0**	
6. OTHER	**13,425**	
TOTAL OTHER DIRECT COSTS	**15,835**	
H. TOTAL DIRECT COSTS (A THROUGH G)	**111,124**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)	**55,562**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**166,686**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)	**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	$ **166,686**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $		

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY
PROPOSAL BUDGET   YEAR   3

ORGANIZATION	FOR NSF USE ONLY		
Purdue University	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By	Funds granted by NSF (if different)
	CAL	ACAD	SI		
1. **Jan P Allebach - Professor**					$
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. ') TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**6,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**2,217**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**14,096**	
TOTAL OTHER DIRECT COSTS				**16,313**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**114,942**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**57,471**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**172,413**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **172,413**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $					

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

3 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

	FOR NSF USE ONLY		
ORGANIZATION	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds	Funds ranted by NSF (if different)
	CAL	ACAD	SI		
1. **Jan P Allebach - Professor**					$ ____
2. **George T.-C. Chiu - Asst. Professor**					____
3. **Edward J Delp - Professor**					____
4.					____
5.					____
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					____
7.) TOTAL SENIOR PERSONNEL (1 - 6)					____
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					____
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					____
3. (GRADUATE STUDENTS					____
4. (**0**) UNDERGRADUATE STUDENTS					____
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					____
6. (**0**) OTHER					____
TOTAL SALARIES AND WAGES (A + B)					____
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					____
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					____
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**18,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**7,027**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**40,307**	
TOTAL OTHER DIRECT COSTS				**47,334**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**333,333**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**166,667**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**500,000**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **500,000**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $					

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

We have scoped this project as a three year effort. During each year, the budget provides 12 months support for three graduate students and   support for the three principal investigators. We have provided $1K travel per year for each person on the grant (including the graduate students) to support travel to a conference to learn about research in this area, and ultimately to present the results of our work. The balance of the budget (approximately $2.5K per year) has been allocated to supplies and expenses. This money will be used to purchase a number of low-end printers, to replace consumables used in the course of the research, including toner cartridges, ink cartridges, and for other incidental expenses associated with the research.

We have not budgeted any funds for permanent equipment, because our laboratories, which are described in the facilities section, are quite well equipped to support this research activity. The only exception is the drum scanner. Our current Howtek D4000 drum scanner needs to be replaced. It has developed an artifact that would prevent it from being used for this project, and which severely restricts its utility in general. The replacement of this scanner at an expense of approximately $50K will be funded as a cost share to this proposal. Professor Warren Stevenson, Associate Dean of the Schools of Engineering has committed to pay 25% of this amount. Professors Kent Fuch and Dan Hirelman, Heads of the Schools of Electrical and Computer Engineering and Mechanical Engineering, respectively, have committed to pay 16.6% and 8.3%, respectively. Finally, the Hewlett-Packard Company has agreed to allow us to pay the remaining 50% from research monies that have been allocated for permanent equipment, or which are residuals from the prior year's projects.

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Jan Allebach**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Printer Characterization and Signature Embedding for Security and Forensic Applications**

Source of Support: **NSF**
Total Award Amount: $ **500,000** Total Award Period Covered: **08/15/02 - 08/14/05**
Location of Project: **Purdue University**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad:**0.00** Sumr: **1.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: ⸱
Location of Project:
Person-Months Per Yea

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: $
Location of Project: ⸱
Person-Months Per Year (

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: ⸱
Location of Project: ⸱
Person-Months Per Year

Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: ⸱
Location of Project: ɪ ʊ
Person-Months Per Year C

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Page G-1   USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **George T.-C. Chiu**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Printer Characterization and Signature Embedding for Security and Forensic Applications**

Source of Support: **NSF**
Total Award Amount: $ **500,000** Total Award Period Covered: **08/15/02 - 08/14/05**
Location of Project: **Purdue University**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **1.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: $
Location of Project:
Person-Months Per Yea

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount: $
Location of Project: r
Person-Months Per Year

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Nonlinear Model Based Information Synthesis and Health Detection with Applications to Drive-by-Wire Engines**

Source of Support: **National Science Foundation**
Total Award Amount: $ **200,000** Total Award Period Covered: **09/01/01 - 08/31/04**
Location of Project: **Purdue University**
Person-Months Per Year Committed to the Project. Cal:**0.00** Acad: **0.00** Sumr: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:
Total Award Amount:
Location of Project:
Person-Months Per Yea

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **George T.-C. Chiu**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: ᴵ

Source of Support:
Total Award Amount:
Location of Project:
Person-Months Per Ⓨ

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project.   Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Edward Delp**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $
Location of Project:
Person-Months Per Ye:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title

Source of Support:
Total Award Amoun
Location of Project:
Person-Months Per Y

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount:
Location of Project:
Person-Months Per Ye:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Printer Characterization and Signature Embedding for Security and Forensic Applications.**

Source of Support: **NSF**
Total Award Amount: $ **500,000** Total Award Period Covered: **08/15/02 - 08/14/05**
Location of Project: **Purdue University**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Page G-4 USE ADDITIONAL SHEETS AS NECESSARY

Facility Description

Electronic Imaging Systems Laboratory (EISL)

The Electronic Imaging Systems Laboratory (EISL) supports research on image capture and rendering, medical imaging, color measurement, and document management. The laboratory is located in a suite of six rooms comprising over 1100 square feet on the ground floor of the Electrical Engineering Building. The computational resources of the laboratory include 9 PCs running LINUX, 6 workstations running HP-UX, and 10 PCs running Microsoft NT, Windows 2000, or Apple Macintosh OS 9. The disk storage that is local to these computers is augmented by approximately 250 Gbytes of server-based disk space.

The laboratory provides both document capture and rendering devices for support of research activities. The capture devices include a Howtek 4000 dpi prepress drum scanner, based on photo-multiplier tube technology, and a Heidelberg Linotype Saphir Ultra2 flatbed scanner with a maximum optical resolution of 1200 dpi × 2400 dpi. Rendering devices include an HP 2500 CP large format inkjet printer (36 inch wide carriage), a 300 dpi Shnko continuous-tone dye-sublimation printer, 2 HP Deskjet 900 series inkjet printers, several workgroup-class HP LaserJet 4000 (monochrome) and 4500 (color) series laser printers, and one each of the department-class HP LaserJet 8500 (color) and 9000 (monochrome) printers.

One of the rooms in the laboratory has been configured as a conference area with a Polycom Soundstation Premiere conference phone for telemeetings with off-site sponsors and collaborators.

Spectral Imaging Systems Laboratory (SISL)

The Spectral Imaging Systems Laboratory (SISL) is located on the second floor of the Materials Science and Electrical Engineering Building. It has been developed for precision color measurement and the collection of multidimensional data sets. The principal sensors include two high spatial resolution digital still cameras, a conventional spectroradiometer, and a novel multispectral scanning system that yields several hundred bands of spectral data at each pixel in the image.

The digital still cameras are a Photometrics Model CH250 with a thermoelectrically cooled 1 Mpixel Kodak CCD array with 12 bits of gray scale on output, and a 6 Mpixel Kodak DCS 460c color digital camera built on a Nikon N90 body. The conventional spectroradiometer is a Gretag SPM-50 which provides its own illumination for measuring the reflectance of flat surfaces. The instrument provides a variety of spectral and colorimetric measurements.

The multispectral scanning system consists of 4 major components. The first is an EG&G Model 2020-31B High Efficiency telescope with a field of view selectable at 6 arcmin, 20 arcmin, 1o, and 3o, and an auxiliary close-up lens. The second is an Acton Research Corporation Model SpectraPro-150 spectrograph with a wavelength range of 0-1400 nm, a slit width adjustable from 10-3,000 m, yielding a resolution of 0.4 nm or better and wavelength accuracy of 0.25 nm. The third component is an EG&G Model 1520A thermoelectrically

cooled 256×x1024 pixel CCD detector with sensitivity from 400-1100 nm and 18 bit dynamic range. Finally, the entire instrument is mounted on a computer-controlled Parker-Daedel azimuth-elevation positioning system with 0.2 arcmin repeatability and 5 arcmin accuracy.

Both the Photometrics camera and all parts of the multispectral scanning system are interfaced to a Compaq PC.

The laboratory includes two special sources of illumination. The first is a Macbeth Spectralight II-65B Viewing Booth for critical color matching and visual color evaluation. The viewing booth allows selection of five different illuminants: Daylight 6500K, Daylight 2300K, Illuminant A, Cool White Fluorescent, and Ultraviolet. The second is a monochromator based on a second Acton Research Corporation Model SpectraPro-150 spectrograph with a TS-428 tungsten-halogen light source. The monochromator provides a tunable source of very narrow-band illumination that can be precisely delivered where needed via an optical fiber. The entire unit can be controlled by a serial interface to a PC or via a handheld HP 48G calculator.

Video and Image Processing Laboratory (VIPER)

The Video and Image Processing Laboratory (VIPER) equipped with state-of-the-art technology to digitize, store, process, stream, and display digital video and images. This technology supports research in areas such as the development of new video compression techniques, new streaming technologies, and creating multimedia material for use in video indexing, storage, and retrieval. Depending on the application, digitizers in the lab can produce digital video in a variety of formats including uncompressed CCIR video, motion JPEG, DV, MPEG-1, MPEG-2, MPEG-4, H.26X, and HDTV. High quality uncompressed video is produced by the Truevision TARGA digitizer, while lower quality video for streaming purposes is produced by the ViewCast Osprey 100 digitizers. Currently the laboratory can digitize four separate video sequences for streaming purposes. In addition the laboratory is equipped with a motion JPEG digitizer that is used for high quality multicast streaming over Internet2. To generate long, high quality, digital video sequences, the Laboratory has two Sony 3 CCD DV Camcorders, a Sony DV VCR, and a Sony DV-Firewire converter. The laboratory also has a complete suite of video editing equipment and a real-time fully configurable MPEG-1/MPEG-2 encoder developed by C-Cube. For Internet applications, the Laboratory is equipped with several Optibase real-time MPEG-1 hardware encoder cards. For recording/streaming HDTV signals, the Laboratory has a Sencore HDTV 996 VSB video server.

The storage facilities of the Laboratory are organized around several file servers. These include one 4 processor and 3 dual processor Sun UltraSparc servers, and a dual-processor Intel server (running NT). The servers are connected to the Engineering Computer Network (ECN) and have a total disk storage capability of 0.6 terabytes. The Laboratory is equipped with a variety of computers for manipulation and processing of the digital data. In addition to the above file servers, the laboratory is equipped with the latest Intel and Sun processors, including a dual processor Pentium III Xeon and a Sun Ultra Blade. There are in total 3 Sun workstations and 8 PCs used exclusively for digital video research. To efficiently stream

digital data, the laboratory has a video server and several dedicated Intel Pentium IIIs for real-time streaming of live data. The laboratory has the capability to multicast multiple simultaneous live video streams in real-time using several different video formats including MPEG-1, RealVideo, Windows Multimedia, H.261, H.263, and motion JPEG. Finally, the Laboratory has a variety of methods used to display digital video. All NTSC video devices are connected to a video cross-bar switch so that a wide variety of possible input and output scenarios may be configured at the touch of a button. For primary NTSC viewing, the laboratory has two 36" RCA monitors so that A/B comparisons may be made directly. In addition, the laboratory has a Proscan 36" 16x9 monitor, a 36" RCA HDTV monitor, and a 38" RCA HDTV monitor. In addition, the laboratory has 6 21" computer monitors for viewing digital data directly at each workstation.

Mechatronic Systems Research Laboratory(MSRL)

The printer characterization as well as extrinsic signature embedding experiments of the proposed research will be performed in the *Mechatronic Systems Research Laboratory* (MSRL). The MSRL is a state-of-the-art research laboratory within the Ruth and Joel Spira Laboratories for Electromechanical Systems in the School of Mechanical Engineering.

The MSRL includes advance instrumentation and and CAD/CAM tools for research in the the integrated design, control and characterization of electromechanical systems. The laboratory include instruments such as the HP 35670A Dynamic Signal Analyzer for performing various signal/spectrum measurement as well as dynamics system identification, two HP 33120A Arbitrary Function Generator, an HP 54645D 100 MHz Mixed Signal Analyzer, an HP 54540A 4 channel 500 MHz Digital Storage Oscilloscope, an HP 5372A Frequency and Time Interval Analyzer for precision timing analysis, and two HP 1146 AC/DC Current Probes. In addition to electronic instruments, the laboratory also has three high resolution Cannon M-1 Laser Optical Rotary Encoder that has 50,000 lines-per-revolution resolution. This encoder can be used to measure and characterize the rotational motion of various document printing platforms. The laboratory also includes various lupes and microscopes of different magnifications that can be used to observe/characterize the structure of the dot/pixel patterns for different printing process. An HP 6300 ScanJet scanner will be used for scanning print outs for image analysis and characterization. The laboratory includes mixed analog and digital electronics simulation tool and digital logic programming tools for programming FPGAs and CPLDs that will be needed in developing interface electronics for characterizing and *finger-printing* printing devices.

SUMMARY
PROPOSAL BUDGET   YEAR 1

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)			

ORGANIZATION

Purdue University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR

Jan P Allebach

	FOR NSF USE ONLY	
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR		
1. Jan P Allebach - Professor					
2. George T.-C. Chiu - Asst. Professor					
3. Edward J Delp - Professor					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**5,759**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**6,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**12,228**	
TOTAL OTHER DIRECT COSTS				**18,228**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**104,075**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**45,925**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**150,000**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			$	**150,000**	$
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY
PROPOSAL BUDGET YEAR 2

	FOR NSF USE ONLY		

ORGANIZATION	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR		
1. **Jan P Allebach - Professor**					$
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7 OTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**1,000**	
2. FOREIGN				**0**	

F. PARTICIPANT SUPPORT COSTS
1. STIPENDS $ **0**
2. TRAVEL **0**
3. SUBSISTENCE **0**
4. OTHER **0**

TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS	**0**	
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES	**957**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	**0**	
3. CONSULTANT SERVICES	**0**	
4. COMPUTER SERVICES	**0**	
5. SUBAWARDS	**0**	
6. OTHER	**12,837**	
TOTAL OTHER DIRECT COSTS	**13,794**	
H. TOTAL DIRECT COSTS (A THROUGH G)	**90,945**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)	**39,055**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**130,000**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)	**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	$ **130,000**	$
M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $		

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

PROPOSAL BUDGET

		FOR NSF USE ONLY	
ORGANIZATION		PROPOSAL NO.	DURATION (months)
Purdue University			Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR		AWARD NO.	
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By proposer	Funds granted by NSF (If different)
	CAL	ACAD	SUMR		
1. **Jan P Allebach - Professor**					$
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. ( ) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,737	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ — 0					
2. TRAVEL — 0					
3. SUBSISTENCE — 0					
4. OTHER — 0					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				900	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				13,482	
TOTAL OTHER DIRECT COSTS				14,382	
H. TOTAL DIRECT COSTS (A THROUGH G)				91,159	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				38,841	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				130,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 130,000	$
M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $					

PI/PD NAME	FOR NSF USE ONLY
Jan P Allebach	INDIRECT COST RATE VERIFICATION
ORG. REP. NAME*	Date Checked / Date Of Rate Sheet / Initials - ORG
Diane troyer	

3 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY
PROPOSAL BUDGET   Cumulative

ORGANIZATION	FOR NSF USE ONLY		
	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR		
1. **Jan P Allebach - Professor**					$
2. **George T.-C. Chiu - Asst. Professor**					
3. **Edward J Delp - Professor**					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,496	
2. FOREIGN				0	

F. PARTICIPANT SUPPORT COSTS
1. STIPENDS $————————— 0
2. TRAVEL   ————————— 0
3. SUBSISTENCE ————————— 0
4. OTHER   ————————— 0

TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS	0	
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES	7,857	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	0	
3. CONSULTANT SERVICES	0	
4. COMPUTER SERVICES	0	
5. SUBAWARDS	0	
6. OTHER	38,547	
TOTAL OTHER DIRECT COSTS	46,404	
H. TOTAL DIRECT COSTS (A THROUGH G)	286,179	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)	123,821	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	410,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)	0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)	$ 410,000	$
M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $		

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Impact Statement

Proposed Research

The description of the proposed research is actually unchanged from that contained in the original proposal. However, we do expect that there will be some minor changes to the investigation, as a consequense of the reduced funding. In particular, we expect to reduce somewhat the number of different types of printers or manufacturers' models that will be characterized to develop models for the print system, as discussed in the second paragraph of the proposed research under "Printer Characterization." We also will consider a smaller number of potential attack scenarios, as discussed under "Signature Embedding, Capacity and Attacks." Overall, we feel that these changes will not significantly impact the effectiveness and value of the research.

Budget

We generally made some redutions across the board to meet the requested levels of funding. Specifically, we reduced the graduate student stipends, the amount of summer support for the co principal investigators, and travel and supplies expenses. Travel and supplies and expenses were significantly cut in the second and third years.

Budget Justification

Again, here we made only minor changes to reflect the revised budget.

Annual Report for Period:09/2003 - 09/2004   **Submitted on:** 07/22/2004
Principal Investigator: Allebach, Jan P.   **Award ID:** 0219893
Organization: Purdue University
Title:
ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications

Project Participants

Senior Personnel

Name: Allebach, Jan
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Delp, Edward
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Chiu, George T.-C.
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Ali, Gazi
Worked for more than 160 Hours: Yes
Contribution to Project:
Gazi is being supported as a research assistant by grant funds. He is the lead student on low-level feature extraction for intrinsic printer signatures.

Name: Mikkilineni, Aravind
Worked for more than 160 Hours: Yes
Contribution to Project:
Aravind is being supported as a research assistant by grant funds. He is the lead student for developing decision structures to perform printer classification based on intrinsic signatures. He also is responsible for developing analyses of information capacity of extrinsic signatures.

Name: Chiang, Pei-Ju
Worked for more than 160 Hours: Yes
Contribution to Project:
Pei-Ju is being supported as a research assistant by grant funds. She is the lead student for developing methods to modify the print mechanism to enable insertion of extrinsic signatures on the printed page.

Name: Kirby, Paul
Worked for more than 160 Hours: Yes
Contribution to Project:
Paul characterized the printers in our test-bed with respect to a set of metrics that were earlier developed for print quality analysis in our laboratory. He also developed an algorithm to characterize the modulation transfer function of a scanner.

Paul was supported by a GEM (Graduate Education for Minorities) fellowship.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

<div align="center">

Organizational Partners

Other Collaborators or Contacts
</div>

We are working with Lorelei Pagano and her research staff all of the U.S. Secret Service to understand how our research could be applied to improving the security of paper documents, and also be used to help to provide information about counterfeiting. Profs. Allebach, Chiu, and Delp visited the Secret Service on June 17, 2004, and gave a one hour presentation on our work, followed by discussions.

We also plan to meet with Sara Church of the Canadian Secret Service in September or October.

<div align="center">

Activities and Findings
</div>

Research and Education Activities:

We have completed set up of the research facility described in our Year 1 report.
It consists of a bank of 24 commercially available desktop printers, all connected to a single host PC, and two components for high-resolution analysis of printed pages to extract signature information. The first of these is a $35K Aztek 8,000 dpi drum scanner The second component of the image analysis lab is a QEA LAS 1000 Automated Image Analysis System which was purchased by HP for $110K in 1999, and which they donated to us. All components of this system are fully operational, and have been extensively used to support the research activities. We are in the process of expanding our bank of printers to include additional printer models, including some used printers that are at the end of their rated lifetime in terms of the number of pages printed. In addition, in the Mechatronics Laboratory we have developed a system that allows us to modulate the intensity of the laser beam to generate extrinsic signatures consisting of multiple frequency components.

We continue to use the project web site as an archive of research records, publications, powerpoint files, and other resources associated with the project.

Our research during the past year was focused in four areas. The first three involve identification of a laser electrophotographic printer, based on the intrinsic signature extracted from documents printed by the device. These are as follows:
1. Use of the metrics from the print quality tool-kit as a means of extracting printer-specific features from printed text and graphics [1].
2. Use of principal components and a Gaussian mixture model-based classifier to analyze projection-based banding signatures of each individual character on the printed page. Eaach character casts a vote for the printer by which it believes it was printed. The printer receiving the majority of the votes is designated as the most probable printer to have printed the subject page.
3. Use of a classifier based on extracting twenty different features from the gray-level co-occurrence matrix, and then performing a five nearest neighbors classification. The process also works on a character-by-character basis, as discussed above, with a majority

vote taken at the end of the procedure.

The fourth area of activity involves modulating the beam intensity of a laser electrophotographic printer to create an extrinsic signature. For a mechanism to effect the desired modulation of the beam intensity, a method to synchronize the modulation to the start of each printed line is required. Also, the printer and scanner need to be fully calibrated in order to be able to accurately measure the effect of different beam intensities. The modulation process introduces new banding frequencies that are not intrinsic to the printer mechanism. These frequencies are chosen to be high enough to not be perceptible to the human viewer û so the signature is not visible on the printed page, but can be detected and decoded by scanning and analyzing the page.

[1] J. Grice and J. P. Allebach, ôThe Print Quality Toolkit: An Integrated Print-Quality Assessment Tool,ö Journal of Imaging Science and Technology, Vol. 43, pp. 187-199, March/April 1999.

Findings:

We will separate our findings according the four separate areas of research activity discussed in the preceding section. Please refer to the publications describing this work that are included elsewhere in this report for additional details on these findings and our research activities.

1. Use of the metrics from the print quality tool-kit as a means of extracting printer-specific features from printed text and graphics.

These metrics did not appear to provide distinguishing characteristics of the printers. We do not plan to further pursue this approach.

2. Use of principal components and a Gaussian mixture model-based classifier to analyze projection-based banding signals.

We have had good success with this method in our preliminary experiments. In one experiment, we were able to distinguish among five different printer models with the only confusion being between two different printers made by the same manufacturer, which have a very similar print mechanism.

3. Use of a five-nearest-neighbor classifier operating on gray-level co-occurrence-based features.

This approach has also performed well in preliminary experiments. In an experiment conducted with ten different printers, only one printer was mis-classified. This approach uses a richer feature set than the method described above, since the features are based directly on the 2-D image of each scanned and segmented character, whereas the method above works only with 1-D project data.

4. Modulation of laser beam intensity in an electrophotographic printer to insert new banding frequencies that serve as an extrinsic printer signature.

We successfully demonstrated an ability to inject and subsequently detect four new banding frequencies in a printed page, without these frequencies giving rise to any perceptible degradation of image quality.

Training and Development:

Gazi Ali, Pei-ju Chiang, and Aravind Mikkilineni continue as the three Ph.D. graduate research assistants on the project. They have all made a great deal of progress during the past year. The focus of GaziÆs and AravindÆs work has been the preprocessing of scanned text data to extract features for pattern recognition and the application of pattern recognition algorithms to these features. Gazi has learned about principal components analysis, Gaussian mixture model-based classifiers, and tree classifiers as part of his research. Aravind has learned about methods for automatic text generation, the gray level co-occurrence matrix, and the five-nearest-neighbor classifier. Both Gazi and Aravind have had to implement a number of low-level image processing tasks, such as segmentation. Pei-ju has learned how to develop and use the mechatronic system for laser

beam intensity modulation. This has required a number of modeling and calibration steps. She has also had to learn about image processing in order to analyze her printed pages for the presence of extrinsic banding signals.

During both the Fall 2003 and Spring 2004 semesters, Gazi, Pei-ju, and Aravind were joined on the project by Paul Kirby. Paul completed his non-thesis Masters degree at the end of the Spring 2004 semester. He received six credits of research project credit for his work. He learned about the print quality metrics that are part of the toolbox that we developed earlier as part of another research project. He also needed to characterize our new drum scanner. For this purpose, he had to learn about imaging systems models, including the modulation transfer function. He developed a novel approach to MTF measurement based on square-wave inputs.

Outreach Activities:

Journal Publications

G. N. Ali, A. K. Mikkilineni, P. J. Chiang, J. P. Allebach, George T. Chiu, and E. J. Delp, "Intrinsic and Extrinsic Signatures for Information Hiding and Secure Printing with
Electrophotographic Devices", Proceedings of IS&T?s NIP 19: International Conference on Digital Printing Technologies, p. 511, vol. 19, (2003). Published

A. K. Mikkilineni, G. N. Ali, P. Chiang, G. T. C. Chiu, J. P. Allebach, and E. J. Delp, "Signature-Embedding in Printed Documents for Security and Forensic Applications,?
Security", Security, Steganography, and Watermarking of Multimedia Contents IV (SPIE/IS&T), p. 455, vol. 5306, (2004). Published

P. Chiang, G. N. Ali, A. K. Mikkilineni, G. T. C. Chiu, J. P. Allebach, and E. J. Delp, "Extrinsic Signatures Embedding Using Exposure Modulation for Information Hiding and
Secure Printing in Electrophotographic Devices", Proceedings of IS&T?s NIP 20: International Conference on Digital Printing Technologies, p. , vol. 20, (2004). Accepted

G. N. Ali, A. K. Mikkilineni, P. Chiang, J. P. Allebach, G. T. C. Chiu, and E. J. Delp, "Application of Principal Components Analysis and Gaussian Mixture Models to Printer
Identification", Proceedings of IS&T?s NIP 20: International Conference on Digital Printing Technologie, p. , vol. 20, (2004). Accepted

A. K. Mikkilineni, G. N. Ali, P. Chiang, G. T. C. Chiu, J. P. Allebach, and E. J. Delp,, "Printer Identification Based on Textural Features", Proceedings of IS&T?s NIP 20: International Conference on Digital Printing Technologies, p. , vol. 20, (2004). Accepted

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:
Within the disciplinary field of the project , there are two main groups to whom this work is relevant. The first group consists of those individuals who are engaged in the development of fundamental printing technologies and design of printing systems. The second group consists of those individuals who are interested in watermarking, data hiding, and security, especially with respect to printing and printed documents.

Both these communities have expressed strong interest in our research. For the watermarking, data hiding, and security community, working at the print mechanism level, rather than the printer driver level is a completely new concept. For the printing technologies and design commmmunity, our work will provide a clear indication of capabilities that they may want to exploit, or may be forced to deal with at some point.

Our research findings during the past year validate the hypothesis of this project, which is that it is possible to partly or completely determine the printer used to print a page of text based on the intrinsic characteristics of that printer. In addition, it is possible to embed an extrinsic signature within a printed page that can subsequently be detected by using image analysis techniques. This extrinsic signature is not visible on the page to a human viewer.

Contributions to Other Disciplines:

We visited the Secret Service in June 2004, and described our research results and plans. They were very interested in what we are doing, and asked to be kept in the loop regarding future results and outcomes of the work. Co-PI Ed Delp visited the Air Force in Rome, NY during the week of July 19th, and discussed our work with them. Again, they are very interested in this activity. Finally, we will visit Sara Church of the Canadian Secret Service during September or October 2004.

Contributions to Human Resource Development:

As mentioned earlier, the training of the three Ph.D. students who are supported on the project has already been very significantly impacted by the research investigation. In addition, this past year, we involved a fourth graduate student in the research program. This individual completed his Masters degree, and is now employed in industry.

Contributions to Resources for Research and Education:

The facilities described earlier that we have developed for working with a large set of different printers, and also for supporting image analysis needs associated with the research project, have broad applicability to the research needs of the Electronic Imaging Systems Laboratory that supports the research efforts of two other faculty members and about 30 graduate students in Electrical and Computer Engineering at Purdue. It is a valuable resource for the faculty members and students working on the Digital Print Systems program at Purdue. This large multidisciplinary program presently involves six faculty members and about 20 graduate students from four different departments at Purdue. Of these 20 students, 10 are also included in the group mentioned above, that is associated with the Electronic Imaging Systems Laboratory.

Contributions Beyond Science and Engineering:

We anticipate that this research will help to assure the security and protection of citizens everywhere from the consequences of terrorist and criminal activities.

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Unobligated funds: $ 31,714.00

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational·Partners
Activities and Findings: Any Outreach Activities
Any Book
Any Web/Internet Site
Any Product

Annual Report for Period:09/2002 - 09/2003   **Submitted on:** 06/15/2003
Principal Investigator: Allebach, Jan P.   **Award ID:** 0219893
Organization: Purdue University
Title:
ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications

Project Participants

Senior Personnel

> **Name:** Allebach, Jan
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**

> **Name:** Delp, Edward
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**

> **Name:** Chiu, George T.-C.
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**

Post-doc

Graduate Student

> **Name:** Ali, Gazi
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**
> Gazi is being supported as a research assistant by grant funds. He is the lead student on low-level feature extraction for intrinsic printer signatures.

> **Name:** Mikkilineni, Aravind
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**
> Aravind is being supported as a research assistant by grant funds. He is the lead student for developing decision structures to perform printer classification based on intrinsic signatures. He also is responsible for developing analyses of information capacity of extrinsic signatures.

> **Name:** Chiang, Pei-Ju
> **Worked for more than 160 Hours:**   Yes
> **Contribution to Project:**
> Pei-Ju is being supported as a research assistant by grant funds. She is the lead student for developing methods to modify the print mechanism to enable insertion of extrinsic signatures on the printed page.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

<div align="center">**Organizational Partners**</div>

<div align="center">**Other Collaborators or Contacts**</div>

<div align="center">**Activities and Findings**</div>

Research and Education Activities:
To enable the research, we are building a facility for analysis of a
large set of commercially available printers. This consists of a
bank of 24 desktop printers, all connected to a single host PC.
This part of the system is complete. The second part of the
system consists of two components for high-resolution analysis
of printed pages to extract signature information. The first of
these is a $35K Aztek 8,000 dpi drum scanner system which is
in final testing stages at the manufacturer, and should be
delivered to Purdue within one or two weeks. This was
purchased with matching funds from Purdue. The second
component of the image analysis lab is a QEA LAS 1000
Automated Image Analysis System which was purchased by HP
for $110K in 1999, and which they recently donated to us. We
are in the process of setting up this system, which is quite
complex.

We have also set up a web page for the project that allows us to
manage all aspects of the research. It contains downloadable
copies of papers that we are using for background information,
Powerpoint presentations from our weekly group meetings,
notes from these meetings, and other documentation
associated with the project.

Our research activities are presently focused in three areas.
First, we have performed a comprehensive review of the
literature in document data hiding, and devoted a number of our
weekly meetings to presentations given by the students on these
papers. The PIs on the project also gave presentations to
provide background on watermarking, printing and halftoning
technologies, and prior research on reduction of printer artifacts
via closed-loop control strategies. All these activities provided an
important educational experience for the graduate students
working on the project, and also gave the entire team a common
research background.

At the present time, the remaining two areas of research activity
are focused on laser and LED electrophotographic printing (EP)
technologies. We are systematically studying the 18 EP printers
in our printer bank, plus about 6 other models that are deployed
in our other labs and around campus, to understand how the
signature characteristics vary with the manufacturer, model, and
unit for each particular model. (We purchased two units of each
printer model included in the printer bank.) We are also studying
how to extract the intrinsic signature information from a variety of
printed content. Here we are exploring two approaches. The first
approach is based on extracting banding frequencies from
printed pages. To do this, we project the scanned page

information in the scan direction (orthogonal to the direction in which the paper exits from the printer), and then examine the spectral content of this one-dimensional signal. The second approach is based on a more general feature extraction strategy in which blocks of pixels are preprocessed to enhance potential features. These features are then extracted from the data. Finally, the feature vectors are clustered in an unsupervised manner using an optimal decision tree structure.

In the final area of activity, we are beginning to develop strategies for embedding extrinsic signatures in printed pages by directly modifying the printer mechanism. The actuation methods that we are considering are the same as those used in our earlier work to reduce banding artifacts. In order to do this, it is necessary to first tear down the target printer mechanism and analyze all its components; so that we can understand precisely how the printer functions, and how we can inject the extrinsic signature at the appropriate point or points in the mechanism. This is a task that we have successfully completed in earlier projects where we wanted to modify EP print mechanisms to suppress banding and also modify an inkjet print mechanism to support a novel adaptive print masking strategy.

Our project is still at an early stage; so we have not had an opportunity yet to give a large number of presentations on the work. However, at the very start of the project, Ed Delp presented a paper entitled ôIs Your Document Safe?: An Overview of Document and Print Security,ö at the Society for Imaging Science and TechnologyÆs Eighteenth International Conference on Digital Printing Technologies held in San Diego in September 2002. This is the leading conference on printing technologies. It is attended by more than one thousand scientists and engineers from all over the world. At the end of his talk, which identified the need and opportunity for research in the area of secure printing, and outlined the plan for our research, Ed was swarmed by people from the audience. These individuals included several representatives from U.S. government agencies. We have since received numerous phone calls from individuals in industry requesting the results of our research, which is still at a very early stage of progress.

Also, on 9 April 2003, Carl Landwehr, our NSF Program Officer for the grant, visited Purdue to give a presentation at the CERIAS Annual Meeting. (CERIAS is the Purdue Center for Education and Research in Information Assurance and Security.) While Carl was on campus, we had an opportunity to meet with him, give him a presentation on our work, and also show him our research facility.

Findings:
As indicated earlier, our project is still at a very early stage; but we can report several findings. First, after conducting a thorough review of the literature, the novelty of what we are trying to do seems evident. Second, even with minimal opportunity to publicize it, the project has attracted a great deal of interest both from government and industry.

Preliminary results of the work described above under Research

and Education Activities have shown that the spectral banding signature for electrophotographic (EP) printers has characteristics that are unique to each family of printer models, and that within a specific model or family of models, the signature is very stable across different units. Thus, this type of signature can be expected to be useful for identifying the manufacturer and model that was used to print a particular document, but not effective for identifying the specific unit among those of a specific model.

To detect banding signatures, we have traditionally used special test patterns consisting of vertical lines of one pixel width spaced two or more pixels apart. However, for the intrinsic signature to be an effective tool to identify the origin of a printed document, it will be necessary to be able to extract the banding signature from a much broader range of printed material. In our research conducted as part of this project, we found that the signature can be extracted from solid or tint fill areas of printed pages. However, we also found that the approach that we have used in the past to extract banding signatures will not succeed with arbitrary pages of printed text. With this type of content, it appears that the spatial variation of the text in the process direction (the direction in which the paper exits from the printer) swamps out the banding signature. We are now working to develop strategies for preprocessing scanned pages to remove this clutter, thereby making it possible to recover the banding signature from the signal that remains.

In addition, as discussed above, we are working on a more general strategy for identifying features from the printed page that could form the basis for an intrinsic printer signature; and we are also developing a prototype solution for embedding an extrinsic signature on pages printed by an EP printer. However, we do not yet have results to report for these two activities.

Training and Development:
Gazi Ali, Pei-ju Chiang, and Aravind Mikkilineni, the three Ph.D. graduate research assistants on the project, are all new to research. They have had to quickly learn a number of basic research skills: how to search the literature and organize the results of the search, how to judge the contribution of the papers, and how to prepare clear and concise presentations describing what they have learned. Presenting their work during our weekly research meetings has helped to develop their oral presentation skills, including the ability to answer questions.

They have all learned the basic concepts of data hiding and watermarking, especially with respect to documents. They have also learned the fundamentals of digital printing, including marking technologies, print mechanisms, the printing pipeline, and how closed loop control can reduce print quality artifacts. The project has also provided an opportunity for the PIs to broaden their research experience, as well. Jan Allebach and George Chiu have gained new knowledge about data hiding and watermarking; and Ed Delp has learned about printing.

During the Fall 2003, we will be adding additional Masters level graduate students to the project, who will work on it solely for

academic credit. Then during the Spring 2004, we expect to develop an undergraduate project experience that will be associated with the research. Both these activities will broaden the educational outreach of the project, and will provide additional teaching and mentoring opportunities for Gazi, Pei-ju, and Aravind.

Outreach Activities:

Journal Publications

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:
Within the disciplinary field of the project , there are two main groups to whom this work is relevant. The first group consists of those individuals who are engaged in the development of fundamental printing technologies and design of printing systems. The second group consists of those individuals who are interested in watermarking, data hiding, and security, especially with respect to printing and printed documents.

Although we are still very early in the project, both these communities have expressed strong interest in our research. For the watermarking, data hiding, and security community,   . working at the print mechanism level, rather than the printer driver level is a completely new concept. For the printing technologies and design commmunity, our work will provide a clear indication of capabilities that they may want to exploit, or may be forced to deal with at some point.

Contributions to Other Disciplines:
While we have not yet made public any research outcomes, we believe that the results of our work will be of great interest to the broad community of individuals interested in security. In fact, representatives of this community have already expressed great interest in our project. These individuals are from the Air Force, CIA, and FBI.

Contributions to Human Resource Development:
As mentioned earlier, the training of the three Ph.D. students who are supported on the project has already been very significantly impacted by the research investigation. Also, as discussed previously, the group of students involved in the research will be expanded as the project continues.

Contributions to Resources for Research and Education:
The facilities described earlier that we are developing for working with a large set of different printers, and also for

supporting image analysis needs associated with the research
project, will have broad applicability to the research needs of the
Electronic Imaging Systems Laboratory that supports the
research efforts of two other faculty members and about 30
graduate students in Electrical and Computer Engineering at
Purdue. It will also be a valuable resource for the faculty
members and students working on the Digital Print Systems
program at Purdue. This large multidisciplinary program
presently involves six faculty members and about 20 graduate
students from four different departments at Purdue. Of these 20
students, 10 are also included in the group mentioned above,
that is associated with the Electronic Imaging Systems
Laboratory.

Contributions Beyond Science and Engineering:
We anticipate that this research will help to assure the security
and protection of citizens everywhere from the consequences of
terrorist and criminal activities.

<div align="center">

Special Requirements

</div>

Special reporting requirements: None
Change in Objectives or Scope: None
Unobligated funds: $ 31,714.00

Animal, Human Subjects, Biohazards: None

<div align="center">

Categories for which nothing is reported:

</div>

Organizational Partners
Activities and Findings: Any Outreach Activities
Any Journal
Any Book
Any Web/Internet Site
Any Product

NATIONAL SCIENCE FOUNDATION
Grant Letter

Award Date: March 3, 2006
Award No.   CNS-0219893
Amendment No.   003

Ms. Rebecca White
Associate Director,   Office of Research   and Program Development
Purdue University
302 Wood Street
West Lafayette, IN 47907-2108

Dear Ms. White:

By letter dated August 27, 2002, as amended, the sum of $410,000 was awarded
to Purdue University, under the direction of Jan P. Allebach, Edward J. Delp,
George T. Chiu for support of the project entitled:

"ITR: Printer Characterization and Signature-Embedding for Security and
Forensic Applications."

The purpose of this amendment is to extend the expiration date of the grant
from February 28, 2006 to August 31, 2006 without additional funds in order to
allow for the completion of the agreed level of effort.

Except as modified by this amendment, the grant conditions remain unchanged.

The cognizant NSF program official for this grant is Karl N. Levitt (703)
292-8950.
The cognizant NSF grants official is Gloria Young (703) 292-8212.

Sincerely,

Gloria Young
Grants and Agreements Officer

CFDA No. 47.070
awards@purdue.edu

Notification Type	Grantee Approved No Cost Extension
Award Number	0219893
Award Title	ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications

Prepared By	Jan P. Allebach
Submitted By	Rebecca L. White
Submitted Date	08/11/05
Revised Exp Date	02/28/06
Justification	When we received the original notice of award in August 2002, it was too close to the start of the Fall semester to find graduate students who were available to work on the project. Thus we were not really able to staff the team until the start of the Spring 2003 semester. Also, Professor George Chiu has been on sabbatical for the past 12 months. This has slowed the progress of the research during this period. We need an additional six months to complete the research as scoped in the original proposal.

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23	FOR NSF USE ONLY
NSF 05-518 02/07/05	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **CNS - CYBER TRUST**	**0524540**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
02/07/2005	5	05050000 CNS	7371		09/19/2006 1:45pm S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES☐ NO☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **Purdue University**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Purdue University** **302 Wood Street** **West Lafayette, IN. 479072108**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0018259000**	

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)	☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION	☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS	☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT   **CT-ISG:Printer and Sensor Forensics**

REQUESTED AMOUNT $ **498,481**	PROPOSED DURATION (1-60 MONTHS) **36** months	REQUESTED STARTING DATE **08/01/05**	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)

☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)

☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)

☐ HISTORIC PLACES (GPG II.C.2.j)

☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)

☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date _____

☐ HUMAN SUBJECTS (GPG II.D.6)

Exemption Subsection _____ or IRB App. Date _____

☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)

_____

☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT **Electrical and Computer Engineering**	PI/PD POSTAL ADDRESS **465 Northwestern Avenue**
PI/PD FAX NUMBER **765-494-3358**	**West Lafayette, IN 47907** **United States**

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Jan P Allebach**	**PhD**	**1976**	**765-494-3535**	**allebach@ecn.purdue.edu**
CO-PI/PD **George T Chiu**	**PhD**	**1994**	**765-494-2688**	**gchiu@purdue.edu**
CO-PI/PD **Edward J Delp**	**PhD**	**1979**	**765-494-1740**	**ace@ecn.purdue.edu**
CO-PI/PD				
CO-PI/PD				

Page 1 of 2   Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

Debarment and Suspension Certification   (If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded
from covered transactions by any Federal department or agency?   Yes ☐   No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE	DATE
NAME **Rebecca L White**		**Electronic Signature**	**Feb 7 2005 4:42PM**
TELEPHONE NUMBER **765-494-1052**	ELECTRONIC MAIL ADDRESS **rlwhite@purdue.edu**	FAX NUMBER **765-494-1360**	

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

Project Summary

Digital media is becoming an increasingly important part of our daily lives. Trust in the source of digital media is an integral part of its value. If an image or document did not actually originate from the source that it is presumed to have come from, its value may be greatly diminished. Knowing the source of a digital image or printed document very often plays an important role in solving or preventing crime, and may play a similar role with respect to acts of terrorism.

The topic of this research project is the forensics of imaging devices. Specifically, given the output of a digital camera or scanner in the form of a digital image or given the output of the printer in the form of a printed document, we wish to determine as uniquely as possible the device that produced this file or image. We will consider two different approaches to this problem.

The first approach is based on identifying an intrinsic signature that is associated with the device. This signature represents artifacts that are due to optical, electrical, or mechanical limitations of the device. To determine an intrinsic signature for a device, we must first identify features that can be extracted by image analysis techniques from the digital image produced by a camera or scanner. In the case of a printer, we scan the printed output, and process the resulting image. These features can then be input to a classifier that has been trained with output samples from a set of candidate devices.

The second approach is based on an extrinsic signature for the imaging device. The extrinsic signature is generated by modulating the parameters that control the intrinsic signature of the device according to a specified pattern that may encode the serial number of the imaging unit or other information. The same algorithms that detect the intrinsic signature can form the basis for detecting and decoding the extrinsic signature.

This work builds on the results of a prior NSF grant in which we investigated intrinsic and extrinsic signatures for laser electrophotographic printers. In that work, we were able to distinguish almost perfectly between 10 different models of similar printers, and we demonstrated the capability to embed new frequencies in the printed output as an extrinsic signature.

It is important to distinguish our work from image forensics in which the image is examined for evidence of tampering, and cryptographic approaches to authentication. Here we are focused entirely on the inherent characteristics of the process by which a device generates an image. We believe that this approach can form the basis for more robust and tamper-resistant methods of device identfication.

Intellectual merit. The proposed research will result in a new understanding of the relation between imaging devices and artifacts produced by those devices. It will lead to new knowledge regarding image analysis for feature extraction and the design of classifiers based on those features. In calculating optimal error control codes and channel capacities for extrinsic signatures, it will extend the application of classical communications theory to a completely new domain.

Broader impact. The proposed research will be of very direct benefit to society by providing law enforcement and government agents new tools for combatting counterfeiting, forgery, and other criminal and terrorist activities. The proposed organization of several teams under the Vertically Integrated Projects umbrella will bring many undergraduate students into close contact with the interface between research and an exciting application area. The proposed disadvantaged and under-represented minorities outreach program will show individuals from these groups how research can be brought to bear on important real-world problems to which they can relate.

1

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

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Table of Contents	1	
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) (Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)	15	
References Cited	4	
Biographical Sketches (Not to exceed 2 pages each)	6	
Budget (Plus up to 3 pages of budget justification)	6	
Current and Pending Support	5	
Facilities, Equipment and Other Resources	4	
Special Information/Supplementary Documentation	0	
Appendix (List below.) (Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)		

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1 Introduction

1.1 The problem

As we become more and more immersed in digital media, the issue of what is reality becomes increasingly pressing. In the physical world, we have scenes consisting of real objects. We also have physical documents printed on paper. In the digital world, all we have are 0s and 1s, which thanks to the marvels of modern imaging technology, may be a representation of any aspect of the physical world. The question here is how do we establish a link between the physical world and the digital data that purports to be representative of that physical world?

This, of course, is not a new question. It crops up in many areas. Digital media may represent intellectual property that needs to be protected, such as the result of a creative endeavor. Its role may be to document a financial transaction. It may serve as evidence of a crime, terrorist act, or historical event. Similarly, a printed document may also serve as the record of a transaction or physical evidence of a crime or terrorist act. Counterfeiting and piracy serve as vehicles for organized crime. There are proven links between counterfeiting and piracy and drugs smuggling, money laundering, pornography, and terrorism. During the year 2002, a total of $130.1M in counterfeit currency was seized worldwide before it could be put in circulation. The amount of counterfeit currency that was successfully passed, and subsequently determined to be counterfeit was $44.3M. It is believed that these figures would be much higher if the U. S. Secret Service were not able to act vigorously to prevent counterfeiting [1].

At a high level, what is needed is a way to establish an inviolable link between the physical and the digital worlds. This is a challenging task that can be approached from a variety of different vantage points. In our research, we will develop new methods to forensically characterize a physical imaging device

1.2 Goal of the research

The goal of our research is to be able to trace from the device output back to the device that generated that output. For a digital camera or scanner, given one or more digital images, we want to determine as much as possible about the device that generated those images. For a printer, given one or more printed pages of output, we want to determine as much as possible about the device on which those pages are printed. This is a very challenging task. The degree of success of the endeavor will depend greatly on the content of the output digital images or printed pages that are available and the device itself that was used to generate that output. Thus, we must think in terms of a hierarchy of information. At the top of this tree, we branch between basic characterisics of the candidate devices. For example, with a digital camera, the base sensor resolution would be such a characteristic. With a printer, whether it is inkjet or laser electrophotographic (EP) is an example. At this level, the differentiation may be relatively easy. However, it becomes increasingly difficult as we move down through the tree. Eventually, we reach the point of determining the manufacturer of the device, then the specific model within that manufacturer's product line, and finally the exact unit among many units of the same model device.

For a law enforcement or other government agent seeking to track a digital image or printed document to its source, it would be ideal to be able to analyze the image or document and to determine the identity of the exact unit that generated it. Even if this is not possible, any information about the device will be of benefit to the investigation.

This research is an extension of a prior NSF-funded project that considered only the problem of identifying a laser EP printer based on analysis of printed output. Section 6 contains a concise summary of this project. Section 2.1 contains a more detailed review of the research results that are pertinent to this proposal.

1.3 Our approach

Our approach will be to focus on the imaging device that was involved in the transformation between the physical world and the digital world, rather than the content itself. We believe that every imaging device possesses an *intrinsic signature* that characterizes one or more aspects of the process of transformation between the physical and digital worlds. This signature is reflected in subtle ways in the structure of the device output. We are interested in three specific classes of imaging devices: digital cameras, flatbed scanners, and digital printers. Digital cameras and scanners are capture devices; so here we must find patterns in the digital data they produce. Digital printers produce hardcopy output that we scan and then analyze to find characteristic patterns.

The intrinsic signature is a characteristic of the off-the-shelf product. We will also develop processes for modifying these devices so that they insert an *extrinsic signature* in the device output. The extrinsic signature could contain a variety of different kinds of information. Certainly, we would expect it to include information, such as a serial number, that would uniquely identify the imaging device. However, it might also include information about the date and time that the image was captured, or the page printed. For digital cameras and scanners, the extrinsic signature is similar to a watermark in that it is associated with subtle modifications to the output digital image. As is also the case for a watermark, it is decoded by operating on the digital image with a specific algorithm. However, our approach to generating the extrinsic signature will be intimately linked to the intrinsic signature of the device. More specifically, we will modulate the device parameters that control this intrinsic signature, according to a specific pattern that will encode the desired information. This modulation will only indirectly modify the data in the digital output image. Similarly, the extrinsic signature for a printer is created by modulating parameters of the print mechanism to create a detectable pattern on the printed page. The process is performed downstream from the point where the digital image data describing the page is transformed to an analog signal. The signature is decoded by scanning the printed page and then operating on the resulting digital image with a specific algorithm.

1.4 Intrinsic signatures

The intrinsic signature is the result of artifacts in the imaging process associated with the device. From the manufacturer's perspective, these artifacts are undesirable, and should be eliminated. However, this increases the cost of the device. The marketplace for products of this type - cameras, scanners, and printers is extremely competitive and price-sensitive. Therefore, manufacturers only reduce the artifacts to the point where they are imperceptible, or at least not objectionable to the user. At this level, these artifacts are still detectable with appropriate image analysis techniques. Thus the artifacts can be used as an intrinsic signature.

For printers, these artifacts are closely linked to the print mechanism. Their nature depends on the specific printing technology being used. The two dominant technologies are electrophotographic (EP) and inkjet. The EP technology is usually implemented with a laser scanning mechanism. For

EP printers, the dominent artifact is banding due to quasiperiodic fluctuations in the angular velocity of rotating components that is caused by gear noise. Inkjet printers also exhibit this type of banding, plus additional artifacts due to the manner in which the print-head nozzles are fired and stitching errors between print-head alignment from swath to swath.

For digital cameras, these artifacts can arise from imperfections in the optics of the imaging system, limitations and imperfections in the sensor array, the process of A/D conversion, demosaicing to create three full-resolution frames of RGB data from the spatially multiplexed sensor array, image processing for contrast adjustment, white balance, and sharpening, and finally compression of the image prior to storage on the camera's flashRAM or mini-drive.

A scanner combines some of the operational components of a printer and a digital camera. Like a digital camera, it has an optical system and a sensor array with the associated A/D convertor and image processing. However, scanner images are generally not compressed. Also, the type of image processing is different from that employed with digital cameras as a consequence of the differences between characteristics of scene content captured by digital cameras and hardcopy printed material captured by scanners. The scanner also needs to move either the media in the case of a sheet feed scanner or the scan bar in the case of a flatbed scanner. The process of generating and controlling this motion is common to the mechanisms associated with printers. The artifacts exhibited by scanners are, then, a combination of the artifacts exhibited by digital cameras and printers.

1.5 Extrinsic signatures

As stated earlier, our approach to generating an extrinsic signature is to modulate the parameters that control the intrinsic signature, according to a specific pattern that can be decoded by analyzing the digital image from a camera or scanner, or analyzing the digital image scanned from a printed page. We envision two modes for the use of an extrinsic signature. In the one scenario, the process for generating the extrinsic signature would be buried deep inside the hardware and would not be accessible to the user. In the other scenario, the process for generating the extrinsic signature would be accessible to the user as a user controllable option. In this case, the user would have the ability to modify the information that is encoded, much in the manner of a watermark. Unless the amount of user control was limited, this mode would have negative implications for the effectivness of the extrinsic signature as a means of identifying the device. For example, if the user had the option to simply shut off the signature, then it would no longer be available for device identification. On the other hand, the manufacturer could set up the process in such a way that the signature always contains the serial number of the device, but might contain additional user-definable information.

In any case, it is important that the extrinsic signature not degrade the quality of the digital image output from a camera or scanner or the quality of the print generated by a printer. This requires an understanding of how the signature is perceived by the human viewer, specifically what is the threshold of perceptibility. However, since the extrinsic signature is generated by modulating the same artifacts that are already present in the device, all the prior work that has been done to understand how human's perceive these artifacts can be leveraged to support this work.

The process of embedding an extrinsic signature in a digital image or print, then decoding it, is analogous to communicating through a noisy channel. Just as with any noisy channel, it may be necessary to use error control coding to yield reliable transmission of information. An important issue will be to determine the channel capacity for the overall system. Since we have complete control of the modulation process up to the limit of generating perceptible artifacts and since we can employ error control coding, the extrinsic signature will inherently be more robust than the

intrinsic signature.

1.6 Device forensics, image forensics, and cryptography

It is important to make a distinction between the work that we are proposing here, which we call *device forensics* and research that has been done on *image forensics* [2, 3]. In our case, we seek to identify as specifically as possible the device that was used to capture a digital image or print a document. Image forensics, on the other hand, seeks to determine whether or not an image has been modified or tampered with. This is not the objective of our research. In addition, our work will not address cyptographic aspects of authentication. Our work will focus entirely on the identification of intrinsic signature features that can provide information about a device, and the modulation of those features to embed specific information in the signature and increase its robustness.

1.7 Signature security and robustness

The question of the security and robustness of the signature is important. For digital cameras and scanners it may be possible to spoof the intrinsic signature by modifying the artifacts in a way that the image could appear to come from a different device. Since these two types devices produces images that are bits, a malicious user may be able insert the signature in an image not from the particular device corresponding to that signature. This would be similar to a copy attack in watermarking. One could also use image processing and editing tools to "scrub" the signature from the image. We will develop techniques that will miitigate these problems as described later in the proposal.

2 Current status of research

2.1 Printer forensics

Banding due to quasiperiodic variations in the angular velocity of rotating components is a prominent artifact for laser EP printers. This artifact is manifested by closely spaced bands on the printed page that are orthogonal to the direction of the paper motion, which we refer to as the *process direction* throughout this proposal. We previously developed three successful approaches to reducing this artifact by modifying the printer mechanism [4, 5, 6]. More recently, we leveraged the knowledge gained about the banding artifact and how to control it to develop methods to identify laser EP printers from their intrinsic signatures and also to embed an extrinsic signature in the printed output from a laser EP printer. In the remainder of this section, we briefly review this work and show some illustrative results.

2.1.1 Printer identification based on intrinsic signatures

We have developed two different approaches to identifying a laser EP printer from scanned pages of text. We chose to focus on printed text rather than images printed on the page because pages with text are much more common than pages with images. This is the more difficult problem because the banding signal is much stronger in halftone areas of the printed page than it is in text regions. A 1-D banding signal can be obtained by projecting the scanned image in the direction
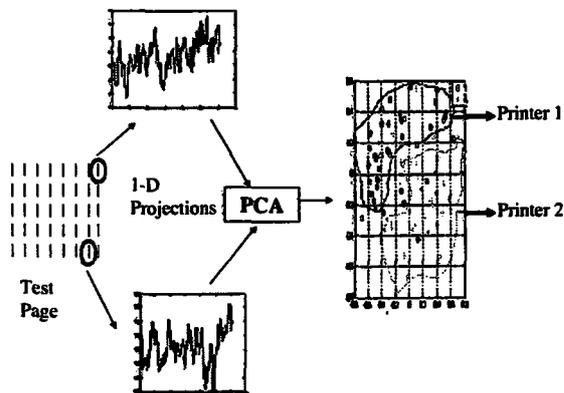
4

Figure 1: Principal component analysis using 1-D projected signals from individual characters.

orthogonal to the process direction. For laser EP printers, this signal contains very distinctive frequency terms. However, the phases of these frequency components are only locally stationary [7]. Therefore, averaging over large areas of the scanned image will reduce the distinctiveness of the signature. Instead, for a page of text, we process each character stroke separately. For each character stroke, we perform a classification to choose the most likely printer that generated this character from the set of printers in the training set. We then pool the votes of all the characters on the page and choose the majority vote as the final decision. Our two different approaches share the steps of segmenting the page into individual characters, indentifying the characters, extracting a set of features for each character, performing a classification to the most likely printer for each character, and then pooling the votes. What differs between the two methods is the nature of the features on which the printer classification is based and also the actual classification algorithm that is used.

Principal components analysis combined with a Gaussian mixture model classifier. Our first approach [8, 9] is illustrated in Fig. 1. In this case, we are processing a page of text containing multiple instances of the letter 'I' in a sans-serif font. After segmentation, for each character, we perform a projection orthogonal to the process direction. We then perform a principal components analysis on this projected 1-D signal using the method of canonical variates to optimally separate the classes, and use the first two components as features for a Gaussian mixture classifier. Training of the Gaussian mixture model is based on the EM algorithm. Our preliminary results with this method showed that we could correctly classify a print sample consisting of a page with multiple letter 'I's from one of a set of five possible printers for all but two printers that came from the same manufacturer and had a very similar mechanism, and thus very similar banding frequencies.

Gray level co-occurrence matrix and image features combined with a 5-NN classifier. Our second approach [10, 11, 12] uses the Graylevel Co-occurrence Matrix (GLCM) [13] and selected character statistics as the basis for the feature vector. The GLCM is an estimate of the second order probability density function of pixels in the character image $Img(i, j)$ separated by a fixed displacement (dr, dc) in the image. It is defined as

$$glcm(n, m) = \sum_{(i,j),(i+dr,j+dc) \in ROI} 1_{\{Img(i,j)=n, Img(i+dr,j+dc)=m\}},$$ (1)

where ROI denotes the region of interest, which consists only of those pixels actually within the

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In\Out	hl1440	lj4050	e320	lj1000	lj1200	lj5M	lj6MP	1250W	14e	ml1430	Majority Vote
hl1440	156	0	2	3	2	18	12	71	32	4	hl1440
lj4050	0	300	0	0	0	0	0	0	0	0	lj4050
e320	0	0	282	0	0	1	0	13	4	0	e320
lj1000	8	0	0	137	89	25	31	8	0	2	lj1000
lj1200	9	0	1	145	93	31	15	5	0	1	lj1200
lj5M	42	0	1	6	10	199	20	22	0	0	lj5M
lj6MP	34	0	24	67	37	39	68	20	0	11	lj6MP
1250W	43	0	105	0	1	24	11	114	2	0	1250W
14e	90	0	36	0	0	0	1	32	120	21	14e
ml1430	36	0	1	15	5	0	35	5	55	148	ml1430

123 Correctly Classified

123 Incorrectly Classified

Bold = 2nd highest classification

Figure 2: Classification results using 4 features and $dr = 2$

outline of the character. Normalizing the GLCM by the number of pixel pairs separated by (dr, dc) which both fall in *ROI* yields the estimated density. Based on the GLCM and the character image itself, we defined a set of 20 features that represent a variety of statistics of the normalized GLCM and the character image. Then, we use a 5 nearest neighbor classifier to select the most likely printer from the training set to have generated the character. As with our first method, the votes of all the characters on the page or in the document are pooled to make the final decision.

In our experiments, we found that we could obtain the same level of classification accuracy using only a subset of the features. However, the confidence level for the decision does decline; so it is not yet clear whether the reduced feature set would be sufficiently robust in practice. This is a subject for future research. Figure 2 illustrates the performance of this approach. Here the classification is based only on the letters 'e' extracted from pages of randomly generated text. The training set consisted of 10 printers. We see that the classification was 100% accurate except for the HP LJ 100 and LJ 1200 printers, which are the same two printers that were misclassified with the first approach.

2.1.2 Embedding extrinsic signatures

There are three possible approaches to controlling banding in a laser EP printer – modulating the laser beam intensity or pulse duration [4], modulating the vertical position of the scan lines [5], or modulating the motor drive signal [6]. To embed an extrinsic signature, we chose to modulate the laser beam intensity by varying the input voltage to the laser diode [14]. To do this successfully, requires consideration of four factors:

1. The frequencies chosen for the extrinsic signature should be well-separated from those associated with the intrinsic signature of the device.

2. The voltage modulation should be synchronized with the scanning process, so the intensity is constant within any scan line, and varies only between scan lines.

3. The voltage modulation should be transformed by the inverse of the voltage–intensity response curve to assure a mapping that is linear overall. If this is not done, spurious frequencies will occur in the signature.

4. At each frequency, the amplitude of the voltage modulation should be limited in accordance with the contrast sensitivity of the human visual system at that frequency.
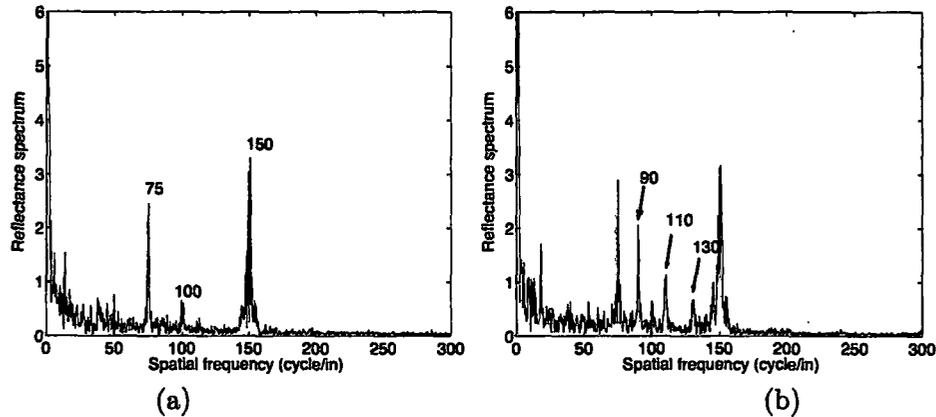
6

Figure 3: Spectra of projected image of lighthouse for (a) original intrinsic signature consisting of frequencies at 75, 100, and 150 cycles/in (b) after adding extrinsic signature with frequencies at 90, 110, and 130 cycles/in.

Figure 3 shows the results of our preiminary experiment with embedding an extrinsic signature within pages printed by an HP LJ 4500 printer. We can see that the method is quite effective in generating the desired new spectral lines. Due to space limitations, we do not show the actual images on which these results are based. However, there was no perceptible difference in the banding between the images with and without the extrinsic signature.

2.2 Digital camera forensics

Our way of addressing the problem of digital camera forensics is to exploit how the camera "makes the picture" and use this to identify the camera from a sample of the output. In essence we will exploit the artifacts and defects of the camera to identify it. Common artifacts in digital cameras include [15, 16, 17]:

- Optics - This source of artifacts includes the frequency response of the lens and color filters (MTF), aberrations, non-uniformity, dust inside the lens, and scratches. The method used for auto focusing may also induce artifacts in the image.

- Noise - This is mainly determined by the sensor geometry, the "dark" noise of the sensor physics, and the way the sensor is read out. The signal-to-noise ratio is somewhat dependent on the "fill factor" of the pixel. This also includes the blue channel noise due to the low sensitivity of the sensors in the short wavelength range.

- Electronics and analog signal processing - This includes artifacts we mentioned above such as dark current; but more importantly artifacts are induced by the way the electronic components operate. For example in [18], a method was described that exploits variations in the A/D converter for adding security features to sensors. This was based on using sigma-delta modulation to model the A/D converter.

- Blooming - Blooming or light spill over, is a problem caused by photons spilling from one sensor element in the imaging array into another sensor element creating what can be a region of over fill, resulting in unreal highlights or colors. Larger sensor elements can collect and contain the photons better than the smaller ones found in most consumer digital cameras.

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- Pixelation - When a relatively low-resolution sensor array is used to create an image, pixelation becomes very apparent. Pixelation is most noticeable as jagged diagonal lines.

- Interpolation - An example of this is the "Christmas tree lights" or color aliasing artifacts which are a function of the way that the color image is formed from the sensor and is particularly apparent when an image is oversampled.

- Compression - Most cameras compress images using JPEG or JPEG2000. Generally, compression artifacts produce "mushy" areas that lack sharpness. This is especially obvious in flat areas of an image. JPEG2000 can produce "texture wash-out" at low data rates whereas JPEG can suffer from block artifacts. Overemphasized edges and unnatural color distribution are other common artifacts. Note also that because compression is done last, image artifacts such as sharpening and color saturating are likely to be compounded.

- Sharpening and Unsharp Masking - Some loss of perceived sharpness occurs at capture stage with any sensing device. Sharpening is sometimes done in the camera to compensate for the apparent loss of resolution of the sensor.

- Color Depth - In many cases, the camera does not completely use the entire color palette. This causes loss in the color rendition of the image.

Our proposed work is to use the above artifacts to identify the camera. Our proposed work in camera forensics is related to, but also different from the work in image forensics. There has been some very interesting work in the area of image forensics where the goal is to determine if an image has been tampered with by exploiting how a user would make a forgery using image processing and editing applications. An excellent set of forensic tools are described in [2, 3, 19, 20] where various models are developed for image editing operations including resampling, color correction and JPEG re-compression. Classification tools are described that use the EM algorithm and Support Vector Machines (SVM) to determine if an image was modified.

We will use some of the concepts developed in image forensics for camera forensics but the problem is also different in that we believe that exploiting the camera optics and electronics through artifacts will allow us to develop more robust solutions. For example, artifacts from the optics such as dust or aberrations are similar to artifacts induced by image editing operations.

2.3   Scanner Forensics

Digital document scanners have been widely used in the documents forensic community for capturing questioned document images for further image processing to facilitate forensic investigation. However, as digital imaging moving into everyday life, digital document scanners are becoming targets for forensic analysis just as digital printers have. Similarly, intrinsic characteristics, i.e. signatures, of scanners can provide valuable information for scanner forensics.

Documented results on scanner characterization and performance evaluation can be found in published literature and standards starting in the early 1990s. Most of the works treat the scanner as an integrated device that is similar to a traditional camera and utilize similar characterization approaches and processes [21, 22, 23, 24, 25, 26], such as the system modulation transfer function (MTF), dynamic range, and tone reproduction curves. Due to the increased demands in digital imaging and performance requirements, the digital scanner image capture process and the resulting artifacts that are intrinsic signature candidates, are being investigated by manufacturers. Similar

to the printer literature, due to intense market competition, the majority of this information is in the form of trade secrets, know-how, and patents.

A digital scanner can be divided into an illumination system, a sensor system, and a media transport system. The stability and characteristics of the light source, the material properties and characteristics of the optics and sensing elements, and the motion quality of the transport system all contribute to the quality of the scanned images. The artifacts due to imperfection in these systems are obvious *intrinsic signature* candidates. Methods to characterize and compensate for the undesirable impacts (scan artifacts) of these components in the image path of a scanner are subjects of interest for many scanner manufacturers [27, 28, 29, 30, 31, 32]. Light source intensity modulation, photosensor calibration and compensation, and motion control of transport mechanisms are core technologies to every scanner. As such, they are obvious candidates for embedding *extrinsic signatures* in scanned images.

3 Proposed research

3.1 Digital camera forensics

Our goal is to use the digital camera artifacts and defects discussed above to form intrinsic and extrinsic signatures to forensically characterize a camera.

We will examine several digital cameras and measure the artifacts to determine how they manifest themselves in the image. We will also purchase a reference design for a digital camera from a vendor in Asia and use this to build a test camera. One of the investigators (Allebach) has extensive experience in optics and another investigator (Delp) has done a great deal of work in the consumer electronics area. This will allow us to model and characterize the optical and electronic artifacts. Our approach will be that if we can model and measure an artifact or defect, we can then use it for the intrinsic signature and modify it for the extrinsic signature.

The construction of the intrinsic signature is a pattern recognition problem where the artifacts and defects serve as features that we can use to identify the camera from these features. We have developed an extensive set of tools from our previous work in classifiers [33, 34, 35], printer forensics [8, 10, 14, 9, 11, 12] and medical imaging [36, 37] that will allow us to develop a classification scheme and determine which features (artifacts and defects) are the most important. We will particularly concentrate on artifacts generated by the optics and electronics because these are methods are representative of the camera and are different than approaches taken in image forensics which attempt to model and classify image processing and editing operations.

The extrinsic signature problem is one where we will modify or "modulate" a set of artifacts that will allow us to insert identifying information into the image. We are in effect modifying the intrinsic signature in a way that will not be detected from a typical artifact but will allow data to be hidden in the image. We have used this approach in our work on printer forensics and have developed a very robust signature method [14] This can be thought of as a form of data hiding or watermarking [38, 39] with the important difference being that the data is not explicitly inserted into the image after it is formed, but is inserted into the image as part of the camera image formation process. As stated above, we find the optical and electronic artifacts particularly attractive. For example, we believe we can modify the noise and spatial mosaic pattern in the sensor to hide information. There has been some reported work in using the variation or selection of electronic components and processing methods to embed ID information (.e.g the A/D converters) [18]. This is

done by modifying the step size and dynamic range of the A/D converter. We find these approaches attractive and note that they are similar to robust data hiding methods [38, 39, 40]. We will avoid artifacts created by image processing operations in the cameras such as compression artifacts since these will be very easy to spoof.

We will examine the following issues:

- Best Artifacts - Which artifacts make the best intrinsic signature features? How do they typically occur in a representative set of cameras?

- Classification Methods - We will concentrate on tree classifiers and support vector machines

- Extrinsic Signature - Which artifacts can be modified and how much data can be hidden? For example, can we easily modify the sensor noise in a way that will not be visible in the image? How easy will it be to extract the extrinisc signature?

- Extrinsic Signature - How difficult would it be to actually add the extrinsic signature to a camera design? For example, every camera may need a unique A/D converter for embedding information.

- Attacks - Can the intrinsic or extrinsic signature method be spoofed? Can an image look like it came from a different camera? This is similar to the copy attack in watermarking. Can image processing and editing techniques damage the signature?

3.2 Digital scanner forensics

The scanning mechanism consists of three principle components: the light source, the photosensor array and optics (scan head), and the motion system that either moves the original image (sheet feed scanners) or the scan head (flatbed scanners). As the photosensor array moves across the media (or vise versa), it is sampled at a rate that matches the nominal velocity of the relative motion to produce *evenly spaced single pixel row of* scanned image at the native resolution. Depending on the construction of the scan head optics, some scanners use a three pass scanning method, where each pass of the image uses a different color filter (red, green or blue) between the lens and the photosensor array. The individual RGB images are then combined to form a full-color image. There are two common one pass scanning approaches: 1) the lens splits the image into three smaller versions of the original and passes them through individual RGB filter and then on to discrete sections of the CCD array; 2) the reflected light goes through a prism that splits the light into RGB spectral components and onto the respective photosensor arrays. The three principle components and examples of corresponding intrinsic characteristics will be discussed.

3.2.1 Illumination system

To produce consistent, high quality scans, scanners need to have light sources that supply stable and uniform lighting. Most scanners control the light intensity with a feedback loop during the scans and try to maintain uniformity. The lighting variations perpendicular to the motion direction are usually measured and adjusted automatically by the photo response non-uniformity (PRNU) compensation mechanism. The PRNU characterizes the pixel-to-pixel variation in the photosensor array's response to a fixed intensity light source.

3.2.2 Sensor system

The sensor component itself is implemented using one of three different technologies: PMT (photo-multiplier tube), CCD (charge-coupled device), or CIS (contact image sensor). The CIS sensor is a relatively new technology which integrates the scanning functions into fewer components, allowing scanners to be more compact in size. The CCD technology is responsible for having made scanning a desktop application and has been used in devices such as fax machines and digital cameras.

Different sensing technologies have different inherent issues that affect the quality of the scanned image. These issues are fundamental and unique to the sensor array, and can be potential candidates for intrinsic signatures. For example, the dark current is the rate at which electrons accumulate in a CCD element or pixel due to thermal noise. The differences in response time of different CCD elements to a fixed-intensity light source is characterized as the PRNU for a CCD array. Dark current and PRNU are compensated in a scanner through the dark voltage and PRNU compensation mechanism. Ineffective dark current/offset voltage compensation will result in artificial lightness or streaks in the shadow regions of the image. Ineffective PRNU compensation causes streaks in the process direction of the image and is typically more noticeable than dark-voltage lightness or streaks.

3.2.3 Transport system

The transport system of a scanner performs the same function as the motion system in a digital printer. It provides relative motion between the original image and the scan head. Most document scanners in the market use a stepper motor and timing belt pulley system (for flatbed scanners) to provide the needed rotational to linear motion conversion.

Similar to printing, the motion quality of the transport system will directly impact the spatial sampling of the image. For example, the torque ripple of the motor and the imperfections of the pulley and timing belt may induce vibration and velocity fluctuations that will cause periodic errors in the spatial positions of the samples acquired from the hardcopy page being scanned. Similar to the banding artifact in printers, the frequency pattern of these periodic errors is an intrinsic characteristic of the scanner model. For multi-pass scanners, due to the inherent difference in the motion system construction from that used for single pass scanners, the image samples for each pass (each RGB color plane) will be from slightly different locations on the hardcopy page. This will produce a color registration scan artifact. The subtle differences in the optics for a single pass scanner can also produce similar artifact.

3.2.4 Intrinsic signatures

Scanning artifacts can be attributed to light source instability, photosensor noise, optics imperfections, or poor motion quality. The artifacts caused by non-ideal sensor and optical characteristics and systematic motion fluctuations are possible intrinsic signature for a digital document scanner. The PRNU, dark current/voltage, and the pattern noise of a CCD array due to inactive photoreceptor sites are intrinsic signature candidates that can be exploited for forensic purposes. The specific spectral characteristics of the light source in the scanner and the resulting image artifacts can also be investigated. However, the stability of the light source may become a limiting factor. Similar to the issues with motion quality in electrophotographic printers, manufacturing and assembly tolerances induce periodic velocity fluctuation in the scanner motion that will produce

periodic scanning artifacts in the process direction. These will be manifested as periodic scanning artifacts at specific spatial frequencies. Through proper image analysis, these process/component induced artifacts can be extracted as distinct intrinsic characteristics of a scanner model or scanner reference design.

3.2.5 Extrinsic signatures

The mechanisms that the scanner manufacturer used to compensate for the artifacts produced by the various non-ideal component characteristics can also be used as inputs/actuators to modulate the scanning process and embed extrinsic signatures. As discussed in the previous section, the PRNU and dark voltage compensation mechanism of a CCD sensor array, the light source intensity modulation mechanism and the motion controller of a scanner can be exploited to embed extrinsic signatures into a scanned image.

Our work with extrinsic signature embedding will build on all aspects of the work with camera and scanner characterization and intrinsic signature identification. In this work, the characterization task will take on a new level of importance. For the extrinsic signature embedding, the links between device parameters such as the PRNU values, dark voltage, and lighting intensity and the corresponding features in the image bits are critical to our ability to generate the extrinsic signal by modulating those very same parameters. As with the intrinsic signatures, we will seek features that are robust across a wide range of image contents. However, we no longer care that the signature be distinctive for the particular device, since we can encode information in the extrinsic signature that will make it distinctive. So whereas the choice of an intrinsic signature may require a tradeoff between robustness and distinctness, here we can choose the most robust feature without regard for distinctness.

3.3 Forensics for printers and multifunction peripheral devices

Our proposed research activity for printers will build on the effort that is already under way with the support of the current NSF grant. For laser EP printers, the focus will be on identifying improved classification methods for identifying printers from their intrinsic signatures and modulating and decoding extrinsic signatures. We plan to investigate tree-structured classifiers as an alternative to the Gassian mixture model-based approach and 5 nearest neighbor-based approaches that we have investigated thus far. As discussed in Sec. 2.1.2, we have demonstrated the ability to inject new banding frequencies in printed output. However, we have not developed an approach to modulate the amplitudes of the frequencies to encode desired information. We also have not developed a method to decode the signatures to recover that information. Finally, we don't know how noise and other sources of variability will impact the accuracy of the decoded information. As mentioned earlier, this is really a communications problem; and having developed the baseline extrinsic signature embedding approach, we are now in a position to address these issues.

The second major area of activity for printing forensics will be to investigate inkjet devices. Here we must undertake the fundamental work of determining a set of robust features for an intrinsic signature. This will be a challenging task due to the complexity of the inkjet printing processing [41, 42, 43]. The printhead has its own specific characteristics, such as nozzle alignment. A function known as the print mask controls the order in which the nozzles are fired. Printing may be done in a unidirectional or bidirectional manner. The head may move at different speeds. Typically slower speeds are used for higher quality printing; and higher speeds are used for draft mode. Printing

may be done in multiple passes. In a one-pass mode, a full swath of pixels — equal to the height of the printhead — is printed in each pass of the printhead across the page by potentially firing every nozzle at every column. Then the paper is advanced by a distance equal to the swath height and the printhead moves across the page to print the next swath. In an N-pass mode, only $1/N$ of the nozzles are fired in each pass of the printhead across the page. After each pass, the paper is advanced by only $1/N$ of the printhead height. So successive swaths are interlaced. Typically, $N = 1$ for draft mode and text; and larger values of N, say 4, are used for higher quality modes. Typically, the driver for an inkjet printer, which is used to control the printing process, provides several different modes. Each mode uses a unique combination of the parameters discussed above. This greatly complicates the determination of an intrinsic signature for an inkjet printer.

As the basis for an extrinsic signature, we propose to modulate the print mode in a spatially varying manner, and thereby encode information in this pattern of variation. We have already demonstrated the ability to modify the print mode on-the-fly [41, 42]. What remains to be done in order for this approach to be feasible is to determine the best features on which to base detection of the underlying intrinsic signature. Finally, because of their widespread use, we plan to conduct much of this work with inkjet printers that are part of an multifunction peripheral device containing a scanner and a printer. Such a device poses some interesting challenges due to the interplay between the signatures of the scanner and the printer.

4 Integration with Education and Outreach

In 1995, the EPICS program (Engineering Projects in Community Service) was initiated at Purdue. This program provides a vertically integrated design experience for Sophomores, Juniors, and Seniors from 30 departments working in teams to develop solutions that meet community and educational needs. To date over 1000 students from Purdue have participated; and the program has spread to six other universities. One of the co-PIs on this proposal (Delp) has advised one of the EPICS teams at Purdue since 1998. Inspired by the EPICS program, six Purdue faculty members including all three of the co-PIs on this proposal started a similar program called Mobile Communications Projects, which provides an opportunity for teams of Senior students to develop solutions to a wide range of campus problems using wireless communications and related technologies. This program has also been very successful. It has enrolled approximately 30 students for each of the past 6 semesters. We are now in the process of significantly expanding the scope of this program with the introduction of a new program called Vertically Integrated Projects (VIP). The goal of VIP will be to improve upon the Mobile Communications Program in three important ways:

1. Teams will consist of a mixture of Sophomores, Juniors, and Seniors, as is the case with EPICS.

2. The technology scope of the team projects will not be limited to applications using wireless and related technologies.

3. Faculty members will be encouraged to link the projects that they supervise to their research activities. Thus students will have a team design experience that is closely coupled to research.

At the time of the writing of this proposal, the VIP program is under review by the ECE Curriculum Committee. We presented the concept at the Curriculum Committee meeting on 3 Februrary 2005, and received a very enthusiastic response and many helpful suggestions. We will

revisit the committee at its next meeting on 10 February 2005 and present a revised plan for the VIP program. Based on the feedback we have received both during the committee meeting and afterwards, we expect approval for the program to be rolled out for the Fall 2005 semester.

We plan to develop several team projects that will be related to the research described in this proposal. These projects will focus on developing prototype applications based on the signature identification technologies that will arise from the research. As mentioned earlier, we have seen considerable interest from practitioners in law enforcement, national security agencies, and financial institutions in having access to software that would implement the concepts from our research. We believe that these teams would provide a means to develop such tools, while providing students a design experience and close exposure to research.

One unique aspect of the proposed research is that images and printed documents are used more and more in our everyday activities. Digital photography is becoming pervasive. People can easily relate to the need for security, trustworthiness, and privacy in thse materials. We will exploit this unique aspect in demonstrating the impact that science and technology have in improving the quality and security of everyday lives. Studies have shown that the decision to pursue higher education and careers in science and technology are being made between the 8th and 12th grade. The scope of the proposed research will provide an excellent vehicle to inspire high school students to consider a career in science and technology, and to pursue higher education. In particular, we will exploit this by giving tours and demonstrating the results of the proposed research to middle and high school students, especially in inner cities and rural areas with high concentration of under-represented minorities. In addition, we will actively recruit women and under-represented minority graduate and undergraduate students to participate in the research.

5 Impact

The proposed research is directed toward addressing a well-defined need to help combat terrorism and crime. It will provide the theory and tools needed by law enforcement agencies, intelligence organizations, and camera, printer, and scanner manufacturers to add a significant new level of accountability and tracking to the process of image capture and printing. The long term result will be a reduction in crime and better security in the face of terrorists threats.

One of the most important concepts of the new millennium will be trust. The attacks on September 11 demonstrated that there is a need to establish the identity of people entering the United States so in essence we can trust them. Society also has a need to trust physical things such as transducers. In this proposal, we will investigate imaging devices (in particular digital cameras, scanners, and printers) and develop methods that can used to authenticate or identify the device based on observing its image output. We will do this not by using cryptographic-based approaches or computer forensics but by exploiting the way the device makes an image. We will develop new methods to forensically characterize a physical device.

The liklihood of the impact of our research is clearly evidenced by the interest that the work has already generated. The Purdue University News Service released an article describing our work on 12 October 2004. Subsequently over two dozen news organizations worldwide picked up the story and ran versions of it, based on interviews with one or more of the Co-Principal Investigators. These articles include ones that appeared in the *The Economist*, *EE Times*, and *Forbes*. The BBC also carried the story. Most of these press releases can be downloaded from our website *http:shay.ecn.purdue.eduprints*. As a result of this press coverage, we were contacted by about a half dozen law enforcement agencies world-wide, who expressed interest in using our tools for printer forensics.

In addition, during the past two years, we have also met with representatives from the Air Force, the FBI, the Secret Service, the Bank of Canada, the Canadian Royal Mounted Police, and the Canada Customs and Revenue Agency. All these organizations expressed strong interest in the work and offered to provide on-going guidance and feedback regarding the direction and possible applications of the research.

Our work to date has attracted a great deal of attention from the printing industry. Since the Fall 2002, we have presented seven papers describing our work [8, 9, 10, 11, 12, 14, 44]. Five of those papers were presented at IS&T's Digital Printing Conference, which is the premiere conference for printer manufacturers. The fact that three of those papers were invited papers is indicative of the interest in our work.

Finally, we will establish a publicly available database of images captured from different digital cameras, scanned from different scanners, and printed from different printers and scanned with a single reference scanner. We already have 60 different printers in our laboratory, and with the purchases planned as part of this proposal will have another 20 printers, plus 20 different digital cameras and 20 different scanners. All data will be fully documented. The reference scanner will be calibrated to a known standard. This data will enable a larger community of researchers to effectively join this research effort and to develop and test algorithms for detecting intrinsic signatures from digital cameras, scanners, and printers. We already have approximately 200 scanned pages of text from more than 22 different printers.

6   Results from Prior NSF Support

All three Co-Principal Investigators received funding from NSF Grant No. CCR-0219893 "ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications," 15 August 2002 – 14 August 2005 in the amount of $410,00. For all three Co-Principal Investigators, this is the NSF grant that is most closely related to the current proposal. The results of the completed work are described in some detail earlier in this proposal as background to the proposed new work. To summarize here briefly, we investigated both intrinsic and extrinsic signatures for electrophotographic printers. Intrinsic signatures are inherent characteristics of the printer that result in a distinctive feature on pages printed by that device. Extrinsic signatures are patterns that have been purposely added by modulating one or more parameters of the printing mechanism. We developed two different approaches to identifying a printer based on its intrinsic signature. The first approach uses principal components and a Gaussian mixture model-based classifier to analyze projection-based banding signals. The second approach uses a five-nearest-neighbor classifer operating on gray-level co-occurence-based features. In preliminary experiments, both methods were able to successfully distinguish among five to ten printers. With regard to extrinsic signatures, we successfully demonstrated the capability to inject and subsequently detect four new banding frequencies in a printed page, without these frequencies giving rise to any perceptible degradation of image quality. We published seven conference papers describing this work [8, 9, 10, 11, 12, 14, 44]. Three of these papers were invited. This work supported three Ph.D. graduate students. None of these individuals has yet completed their degree requirements. In addition, a non-thesis Masters student earned six research project credits for his work on the project. This individual who was from an under-represented minority group, graduated at the end of the Spring 2004 semester, and is now working in industry.

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4

SUMMARY PROPOSAL BUDGET   YEAR 1

ORGANIZATION			FOR NSF USE ONLY		
Purdue University			PROPOSAL NO.	DURATION (months)	
				Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR			AWARD NO.		
Jan P Allebach					

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds ed by NSF different)
	CAL	ACAD	SUMF	
1. **Jan P Allebach - PI**				
2. **George T Chiu - Co-PI**				
3. **Edward J Delp - Co-PI**				
4.				
5.				
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (**0**) POST DOCTORAL ASSOCIATES				
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				
3. (**3**) GRADUATE STUDENTS				
4. (**0**) UNDERGRADUATE STUDENTS				
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				
6. (**0**) OTHER				
TOTAL SALARIES AND WAGES (A + B)				
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)				
General Purpose Equipment $ **10,000**				
TOTAL EQUIPMENT			**10,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)			**5,000**	
2. FOREIGN			**0**	
F. PARTICIPANT SUPPORT COSTS				
1. STIPENDS $ **0**				
2. TRAVEL **0**				
3. SUBSISTENCE **0**				
4. OTHER **0**				
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS			**0**	
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES			**3,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION			**1,000**	
3. CONSULTANT SERVICES			**0**	
4. COMPUTER SERVICES			**0**	
5. SUBAWARDS			**0**	
6. OTHER			**16,380**	
TOTAL OTHER DIRECT COSTS			**20,380**	
H. TOTAL DIRECT COSTS (A THROUGH G)			**115,766**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)				
TOTAL INDIRECT COSTS (F&A)			**46,482**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)			**162,248**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)			**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			$ **162,248**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $				

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

PROPOSAL BUDGET

	FOR NSF USE ONLY		
ORGANIZATION	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months		Funds	Funds nted by NSF if different)
1. **Jan P Allebach - PI**				
2. **George T Chiu - CO-PI**				
3. **Edward J Delp - CO-PI**				
4.				
5.				
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (**0**) POST DOCTORAL ASSOCIATES				
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				
3. (**3**) GRADUATE STUDENTS				
4. (**0**) UNDERGRADUATE STUDENTS				
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				
6. (**0**) OTHER				
TOTAL SALARIES AND WAGES (A + B)				
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **GENERAL PURPOSE EQUIPMENT** $ 10,000				
TOTAL EQUIPMENT		10,000		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)		5,000		
2. FOREIGN		0		
F. PARTICIPANT SUPPORT COSTS				
1. STIPENDS $ 0				
2. TRAVEL 0				
3. SUBSISTENCE 0				
4. OTHER 0				
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS		0		
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES		3,000		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION		1,000		
3. CONSULTANT SERVICES		0		
4. COMPUTER SERVICES		0		
5. SUBAWARDS		0		
6. OTHER		16,898		
TOTAL OTHER DIRECT COSTS		20,898		
H. TOTAL DIRECT COSTS (A THROUGH G)		119,171		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)				
TOTAL INDIRECT COSTS (F&A)		47,980		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)		167,151		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)		0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$ 167,151	$	
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $				

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

SUMMARY
PROPOSAL BUDGET   YEAR 3

ORGANIZATION		FOR NSF USE ONLY		
Purdue University		PROPOSAL NO.	DURATION (months)	
			Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR		AWARD NO.		
Jan P Allebach				

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds	Funds nted by NSF I different)
	CAL	ACAD	SUM		
1. **Jan P Allebach - PI**					
2. **George T Chiu - CO-PI**					
3. **Edward J Delp - CO-PI**					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (**3**) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **GENERAL PURPOSE EQUIPMENT** $ 6,000					
TOTAL EQUIPMENT				**6,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**5,000**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**3,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**1,000**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**18,268**	
TOTAL OTHER DIRECT COSTS				**22,268**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**119,542**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**49,540**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**169,082**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **169,082**	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $					

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

SUMMARY
PROPOSAL BUDGET

Cumulative

ORGANIZATION			FOR NSF USE ONLY		
Purdue University			PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR			AWAR	Proposed	Granted
Jan P Allebach					

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months				Funds anted by NSF (if different)
	CAL	ACAD	SUI		
1. Jan P Allebach - PI					
2. George T Chiu - CO-PI					
3. Edward J Delp - CO-PI					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES					
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (9) GRADUATE STUDENTS					
4. (0) UNDERGRADUATE STUDENTS					
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (0) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 26,000					
TOTAL EQUIPMENT				26,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				9,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				3,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				51,546	
TOTAL OTHER DIRECT COSTS				63,546	
H. TOTAL DIRECT COSTS (A THROUGH G)				354,479	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				144,002	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				498,481	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 498,481	$
M. COST SHARING PROPOSED LEVEL $ **Not Shown** AGREED LEVEL IF DIFFERENT $					

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

We have scoped this project as a three year effort. We will discuss the budget section-by-section.

Secs. A – C: Personnel and Fringe Benefits

Sec. D: Equipment

We have budgeted $10K during each of the first two years of the project and $6K during the third year of the project for equipment to be used in support of the research. In order to effectively conduct our research, we need large numbers of different models and multiple units of the same model of the digital cameras, scanners, and multifunction peripheral (MFP) devices (scanner plus printer) that we are characterizing. This is necessary to be able to delineate between different models and manufacturers and to also understand the role of unit-to-unit variability for the same model device.

To perform these device characterizations, we will be capturing large numbers of very high-resolution images. A single 8.5×11 in$sup2$ page scanned in RGB at just 1200 dpi and 1 byte per pixel will require 0.4 Gybtes to store uncompressed. Since we will not know at the outset how much compression is acceptable before the features computed from the scanned page is degraded, we will need to use a lossless compression algorithm which limits the amount of compression that can be achieved. Thus we will need very large amounts of storage. We plan to purchase a RAID and server for this purpose. This system will be dedicated exclusively to this project.

The table below summarizes the equipment that we plan to purchase.

Item	Unit cost	No. items	Extended cost
Digital cameras	$500	20	$10,000
Multifunction Peripheral Devices	$200	20	$4,000
Scanners	$100	20	$2,000
Server with 5 TByte RAID array	$10,000	1	$10,000
		Total	$26,000

Sec. E: Travel

We have provided $667 travel per year for each person on the grant (including the graduate students) to support travel to a conference to learn about research in this area, and ultimately to present the results of our work.

Sec. G: Other Direct Costs

We have budgeted $3K per year for materials and supplies (Line G1). This will be used to purchase consumable supplies, parts, and software, as needed for the research. We have also budgeted $1K per year for publication costs. This will primarily be used to defray the cost of page charges for publications (Line G2). Line G6 includes Grad Fee Remissions for three graduate students. These are customarily charged to research projects in lieu of paying tuition for graduate research assistants.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.		

Investigator: Jan Allebach	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support
Project/P.		
Source of		
Total Awь		
Location Oı ı ıυjoui. ı		
Person-Months Per Y		

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support
Project/Propoı		
Source of Suppı		
Total Award An		
Location of Prо,		

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Location oı ı ıυjoui. ı aıu

Person-Months Per Year C 0.5

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support
Project/Propс		
Source of Sup		
Total Award ı		
Location of F .υ,ı		
Person-Months F		

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support
Project/Proposal		
Source of Suppoʳ		
Total Award Amс		
Location of Projeuı.		
Person-Months Per		

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **George T.-C. Chiu**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support:	☒ Current	☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

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Person-Mont.

Support:	☒ Current	☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title: **ITR: Printer Characterization and Signature-Embedding for Security and Forensic Applications**

Source of Support: **National Science Foundation**

Total Award Amount: **$150,000**   Total Award Period Covered: **09/01/02 – 08/31/05**

Location of Project: **Purdue University**

Person-Months Per Year Committed to the Project.   Cal: **0.0**   Acad: **0.0**   Sumr: **0.5**

Support:	☒ Current	☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: Sensing and Control of Digital Color Xerographic Imaging Systems**

Source of Support: **National Science Foundation**

Total Award Amount: **$172,000**   Total Award Period Covered: **09/01/02 – 08/31/05**

Location of Project: **Purdue University**

Person-Months Per Year Committed to the Project.   Cal: **0.0**   Acad: **0.0**   Sumr: **0.5**

Support:	☒ Current	☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title: **NASA Specialized Center of Research and Training(NSCORT) for Advanced Life Support**

Source of Support: **NASA**

Total Award Amount: **$10,000,000**   Total Award Period Covered: **01/01/03 – 12/31/08**

Location of Project: **Purdue University**

Person-Months Per Year Committed to the Project.   Cal: **0.0**   Acad: **0.5**   Sumr: **0.5**

Support:	☒ Current	☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99)   USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.b for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **George T.-C. Chiu**	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title: **IGERT ...**

Source of Support: **National Science Foundation**

Total Award Amount: Total Award Period Covered:

Location of Project: **Purdue University**

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Proposal Title: **Towards Real-Time Sensing and Control of Active Structures**

Source of Support: **National Science Foundation**

Total Award Amount: **$200,000**   Total Award Period Covered: **08/01/04 – 07/31/06**

Location of Project: **Purdue University**

Person-Months Per Year Committed to the Project.   Cal: **0.0**   Acad: **0.0**   Sumr: **0.5**

Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/:

Source of

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Location ԁ. . ,-

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Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

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Support: ☒ Current ☐ Pending	☐ Submission Planned in Near Future	☐ *Transfer of Support

Project/Propℴ.

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99)   USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Other agencies (including NSF) to which this proposal has been/will be submit-

Investigator: Delp, Edwards, J

| Support: | X Current | ☐ Pending | ☐ Submission Planned in Near Future | ☐ *Transfer of Support |

Project/Proposal Title: Printer Characterization and Signature Embedding for Security & Forensic Applications

Source of Support: National Science Foundation

Total Award Amount: $130,000   Total Award Period Covered: 9/1/02-8/31/05

Location of Project: Purdue University

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr: .5

| Support: | X Current | ☐ Pending | ☐ Submission Planned in Near Future | ☐ *Transfer of Support |

Project/Proj

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| Support: | X Current | ☐ Pending | ☐ Submission Planned in Near Future | ☐ *Transfer of Support |

Project/Proposal Title: Watermarking Test & Evaluation

Source of Support: Air Force Research Laboratory

Total Award Amount: $288,201   Total Award Period Covered: 3/1/04-9/25/05

Location of Project: Purdue University

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr: .5

| Support: | X Current | ☐ Pending | ☐ Submission Planned in Near Future | ☐ *Transfer of Support |

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| Support: | X Current | ☐ Pending | ☐ Submission Planned in Near Future | ☐ *Transfer of Support |

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*If this project has previously been funded by another agency, please list and furnish information for immediately pre-ceding funding period.

NSF Form 1239 (10/99)   USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support
(See GPG Section II.D.8 for guidance on Information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Delp, Edward, J	Other agencies (including NSF) to which this proposal has been/will be submit-

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/.

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Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

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Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Printed & Sensor Forensics; A Working Title

Source of Support: National Science Foundation

Total Award Amount: $500,000   Total Award Period Covered: 8/01/2005-07/31/2008

Location of Project: Purdue University

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr: .50

Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

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Location o:

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Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Location oι

Person-Mo

Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title

Source of Support:

Total Award Amount: $ Total Award Period Covered

Location of Project:

Person-Months Per Year Committed to the Project.   Cal: Acad: Sumr

Facility Description

Electronic Imaging Systems Laboratory (EISL)

The Electronic Imaging Systems Laboratory (EISL) supports research on image capture and rendering, medical imaging, color measurement, and document management. The laboratory is located in a suite of six rooms comprising over 1100 square feet on the ground floor of the Electrical Engineering Building. The computational resources of the laboratory include 9 PCs running LINUX, 6 workstations running HP-UX, and 10 PCs running Microsoft NT, Windows 2000, or Apple Macintosh OS 10. The disk storage that is local to these computers is augmented by over one Terabyte of server-based disk space.

The laboratory provides both document capture and rendering devices for support of research activities. The capture devices include an Aztek Premier 8000 dpi prepress drum scanner, based on photo-multiplier tube technology, and a Heidelberg Linotype Saphir Ultra2 flatbed scanner with a maximum optical resolution of 1200 dpi × 2400 dpi. The laboratory has a total of 60 printers consisting of 21 different low-end models from 8 different manufacturers. These devices are all dedicated to our work on printer forensics. In addition, the laboratory contains another dozen or so printers from mid-range to high-end that are used for other printing related research activities and general purpose printing, in addition to supporting the printer forensics work.

The laboratory also includes a Quality Engineering Assocates IAS-1000 Image Analysis System that consists of a computer-positioned x-y translation table with a vacuum-based sample holder, a VGA resolution CCD camera with a macro-lens, a Gretag-MacBeth Spectrolino spectrophotometer, and a Hunter gloss meter. All these instruments are mounted on separate computer-controlled arms, thus enabling a completely automated measurement process once the sample is in place. Finally, the laboratory includes a Barco 21 inch self-calibrating monitor for precision viewing of color stimuli.

One of the rooms in the laboratory has been configured as a conference area with a Polycom Soundstation Premiere conference phone for telemeetings with off-site sponsors and collaborators.

Spectral Imaging Systems Laboratory (SISL)

The Spectral Imaging Systems Laboratory (SISL) is located on the second floor of the Materials Science and Electrical Engineering Building. It has been developed for precision color measurement and the collection of multidimensional data sets. The principal sensors include two high spatial resolution digital still cameras, two conventional spectroradiometers, and a novel multispectral scanning system that yields several hundred bands of spectral data at each pixel in the image.

The digital still cameras are a Photometrics Model CH250 with a thermoelectrically cooled 1 Mpixel Kodak CCD array with 12 bits of gray scale on output, and a 6 Mpixel Kodak DCS 460c color digital camera built on a Nikon N90 body. The first conventional spectroradiometer is a Gretag SPM-50 which provides its own illumination for measuring the

1

reflectance of flat surfaces. The instrument provides a variety of spectral and colorimetric measurements.

The second conventional spectroradiometer is a Photo Research PR-705 SpectraScan system. It consists of a diffraction grating that disperses the visible spectrum from 380 nm to 780 nm with 2 nm in spectral accuracy, a 55 mm variable focus objective lens and apertures of 1/2 and 2 degrees. The SpectraScan spectroradiometer is portable and can be mounted on a standard tripod. The measurement operations are controlled by an internal Intel 486 microprocessor. The measurement data can be downloaded to a 3.5-inch floppy disk through a built-in floppy drive or to a PC through the RS232 interface, displayed and processed using the SpectraWin program which is installed in the host computer. This program also allows the host computer to control the SpectraScan remotely.

The multispectral scanning system consists of 4 major components. The first is an EG&G Model 2020-31B High Efficiency telescope with a field of view selectable at 6 arcmin, 20 arcmin, 1 degree, and 3 degree, and an auxiliary close-up lens. The second is an Acton Research Corporation Model SpectraPro-150 spectrograph with a wavelength range of 0-1400 nm, a slit width adjustable from 10-3,000 m, yielding a resolution of 0.4 nm or better and wavelength accuracy of 0.25 nm. The third component is an EG&G Model 1520A thermoelectrically cooled 256×x1024 pixel CCD detector with sensitivity from 400-1100 nm and 18 bit dynamic range. Finally, the entire instrument is mounted on a computer-controlled Parker-Daedel azimuth-elevation positioning system with 0.2 arcmin repeatability and 5 arcmin accuracy.

Both the Photometrics camera and all parts of the multispectral scanning system are interfaced to a Compaq PC.

The laboratory includes two special sources of illumination. The first is a Macbeth Spectralight II-65B Viewing Booth for critical color matching and visual color evaluation. The viewing booth allows selection of five different illuminants: Daylight 6500K, Daylight 2300K, Illuminant A, Cool White Fluorescent, and Ultraviolet. The second is a monochromator based on a second Acton Research Corporation Model SpectraPro-150 spectrograph with a TS-428 tungsten-halogen light source. The monochromator provides a tunable source of very narrow-band illumination that can be precisely delivered where needed via an optical fiber. The entire unit can be controlled by a serial interface to a PC or via a handheld HP 48G calculator.

Video and Image Processing Laboratory (VIPER)

The Video and Image Processing Laboratory (VIPER) is equipped with state-of-the-art technology to digitize, store, process, stream, and display digital video and images. These technologies support research in areas such as the development of new video compression techniques, new streaming technologies, and creating multimedia material for use in video indexing, storage, and retrieval.

Depending on the application, digitizers in the laboratory can produce digital video in a variety of formats including uncompressed CCIR video, motion JPEG, DV, MPEG-1,

MPEG-2, MPEG-4, H.26X, and HDTV.

High quality uncompressed video is produced by the Truevision TARGA digitizer, while lower quality video for streaming purposes is produced by the ViewCast Osprey 100 digitizer. Currently the laboratory can digitize four separate video sequences for streaming purposes. In addition the laboratory is equipped with a motion JPEG digitizer that is used for high quality multicast streaming over Internet2. To generate long, high quality, digital video sequences, the Laboratory has two Sony 3 CCD DV Camcorders, a Sony DV VCR, and a Sony DV-Firewire converter. The laboratory also has a complete suite of video editing equipment and a real-time fully configurable MPEG-1/MPEG-2 encoder. For recording/streaming HDTV signals, the Laboratory has a Sencore HDTV 996 VSB video server.

The storage facilities of the Laboratory are organized around several file servers. These include one four processor and one dual processor Sun UltraSparc servers. The servers are connected to the Engineering Computer Network (ECN) and have a total disk storage capability of 6 terabytes.

Finally, the Laboratory has a variety of methods used to display digital video. All NTSC video devices are connected to a video cross-bar switch so that a wide variety of possible input and output scenarios may be configured at the touch of a button. For primary NTSC viewing, the laboratory has two 36" RCA monitors so that A/B comparisons may be made directly. In addition, the laboratory has a Proscan 36" 16x9 monitor, a 36" RCA HDTV monitor, and a 38" RCA HDTV monitor.

Mechatronic Systems Research Laboratory (MSRL)

The scanner characterization, some of the camera characterization, and the extrinsic signature embedding experiments of the proposed research will be performed in the *Mechatronic Systems Research Laboratory* (MSRL). The MSRL is a state-of-the-art research laboratory within the Ruth and Joel Spira Laboratories for Electromechanical Systems in the School of Mechanical Engineering.

The MSRL includes advance instrumentation and and CAD/CAM tools for research in the the integrated design, control and characterization of electromechanical systems. The laboratory include instruments such as the HP 35670A Dynamic Signal Analyzer for performing various signal/spectrum measurement as well as dynamics system identification, two HP 33120A Arbitrary Function Generator, an HP 54645D 100 MHz Mixed Signal Analyzer, an HP 54540A 4 channel 500 MHz Digital Storage Oscilloscope, an HP 5372A Frequency and Time Interval Analyzer for precision timing analysis, and two HP 1146 AC/DC Current Probes. In addition to electronic instruments, the laboratory also has three high resolution Cannon M-1 Laser Optical Rotary Encoder that has 50,000 lines-per-revolution resolution. This encoder can be used to measure and characterize the rotational motion of various scanning platforms. The laboratory also includes two Gretag sprectrophotometers for characterizing color and target images. A Barco 21 inch adjustable monitor can be used for various psychophysical experiments. An Epson Perfection 4870 scanner and an HP 6300 ScanJet scanner will be used for the scanning platform for image analysis and characterization. The laboratory includes mixed analog and digital electronics simulation tool and

digital logic programming tools for programming FPGAs and CPLDs that will be needed in developing interface electronics for characterizing and finger-printing image capture and printing devices.

	FOR NSF USE ONLY		
ORGANIZATION **Purdue University**	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Jan P Allebach**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR		
1. Jan P Allebach - PI					$
2. George T Chiu - Co-PI					
3. Edward J Delp - Co-PI					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (**3**) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,000	
2. FOREIGN				0	

F. PARTICIPANT SUPPORT COSTS		
1. STIPENDS $	0	
2. TRAVEL	0	
3. SUBSISTENCE	0	
4. OTHER	0	
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS		0
G. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES		6,173
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION		350
3. CONSULTANT SERVICES		0
4. COMPUTER SERVICES		0
5. SUBAWARDS		0
6. OTHER		16,380
TOTAL OTHER DIRECT COSTS		22,903
H. TOTAL DIRECT COSTS (A THROUGH G)		91,925
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)		
TOTAL INDIRECT COSTS (F&A)		39,279
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)		131,204
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)		0
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$ 131,204 $
M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $		

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Rebecca white**	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Revised Proposal Budget Revision # 1 for 0524540 Submitted On Jul 22 2005 8:23AM Electronic Signature

ORGANIZATION	FOR NSF USE ONLY		
Purdue University	PROPOSAL NO.	DURATION (months)	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR		Proposed	Granted
Jan P Allebach	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	SUMR	Funds Requested By	Funds granted by NSF (if different)
1. **Jan P Allebach - PI**				
2. **George T Chiu - CO-PI**				
3. **Edward J Delp - CO-PI**				
4.				
5.				
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (**0**) POST DOCTORAL ASSOCIATES				
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				
3. (**3**) GRADUATE STUDENTS				
4. (**0**) UNDERGRADUATE STUDENTS				
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				
6. (**0**) OTHER				
TOTAL SALARIES AND WAGES (A + B)				
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)				
TOTAL EQUIPMENT			**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)			**3,000**	
2. FOREIGN			**0**	
F. PARTICIPANT SUPPORT COSTS				
1. STIPENDS $ **0**				
2. TRAVEL **0**				
3. SUBSISTENCE **0**				
4. OTHER **0**				
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS			**0**	
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES			**6,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION			**350**	
3. CONSULTANT SERVICES			**0**	
4. COMPUTER SERVICES			**0**	
5. SUBAWARDS			**0**	
6. OTHER			**16,898**	
TOTAL OTHER DIRECT COSTS			**23,248**	
H. TOTAL DIRECT COSTS (A THROUGH G)			**95,941**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)				
TOTAL INDIRECT COSTS (F&A)			**41,103**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)			**137,044**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)			**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			$ **137,044**	$
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $			

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

SUMMARY PROPOSAL BUDGET	FOR NSF USE ONLY		
ORGANIZATION Purdue University	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jan P Allebach	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL ACAD SUMR	Funds	Funds ed by NSF lifferent)
1. Jan P Allebach - PI			
2. George T Chiu - CO-PI			
3. Edward J Delp - CO-PI			
4.			
5.			
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)			
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)			
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1. (**0**) POST DOCTORAL ASSOCIATES			
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)			
3. (**3**) GRADUATE STUDENTS			
4. (**0**) UNDERGRADUATE STUDENTS			
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)			
6. (**0**) OTHER			
TOTAL SALARIES AND WAGES (A + B)			
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)			
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)			
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
TOTAL EQUIPMENT		0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)		3,000	
2. FOREIGN		0	
F. PARTICIPANT SUPPORT COSTS			
1. STIPENDS $ 0			
2. TRAVEL 0			
3. SUBSISTENCE 0			
4. OTHER 0			
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS		0	
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES		3,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION		350	
3. CONSULTANT SERVICES		0	
4. COMPUTER SERVICES		0	
5. SUBAWARDS		0	
6. OTHER		18,268	
TOTAL OTHER DIRECT COSTS		21,618	
H. TOTAL DIRECT COSTS (A THROUGH G)		92,928	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)			
TOTAL INDIRECT COSTS (F&A)		38,824	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)		131,752	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)		0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$ 131,752	$
M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $			

PI/PD NAME Jan P Allebach	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Rebecca white	Date Checked	Date Of Rate Sheet	Initials - ORG

3 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY
PROPOSAL BUDGET

Cumulative

	FOR NSF USE ONLY		

ORGANIZATION	PROPOSAL NO.	DURATION (months)	
Purdue University		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Jan P Allebach			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested By	Funds granted by NSF (if different)
	CAL	ACAD	SU		
1. **Jan P Allebach - PI**					
2. **George T Chiu - Co-PI**					
3. **Edward J Delp - CO-PI**					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES					
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (**9**) GRADUATE STUDENTS					
4. (**0**) UNDERGRADUATE STUDENTS					
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. (**0**) OTHER					
TOTAL SALARIES AND WAGES (A + B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,000	
2. FOREIGN				0	

F. PARTICIPANT SUPPORT COSTS		
1. STIPENDS $	0	
2. TRAVEL	0	
3. SUBSISTENCE	0	
4. OTHER	0	

		Funds Requested	Funds granted
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS		0	
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES		15,173	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION		1,050	
3. CONSULTANT SERVICES		0	
4. COMPUTER SERVICES		0	
5. SUBAWARDS		0	
6. OTHER		51,546	
TOTAL OTHER DIRECT COSTS		67,769	
H. TOTAL DIRECT COSTS (A THROUGH G)		280,794	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)			
TOTAL INDIRECT COSTS (F&A)		119,206	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)		400,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)		0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$ 400,000	$
M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $			

PI/PD NAME	FOR NSF USE ONLY		
Jan P Allebach	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Rebecca white			

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Impact Statement

We will pursue the full extent of the proposed research to the extent that resources permit.

Revised Budget Justification

We have scoped this project as a three year effort. We will discuss the budget section-by-section.

Secs. A – C: Personnel and Fringe Benefits

Sec. D: Equipment

We have budgeted $5K during each of the first two years of the project and $2K during the third year of the project for equipment to be used in support of the research. In order to effectively conduct our research, we need large numbers of different models and multiple units of the same model of the digital cameras, scanners, and multifunction peripheral (MFP) devices (scanner plus printer) that we are characterizing. This is necessary to be able to delineate between different models and manufacturers and to also understand the role of unit-to-unit variability for the same model device. This amount is included with supplies and materials (Line G1, see Sec. G below), since each item costs less than $2,500, and thus does not qualify as "Equipment".

To perform these device characterizations, we will be capturing large numbers of very high-resolution images. A single 8.5 × 11 in^2 page scanned in RGB at just 1200 dpi and 1 byte per pixel will require 0.4 Gybtes to store uncompressed. Since we will not know at the outset how much compression is acceptable before the features computed from the scanned page are degraded, we will need to use a lossless compression algorithm which limits the amount of compression that can be achieved. Thus we will need very large amounts of storage. We plan to use an existing RAID and server that we have in our laboratory for this purpose. This system will be shared with other projects.

The table below summarizes the equipment that we plan to purchase.

Item	Unit cost	No. items	Extended cost
Digital cameras	$500	15	$7,500
Multifunction Peripheral Devices	$200	15	$3,000
Scanners	$100	15	$1,500
		Total	$12,000

1

Sec. E: Travel

We have provided $500 travel per year for each person on the grant (including the graduate students) to support travel to a conference to learn about research in this area, and ultimately to present the results of our work.

Sec. G: Other Direct Costs

We have budgeted $1,173 for the first year and $1,000 for the second and third years for materials and supplies (Line G1). This will be used to purchase consumable supplies, parts, and software, as needed for the research. Note that Line G1 also includes the amounts for equipment discussesd in Sec. D above. We have also budgeted $350 per year for publication costs. This will primarily be used to partially defray the cost of page charges for publications (Line G2). Line G6 includes Grad Fee Remissions for three graduate students. These are customarily charged to research projects in lieu of paying tuition for graduate research assistants.

ACTION PROCESSING FORM

1. PROPOSAL NO CNS-0524540	2. AWARD NO. 0524540	3. NSF ORGANIZATION DIVISION OF COMPUTER AND NETWORK SYSTEMS		4. DOCUMENT DATE 09/19/06

5. AWARD ISTR STND	5A. CODE 0	5. AWARD ISTR	5A. CODE	5B. NATR OF RQST NEW	5C. CODE 1	5B. NATR OF RQST	5C. CODE	6. REQ. EFF. DATE 08/01/05

7. DATE RECEIVED 02/07/05	7. DATE RECEIVED	8. REQ. DUR. 36	8. REQ. DUR.	9. REQUESTED AMOUNT 400000.00	9. REQUESTED AMOUNT

SUBMITTING INSTITUTION DATA

10 DIGIT CODE

10. SUBMITTING INST. CODE	0018259000	10.
10A. NAME	Purdue University	10A.
10B. ADDRESS 1	302 Wood Street	10B.
10C. ADDRESS 2		10C.
10D. CITY-STATE-ZIP	West Lafayette, IN - 479072108	10D.

NAME PI/PD DATA

10 DIGIT CODE

11.	Allebach Jan		11.
11A. INST. CODE	0018259000	PRIOR SUPPORT: Y	11A.
11B. ADDRESS 1	465 Northwestern Avenue		11B.
11C. ADDRESS 2			11C.
11D. DEPT.	Electrical and Computer Engineering		11D.
11E. CITY-STATE-ZIP	West Lafayette, IN - 47907		11E.

NAME CO-PI/PD DATA

12.	Delp Edward	12.
12A.	Chiu George	12A.
12B.		12B.
12C.		12C.

13. TITLE	CT-ISG:Printer and Sensor Forensics

13. TITLE	

14. MANAGING ORGANIZATION	DIVISION OF COMPUTER AND NETWORK SYSTEMS	CODE	05050000	CODE
15. PROGRAM ELEMENT	CYBER TRUST		7371	
16. OBJECT CLASS	RESEARCH GRANTS-NOT ELSEWH CLA		4110	

17. PROGRAM REFERENCE CODES	7254	9218	HPCC						

18A. SITE VISIT FLAG		19. FIELDS OF APPLICATION	CODE	CODE
18B. CONTEXT STATEMENT ID	ct2005	Computer Science	0000912	

20. % BASIC RESEARCH 100	% MAJOR EQUIPMENT 0
% APPLIED RESEARCH 0	% LAND, BLDG & FIXED EQUIPMENT 0
% EDUCATION AND TRAINING 0	% NON-INVESTMENT ACTIVITIES 0

21. SBIR TOPIC ID	INSTRUMENTATION

22. SPECIAL PROGRAM DATA ELEMENTS (10 CHARS. MAX. IN A-M; 8 CHARS. MAX. IN N-Z; N-Z RESERVED FOR WHOLE NUMBERS ONLY)

A.	B.	C.	D.	E.	F.	G.
H.	I.	J.	K.	L.	M.	N. 0
O. 0	P. 0	Q. 0	R. 0	S. 0	T. 0	U. 0
V. 0	W. 0	X. 0	Y. 0	Z. 0		

NON-AWARD ACTION

23. WITHDRAWAL ☐ P.I./INSTITUTION INITIATED (20) ☐ PROJECT FUNDED ELSEWHERE (21)	24. ☐ DECLINATION (10)	25. ☐ RETURNED WITHOUT REVIEW	26. ☐ INAPPROPRIATE FOR NSF (30)

27. SIGNATURE, PROGRAM OFFICER	28. DATE	29. SIGNATURE, DIVISION DIRECTOR	30. DATE

ACTION PROCESSING FORM

I RECOMMENDED AWARD DATA

30. Proposal No. CNS-0524540	31. Prev. Award No.	32.& 33. Submitting Inst. & Inst. Code Purdue University 0018259000	34. Rec. Award ISTR STND

35. Rec. Eff. Date 08/01/05	36. Award Dur 36	37. Name of PI(s)/PD(s) Allebach Jan AND OTHERS	38. Rec. Natr of Award NEW

39. Title **CT-ISG:Printer and Sensor Forensics**

40.

	Organization	Prog. Element	Appr.	Obj. Class	Funded Amount	PO or Recommending Official & eAprv Date	DD or Approving Official
	05050000	7456	0105	4110	400000.00		
1	Prog Refs: 7254 9218 HPCC						
2	Prog Refs:						
3	Prog Refs:						
4	Prog Refs:						
5	Prog Refs:						
6	Prog Refs:						
7	Prog Refs:						
8	Prog Refs:						

FINANCIAL CODES

TOTAL RECOMMENDED AMOUNT *   400000.00

41. FUTURE YEAR COMMITMENTS

FY   FY   FY   FY

42.SPECIAL CERTIFICATIONS	☐ Human Subjects	☐ Vert. Animals	
	☐ I.R.B. ☐ Exempt	☐ IACUC	

43.Foreign or International Implications		Name of Country or World Region		Award $ for International
Types(s) of Implications(one or more)		Code		$0

☐ 01. International Agreement Research
☐ 02. International Collaboration
☐ 03. Research Outside the United States
☐ 04. Education Outside the United States
☐ 05. International Seminar or Workshop
☐ 06. Travel to Int'l Scientific Conferences
☐ 07. Other

44. Signature of Managing Program Officer and Section Head (if required) and Date standard grant	Managing Org 05050000

45. Signature of Managing Division Director and Assistant Director (if required) and Date   Wei Zhao

46. Division Funds Certification Signature (if required) and Date

II. AWARD DATA (DGA USE ONLY)

47. Date of Award 08/10/05	48. Award No. (if different) 0524540	49. Award Amount (if different) 400000.0	50. Cumulative Amount 400000

51. Award Duration (if different) 36	52. Effective Date (if different) 08/15/05	53. Expiration Date 06/30/08	54. Submitting Inst. Code (if different) 0018259000

55. Award Instrument STND	56. Nature of Award (if different)	57. Type of Contract	58. DGA Initials and Date

59. Remarks

☐ _____ Month(s) No-Cost Extension From: _____ To: _____ Mode of Support: RSRH
☐ Original NSF Abstract Still Valid
☐ P.I Transfer
☐ Pre-College Curriculum

NSF FORM 1036

NATIONAL SCIENCE FOUNDATION

PROPOSAL BUDGET

	FOR NSF USE ONLY		
ORGANIZATION **Purdue University**	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Allebach, Jan P.**	AWARD NO. **0524540**		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each seperately with title, A.7. show number in brackets)	NSF Funded Person-months			Funds Requested by proposer
	CAL	ACAD	SUM	
1.				$
2.				
3.				
4.				
5.				
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)				
7. (3) TOTAL SENIOR PERSONNEL (1-6)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (0) POST DOCTORIAL ASSOCIATES	0.0	0.0	0.0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.0	0.0	0.0	
3. (9) GRADUATE STUDENTS				
4. (0) UNDERGRADUATE STUDENTS				
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				
6. (0) OTHER				
TOTAL SALARIES AND WAGES (A + B)				
C. FRINGE BENIFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENIFITS (A + B + C)				

D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5000.)
1 $
2 $
3 $
Others: (see budget comment page ...) $
TOTAL EQUIPMENT

E. TRAVEL	1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)	
	2. FOREIGN	

F. PARTICIPANT SUPPORT COSTS
1. STIPENDS $
2. TRAVEL
3. SUBSISTENCE
4. OTHER
(0) TOTAL PARTICIPANT COSTS

G. OTHER DIRECT COSTS	
1. MATERIALS AND SUPPLIES	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION	
3. CONSULTANT SERVICES	
5. COMPUTER SERVICES	
5. SUBAWARDS	
6. OTHER	
TOTAL OTHER DIRECT COSTS	
H. TOTAL DIRECT COSTS (A THROUGH G)	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)	
TOTAL INDIRECT COSTS (F&A)	
J. TOTAL DIRECT AND INDIRECT COSTS (A THROUGH G)	
K. RESIDUAL FUNDS (0 + 0)	
L. AMOUNT OF THIS REQUEST(J) OR (J MINUS K)	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - ORG

NSF Form 1030 (10/99) Supersedes all previous editions   *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

NATIONAL SCIENCE FOUNDATION
Grant Letter

Award Date: August 10, 2005
Award No.   CNS-0524540
Proposal No.   CNS-0524540

Ms. Rebecca White
Associate Director,   Office of Research and Program Development
Purdue University
Young Hall
302 Wood Street
West Lafayette, IN   47907-2108

Dear Ms. White:

The National Science Foundation hereby awards a grant of $400,000 to Purdue University for support of the project described in the proposal referenced above as modified by revised budget dated July 22, 2005.

This project, entitled "CT-ISG:Printer and Sensor Forensics," is under the direction of Jan P. Allebach, Edward J. Delp, George T. Chiu.

This award is effective August 15, 2005 and expires July 31, 2008.

This grant is awarded pursuant to the authority of the National Science Foundation Act of 1950, as amended (42 U.S.C. 1861-75) and is subject to Federal Demonstration Partnership General Terms and Conditions (FDP-IV, dated 04/1/05) and the NSF Agency-Specific Requirements (dated 10/04) available at http://www.nsf.gov/awards/managing/fed_dem_part.jsp.

To comply with section 16 of the Cyber Security Research and Development Act (15 U.S.C.A. 7410), the grantee will ensure that no grant funds go to:

a) any individual who is in violation of the terms of his or her status as a nonimmigrant or

b) any alien from a country determined by the Secretary of State to be a state sponsor of international terrorism unless that individual has a visa permitting him or her to enter and remain in the United States.

The grantee must immediately notify NSF if its ability to receive nonimmigrant students or exchange visitor program participants has been suspended or terminated.

The attached budget indicates the amounts, by categories, on which NSF has based its support.

The cognizant NSF program official for this grant is Joseph B. Evans, (703) 292-4550. The cognizant NSF grants official contact is Andrea R. Kline, (703) 292-8212.

Sincerely,

Mavis J. Sinkular
Grants and Agreements Officer

CFDA No. 47.070
awards@purdue.edu

NATIONAL SCIENCE FOUNDATION
Grant Letter

CNS-0524540
000

SUMMARY PROPOSAL BUDGET

Person MOS	cal	acad	sumr	Funds granted By NSF
A. (3.00) Total Senior personnel				
B. Other Personnel				
1. (0.00) Post Doctoral associates				
2. (0.00) Other professionals				
3. (9.00) Graduate students				
4. (0.00) Secretarial-clerical				
5. (0.00) Undergraduate students				
6. (0.00) Other				
Total salaries and wages (A+B)				
C. Fringe benefits (if charged as direct cost)				
Total salaries wages and fringes (A+B+C)				
D. Total permanent equipment				$0
E. Travel				
1. Domestic				$9,000
2. Foreign				$0
F. Total participant support costs				$0
G. Other direct costs				
1. Materials and supplies				$15,173
2. Publication costs/page charges				$1,050
3. Consultant services				$0
4. Computer (ADPE) services				$0
5. Subcontracts				$0
6. Other				$51,546
Total other direct costs				$67,769
H. Total direct costs (A through G)				$280,794
I. Total indirect costs				$119,206
J. Total direct and indirect costs (H+I)				$400,000
K. Residual funds / Small business fee				
1. Residual funds (if for further support of current projects GPM 252 and 253)				$0
2. Small business fee				$0
L. Amount of this request (J) or (J-K1+K2)				$400,000
M. Cost sharing				$0