Image Integrity and the Admissibility of Digital Imaging in Court

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The purpose of this paper is to present an overview of Digital Electronic Imaging and Image processing and their impact on use as evidence.

Photographic misrepresentation dates almost to the beginning of photography. Subtle manipulations and outright lies can be propagated through manipulating images to rewrite the "truth.". The recent fervor over the Time magazine cover that darkened the face of OJ Simpson is an example of the former, and the bald faced erasures and wholesale alterations of images by the propaganda machines of the former Soviet block are examples of the latter.

In the era of chemical photography, a negative, the best original evidence, could always be produced if there were some doubt about a photographic print. The negative was in the camera at the time of the exposure and has probably remained intact since it left the scene of the crime. Methods are available to detect negative alterations.

However, in the age of digital imaging, no permanent, silver nitrate negative is produced. Images are merely files of bytes on data storage media. If an image is suspected of alteration, erasure of the original file would destroy any trace of an uncorrupted image. "Image enhancement," also is now commonly referred to in digital imaging. Is "enhancement," alteration?

There are methods available now and coming in the future, for dealing with the authenticity dilemma. Various types of audit mechanisms (some used in general computer security and some specifically aimed at digital imaging) are available. In addition to deliberate alteration, some images may be innocently altered by compression algorithms, and/or the selection of unreliable storage media. Many image compression algorithms alter images by elimination or averaging high frequency information (details), some with great losses. Images stored on Magnetic tape deteriorate over time causing a partial or complete loss of image information. Careful selection of these products can reduce these hazards.

Another issue dealing with image manipulation and the ease of altering digital images is their admission as evidence in court. **Currently the Federal Rules of Evidence allow printouts that represent the contents of a computer's memory to be admitted as evidence. This would seem to apply to digital images. Also, photographs may be authenticated by anyone familiar with the conditions that they represent.** Some state courts have differed. As digital imaging becomes more sophisticated, so will dedicated

image liars. However, with available technology and careful common sense, most cases of image misrepresentation should be detected.

Image integrity is comprised of two bases,

1. Maintaining the original image file in a true and lasting form, and,
2. Protecting the computer system that uses the image from intentional or accidental compromise.

Computer security involves a variety of physical plant, hardware, and software systems to reduce threats to acceptable levels. The threats may be from actual physical destruction of data storage and processing equipment, to viruses, worms, and other fraudulent software modifications. From image handling, processing, and transmission software, the image becomes the same as any other data file. The major exception is that image files tend to be much larger than text files. Also compression of image files is trickier than compressing text files.

The physical security, software, hardware, and transmission security for text files are the same as those for image files. Both are subject to the same threats and damage, whether it is unauthorized access, earthquake, software corruption, or telephone outages. Image file security appears to be the same picture at some future date. We have lived with such pat phrases as, "Photographs don't lie," and, "A picture is worth a thousand words," that we accept them as truth. The unique impact that, "Seeing believes," has on people warrants a special look at efforts to maintain image integrity as an overall part of computer security.

Image Integrity

As an examiner in the FBI Laboratory's Special Photographic Unit, I am periodically called upon to examine photographic images to determine their origin and authenticity. At other times I am required to take evidentiary photographs of surveillances, or crime scenes and authenticate these in court. With conventional photography, the ultimate evidence of authenticity (except for your testimony) has always been the actual photographic negative or slide. This piece of film was actually in the camera at the time and place you claimed. It was exposed to the light rays of the subject in question before the court. And its image was permanently fixed on film that could only be exposed and developed once. The film was not only the imaging sensor it was the principle image storage device (1).

Authenticity was established through testimony of the photographer's actions in taking the picture. Several other factors acted in concert to assure the presentation of only original images. If an image was challenged these factors could be examined individually for incongruities:

> The fact that it was only one frame of a continuous roll of evidentiary images relating logically in time and space to the challenged image.
>
> Through examination of the negative and the near impossibility of undetectably altering its silver halide/gelatin structure, it could be established that nothing in the image was retouched or otherwise altered.
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> The photographer's initials and other identifying marks may be scratched into the film emulsion or written on it in indelible ink.
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> The uninterrupted frame markings placed on the film by the manufacturer would tend to show that the negative in question was not removed from another roll of film and inserted into this evidentiary roll.
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> And finally the photographer would be able to testify (if questioned) as to which camera was used to take these images. This camera would leave unique, distinct marks on the edges of the exposed frames as the mask at the camera's film plane formed the border of the negative. This mask is cut and formed with machine tools and molds that leave unique toolmarks around the edge. This edge is imaged in every frame the camera exposes (2).

As a photographer and law enforcement officer I have a number of ways to maintain, and prove the integrity of the image I am presenting in court.

Also through the same tests I may challenge the authenticity of other images introduced as evidence. The reliability of conventional photography has led it to be termed, "The Silent Witness," in court, and be admitted as evidence without collateral testimony (3). To admit a photograph into evidence, all that is needed is the testimony of a witness (not necessarily the photographer) who saw what was photographed and can affirm that it is a true and accurate representation of the scene in question. (4)

This is not to say that photography is entirely unbiased in its employ as evidence. It has always been subject to manipulation through exposure, camera angle, lens selection, and other techniques. A wide angle lens used for a lawsuit photograph of a small hole in a sidewalk can make it look like the Grand Canyon (5). These manipulations are not what I want to examine in this paper. The Grand Canyon can be created with a conventional or electronic digital cameras and the effect would probably be the same. Where the lawyers advertising for your accident case on late night television now use film and a darkroom for their biased images, in ten years they will be suing something electronic. The issue is not one of how honest the camera work is, but instead one of how secure is the image over time.

In the electronic realm I can photograph and print my yawning chasm just like I do with a conventional camera. However with the electronic camera and image processing programs, I can add some wrecked vehicles and injured bodies at the bottom of the pit and claim that it is the original image. The issue here is not one of making a case for an ambulance chaser, but one of whether or not the image taken at the scene (with all of its biased camera angles, and exposure to tricks) is the same one presented in court. And if it isn't, how can the fraud be detected?

Electronic Imaging

Until November of 1990 I had viewed the growing momentum of "Still Video," (Electronic Still Photography-ESP) photography with little enthusiasm. Every ESP camera on the market was based on conventional NTSC television standards (about 480 horizontal lines), and imaging a fuzzy, low quality analog picture on a removable disc. Invariably to increase the image capacity of the units, the option of imaging only a field (half the number of video horizontal lines) doubled the picture storage capacity of the storage discs. However this halved the quality of the image. As long as this was the extent of electronic still photography (ESP), there was little interest on my part, and my employer, the Special Photographic Unit (SPU).

Also, until this time electronic digital image processing had largely been a function of space agencies, and printing layout artists. Image processing computers and software were prohibitively expensive and difficult to operate. The SPU had an image processing machine that was purchased in 1979, a DEC PDP 11/70. It filled an entire room, and took a staff of three to four just to keep it working. The subject input for these devices were mostly conventional photographs that were scanned or video frame microdensitometer (costing $180,000). In any instance, if there was a question about the accuracy or subject matter of the original photograph, the negative was probably still available for examination. If an ESP camera had been used and the need for maintaining the original image became an issue, the recording disc from the camera could be saved as evidence (the same could be said of video tape images). In either case there was some kind of original image storage media to refer to.

Kodak Hawkeye II Camera

In November 1990 I attended a demonstration of the Kodak Hawkeye II digital camera at Eastman Kodak in Rochester, NY. This camera represented a new direction in photography. It was a still video camera using a CCD (Charged Coupled Device) as a detector; however this was where the similarity with the previous ESP cameras ended. The Hawkeye II imaged a much denser, higher resolution image. Where other ESP cameras used a conventional NTSC standard CCD, yielding approximately 240,000

pixels (picture elements); the Hawkeye II used a CCD that yielded approximately 1.3 million pixels. In addition to this higher resolution, the Hawkeye II eliminated analog disc recording by writing the image directly to a computer hard drive (incorporated into

the camera system) as a digital binary image file. (6) This new camera caught the attention of the SPU and several versions were purchased.

Digital ESP cameras (there are now other manufacturers besides Kodak) have the availability to take a high quality image, download it to a mini or microcomputer as a digital file, and then send, store, or print the file as needed. This new technology tended to upend conventional technical and legal considerations in the security and integrity of images. Preliminary tests by the SPU showed that digital ESP cameras rivaled film in their ability to image details.

Subsequent versions of these cameras have used increasingly larger CCD images that are getting closer to the image resolution of fine grain professional film. The technological bottleneck with these cameras (read: Why are they so expensive and not in more common use?) is the speed and capacity of the computer handling their images. Microcomputers that were whizzes with 5KB and 10KB text files became snails when handling a 1.4MB image file. The ability of digital ESP CCD's to image details has vastly surpassed the microcomputer's ability to efficiently handle them. The color versions of the Kodak Hawkeye II generate 3.9 MB files. The Leaf studio camera generates a 16 MB file. Rollei makes a digital back for their 6x6 CM cameras that generates a 45 MB file (I have not seen this in print though).

As the price of these cameras falls (like pocket calculators), and the efficiency of microcomputers increases, they will fall within the range of the incredible cost/effectiveness of film. Ten years from now a substantial portion of crime scene and surveillance photography may be taking place in the digital electronic realm.

Three issues impact image integrity:

> The reliability of the image file's storage media (against unintended image destruction or alteration).
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> The extent to which image compression for purposes of increasing storage efficiency actually alters the original image.
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> The ease with which this media may be altered (intentional destruction or alteration) without detection. I will briefly cover issues one and two and then devote the rest of this paper to number three. It is at the heart of the security and integrity of computer imaging.

Storing Images

Image files may be stored on any media currently in use that has sufficient capacity. Obviously you couldn't store a 1.4 MB image on a 320 KB floppy disc. Mot images that are being processed or printed are stored for a time on hard discs. This is simply because

of the speed that they can write and read a large image file. Permanent storage isn't supposed to take place on discs, or floppy discs. However the actual permanence of this media will not be known until fifty or a hundred years has passed. Video tape, which is in wide use in video tape "juke boxes" to affect mass image storage, has, according to SONY, only a fifteen year life under ideal conditions. An anecdote from, "Videotape is Dead," by William J. Staples is illustrative:

> "A curator...at a major air and space museum, told me years ago that they'd get donations of the original and only, declassified videotapes of the sole flight of the X-something, compete with close-ups of the still-unsolved midair disintegration, and they'd open the box of the cassette, and find a ribbon of clear acetate and a pile of brown powder." (7)

Hopefully tapes, CDs and other optical, and floppy discs, will not prove their manufacturers to be liars and hold up through time as well or better than conventional chemical photography (conventional photography has had its share of storage disasters like the old nitrocellulose movie stock).

Compressing Images

The size of image files has encouraged a whole sub industry in computers dedicated to compression hardware and software. Fundamentally compression attempts to decrease file sizes through more efficient means of compression attempts to decrease file sizes through more efficient means of cataloging repetitious image information. If the sky in an image is uniformly light, then instead of storing thousands of pixels (picture elements) with the same image value as separate numbers, an algorithm simply counts the number and stores it as "the next X-thousand pixels will be X-value." This saves a lot of space-wasting repetition. Compression can be classified as "lossless," with no image detail compromised even under close inspection. Or it can be "lossy", with a range of some minor detail loss to massive amounts lost through the application of a compression algorithm. It is governed by how much storage space you have, or can afford. (8)

If law enforcement seriously enters digital ESP photography, compression, and its money saving aspects, will become an important issue. Image details may be lost to storage costs if evidentiary images are routinely compressed for storage. This loss of detail will not

only result in a poorer image with which to convince a jury, but in an image being thrown out of a state or local court, due to its being altered by compression. However by the time law enforcement is seriously into digital ESP, these problems may well have been solved technically and legally.

"Smart Compression" is being developed for the military, where important subjects in an image may be selected and preserved at full detail, leaving the rest of the image for

compression. (9) Technology's forward progress will probably solve the problems we speculate about today. This progress will also abandon older methods to create new problems. What good will a pristine 100 year old SONY U-Matic format tape have if there are no machines in which to play it. I hope you aren't hanging onto any data on old Radio Shack 8 inch discs, or onto any eight-track tapes?

Altering Original Images

The heart of image integrity is the ability to modify electronic image files easily, quickly, and in many cases without any record remaining of the original image. The very nature of the computer that makes them so valuable for most of us, and so abhorrent to lawyers, is that it is by design an impermanent fixture. Data held in the memory is constantly being updated, with the old data (in most instances) being lost. Tapes and discs are continually updated to be current at closing time every day. The old data is no longer useful and is discarded, most likely being written over with new data.

Early on in the computer age someone discovered this impermanence, and the first computer crimes were committed. Shortly thereafter, the first security procedures, like audit trails, terminal IDs, passwords, and key stroke recorders were instituted. These measures were not intended to recreate all of the old data that is no longer useful. Instead they were intended to assure that only new updated authorized data replaced the old record. And if unauthorized transactions took place, they could be traced to a particular source.

This impermanence and ease with which images may be altered is the central issue in image integrity. We assume that what we perceive to be a photograph, is indeed a photograph and that is must have been taken at some particular place and time. When National Geographic Magazine published an image of the pyramids in Egypt that had been processed to fit the magazine's vertical cover format, thus altering the pyramid's relative position to each other, Nation Geographic, and not the pyramids, became the subject of news stories. Readers who had relied on National Geographic's reputation for accuracy were greatly disappointed.

Image manipulation in journalism is becoming an ethical question. Publications are increasingly finding conflict between reporters who want to tell the truth (as they

interpret it), and the production department, that wants a good looking magazine or newspaper to sell. In the article, "Journalism's Image Manipulation Debate: Whose Ethics Will Matter?" Don Sutherland reports:

> "The production department's obligations include making the newspaper easy to look at. This involved printing new photos lighter or darker, with more or less contrast, or in a different color. 'Did you see all of the photographs published of the Challenger disaster?' John Long (former president of the National Press Photographers Association, moderating a seminar on ethics) asked...'What did the sky look like? Nice deep blue? I saw the videotapes when it first happened. The sky was pale.' Okay, okay, somebody from production colored the sky. You gotta sell the paper before people will read it, and they buy color.
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> 'Could that recoloring compromise the integrity of that news photo?' ethicist Long asked. 'What if something about the weather contributed to the accident," came a reply from the floor. 'Yes,' came another, 'coming to light only after publication.' So this is not a question just for photographers any more." (10)

The impermanent recording of an image by rearranging a bunch of magnetic particles and corresponding pixels seems to lack the security and integrity of good old film. However image manipulation might prove more consequential for law enforcement than mere embarrassment for journalists. Important cases may be lost because a jury didn't believe that an important photo in the case wasn't concocted like the cover of a magazine. Good photographic skills might render a photo looking so good as to render it incredible. Image processing might be employed to make it look more like the "real" police photos a jury is used to seeing on "Geraldo," "America's Most Wanted," and "Cops." Photographs, electronic or conventional, are only of value to law enforcement if they fulfill the legal strictures imposed on them. Image integrity appears to have already been sacrificed by journalists, and law enforcement can't afford to take the same path. For law enforcement to correct for problems like the color of the Challenger sky, it will be necessary to establish color standards. This will involve using color chips similar to those now used it to establish conventional photography color standards.

Evidentiary Concerns

Federal Rules of Evidence (FRE) 1001 through 1006 deal with photographic and computer generated evidence. Rule 1001 establishes definitions of writings and recordings to include, "...photographing, magnetic impulse, mechanical or electronic recording, or other form of data compilation." It defines an original photograph as the negative, or any print made from the negative. If there is any

conflict with the hard disk of a digital ESP camera not qualifying as a photographic negative, the next sentence says, "If data are stored in a computer or similar device, any printout or output readable by sight show to reflect the data accurately is an 'original.'" This seems to include any images whether produced chemically or electronically. Rule 1002 requires the original to prove its content, and a printout has been defined as an original. (11)

State courts seem to arrive at the same conclusion; however they tend to view electronic computer (and logically image records) as exceptions to the hearsay rule under records regularly kept in the course of business. (12)

Image Processed Original Images

In a legal domain that shares some common ground with law enforcement, the issue of image integrity has become of increasing concern in copyright infringement lawsuits. Under traditional copyright law all of the original elements of the photograph are protected, but not necessarily the subject (unless it is also copyrighted). It is an infringement to use these original elements without permission. The speed and ease of modern image processing programs allow someone to "borrow" numerous minor elements of different copyrighted images to create an apparently new image. The details used may be too small to be identified as original elements by a juror. (13) In this case, has image processing created an entirely new image, independent of the originals?

This "civil" view of image processing and electronic image files may add confusion to the evidentiary value of law enforcement electronic images. In law enforcement there is no concern over whether the image is copyrighted, or used without permission. To define a processed image as a new image, as with copyrights, would run counter to the law enforcement desire to introduce the processed image as original evidence. If a surveillance image is subjected to image processing algorithms that increase contrast, or sharpen edges, is it now no longer original evidence? In this area of concern, I was only able to locate two cases involving image processing, a civil case based on medical imaging in Wisconsin (largely irrelevant), and a criminal homicide case from Henrico County Virginia. **In the Virginia case, image processing was accepted by the court as a means to make a fingerprint more legible. The court noted that image processing did not alter the fingerprint, but only made it more easy to see. (14)**

A Stricter Standard for Admitting Images as Evidence

Christine A. Gilshan in her article, "A Picture is Worth a Thousand Lies: Electronic Imaging and the Future of the Admissibility of Photographs Into Evidence" sees so much potential mischief in digital ESP cameras, and computer based image processing that a change of the Federal Rules of Evidence is in order. **The possibility of creating virtually undetectable changes in an evidentiary photograph should result in**

allowing into evidence only photographs that can be authenticated by the photographer. The photographer, who understands the technology involved, would be subject to cross examination on authenticity and any processing or alteration to the image. (15)

Potential Problems

In computer integrity, a major threat to system security is the "Trusted Insider." This may end up being the case in law enforcement digital ESP. We have seen where the FRE allows the introduction of photographs if they can be authenticated, regardless of whether or not a negative (original best evidence) is available or was even made. Where a

conventional photograph could be verified in many ways, digital ESP may not. Here is an example to illustrate:

Four wise guys, Cosa Nostra made members, Angie, Sal, Vinnie, and Tony always meet at Mara's Restaurant in South Philadelphia to talk over their various criminal activities. An agent of the Philadelphia office always parks a van across the street and gets pictures of them entering and leaving as a group. These photos have helped to establish the ongoing conspiracy (for RICO charges) between these subjects as well as aid (early on in the case) in their identification. Today they meet as usual and the van, as usual is outside taking pictures. Today Sal is not with the group and the images taken by the agent in the van reflect this. Wiretap information indicated today's meeting would focus on knocking off a rival LCN member, Big Louie. The surveilling agent is disappointed that his photo will not directly link Sal to the plan to blow away Big Louie. This coupled with the fact that the previous week the surveillance van had been towed away for illegally parking because Sal had taken the van's usual parking space, left the surveilling agent particularly aggrieved. In retaliation the agent quickly manipulates today's images, sans Sal, to include Sal (this seems to qualify as "Data Diddling"). The agent simply recalls some previous images from the portable computer he uses with the Digital ESP camera, and constructs new pictures bearing the original DOS system time and date. Sal has now made the meeting, even though he was somewhere else.

In this scenario, the original image written on the digital ESP camera hard drive will be obliterated the next time the disc fills up and needs to be erased. The camera has the option of recording the time and date with each image as part of the image file. However this is easily circumvented by resetting the digital ESP camera. The DOS system of the downloading computer will only carry the time and date that the image file was transferred from the camera to the computer. And the DOS computer time and date, like those in the camera, will only be as accurate as the operator allows.

In this particular case Sal probably won't contest the photo, because all of those meetings run together in his head anyway. And besides Sal really hated Big Louie, and was proud

to be included in the conspiracy to knock him off. Even Sal's lawyer probably doesn't know a kilobyte from a dog bite and won't object. However, whether or not the change is detected, it is a trusted civil servant committing perjury, and it is illustrative of the potential for trouble. Unlike film, there is nothing to initial. If you try to initial the hard drive disc, you will probably end up ruining and replacing them. Besides the hard disc in the camera is never intended as a permanent means of image storage. With the hard disc there is no sequential frame numbering on the edges of the film. The disc writes the image wherever it has room. It assigns a number that the operator is free to change at any time. Finally there are no individual edge markings to identify an image with a particular camera. The CCD doesn't come in contact with the machined edges of the film plane inside the camera. And I am unaware of any capability to detect unique edge marks on CCD images.

A great problem may arise in situations where the digital camera is used to record a crime scene. The photographer may have been the only one there at the time. A particularly damning piece of evidence could be later undetectably inserted into the images through an image processing program. As digital photography becomes more widespread in law enforcement, I could see this becoming a problem for overzealous or dishonest officers.

In the FBI Laboratory the Computer Analysis Response Team (CART) attempts to restore data that has been erased or altered for various reasons from computer discs. I am not aware of any cases where they have attempted to restore an erased image, or determined if an image had been altered.

Possible Solutions

The first solution to this problem is to have only the most honest, or the least computer literate agents taking the surveillance pictures. **If this fails to satisfy any judicial suspicions, then the implementation of some kind of audit trail to verify the time, date, and originality of the images.** This may involve a system where the image coming from the CCD is written to a WORM optical disc. Once recorded the original image couldn't be changed. Optical discs may be entirely too expensive compared to a rewritable hard drive that only downloads the few images you want to actually save. **The audit trail would provide an independent record of when the image was taken and anytime it has been altered from the original.** It could probably run as some kind of file comparison utility that is available on micro computers. This would involve having to establish a centralized image storage and retrieval system within a given agency for the trail to have any meaning. Any software or data on an independent unconnected microcomputer is pretty much at the mercy of any body running it.

From my experience, this probably won't be much of a problem. In all of the cases I have had to testify to photographs I have taken, I have never been asked about the negatives. I am only asked if the photograph is a true and accurate representation of

what I saw. I say yes, and the case goes on. Whether I took the picture with a Polaroid, an Instamatic, a Nikon, or some digital device, I testify that it is true and accurate. The defense has the opportunity to question me about the image to their satisfaction, and introduce any reasonable evidence that would discredit it. If there are problems with the security or integrity of the evidence, it will still be admitted. Under the federal rules, breaks in the "chain of custody," affect only the weight, not the admissibility of the evidence. The jury is the sole determiner of the evidence's believability. It's the province of the jury to believe me or not.

Ultimately somebody in Hollywood will catch onto the story potential of the above scenario (and I won't even get a screen credit for it) and make a TV movie of the week about a dirty cop who manipulates pictures. Attorneys and judges will howl, and we in law enforcement will wind up with an audit system, or some other method to ensure image integrity.

Footnotes

1. Sampat, Nitin. Fundamentals of Electronic Imaging; Rochester Institute of Technology, Rochester, NY. 1993
2. Kuppuswamy, R. Forensic Science Investigations in Vehicular Collisions and Camera Identification; Bharathidasan University, Tamil Nadu, India. January 1989
3. Guilshan, Christine A. "A Picture is Worth a Thousand Lies: Electronic Imaging and the Future of the Admissibility of Photographs Into Evidence"; Rutgers Computer and Technology Law Journal, Vol. 18, No. 1 1992 PP. 368-369
4. Federal Rules of Evidence, West Law Publishing, 1991. pp. 297
5. Houts, Marshall. Photographic Misrepresentation; Matthew Bender, New York, NY 1969 Section 12
6. User's Manual Kodak Professional Digital Camera System; Eastman Kodak Co. Rochester, NY. 1991
7. Staple, William J. "Videotape is Dead"; Industrial Photography, March 1993 pp. 46-50
8. Mills, Karen. "1993 A Compression Odyssey"; TV Technology, January 1993 pp. 46-50
9. McCarthy, Shawn P. "Smart Compression Will Ease the Use of Image Data"; Government Computer New, April 12, 1993 p. 61
10. Sutherland, Don. "Journalism's Image Manipulation Debate: Whose Ethics Will Matter?" Advanced Imaging, November 1991 pp. 59-61
11. #4 pp.297-8

12. Vergari, James V. "Evidential Value and Acceptability of Computer Digital-Image Printouts"; Defense Law Journal, 1984 pp. 275-282
13. Gastinear, John. "bent Fish: Issues of Ownership and Infringement in Digitally Processed Images:' Indiana Law Journal, Vol 67, No. 95 pp. 95-128
14. Tiller, Norman. Tiller, Thomas. "The Power of Physical Evidence: A Capital Murder Case Study; Journal of Forensic Identification, March/April 1992 pp. 79-83
15. #3 pp. 378-80

Other References Not Specifically Cited

1. Alldrin, Loren. "Tape Truths, An Exciting Overview of the Making or Video Tape"; Videomaker, November 1992 pp. 46-143
2. Caspe, Bob. "Digital Still Cameras, Getting a Grasp on Direct Electronic Imaging"; April 1993 pp. 38-42
3. DeBat, Alfred. "Portrait Magic One-stop Electronic Studios Offer Fantasy Portraits"; Professional Photographer, February 1992 pp. 36-38
4. Drei, Pat. "The Photographer's Dreambox"; Photomethods, May 1990 pp. 14-15
5. Eggars, Ron. Farace, Joe. and Sapwater, Elmo. "Digital Image Manipulation"; Photo Electronic Imaging, July 1992
6. Farace, Joe. "PhotoCD: Expanding Options"; Photo Electronic Imaging"; April 1993, pp. 10-12
7. Foss Kurt. "Electronic Image Storage: The Search for Eternity"; Photo Electronic Imaging May 1992 pp. 44-45
8. Foss, Kurt. "New Age of Digital Cameras"; Photo Electronic Imaging, January 1992 pp. 34-39
9. Goldsmith, Arthur. "Photos Always Lied"; Popular Photography, November 1991 pp. 68-75
10. Gustafson, Steven C. Little, Gordon R. Loomis, John S. and Puterbaugh, Todd S. "Optimal Reconstruction of Missing Pixel Images"; Applied Optics, November 10, 1992 pp. 6829-30
11. Hyzer, William G. "Photographic Interpretation Can Go Astray"; Photomethods, January 1991 pp. 12-14
12. Hyzer, William G. "Deceptive Imagery"; Photomethods, March 1991 pp. 20-21
13. Hyzer, William G. "More Deceptive Imagery"; Photomethods, September 1991 pp. 12-13

14. Jaubert. Alain. Making People Disappear An Amazing Chronicle of Photographic Deception; Pergamon-Brassey's Washington, DC 1986
15. Lake, Don. "Electronic Cameras, Sensors, and Electronic Exposure Control"; Advanced Imaging July 1992 pp. 24-30
16. Lake, Don. "Feature Size and Positional Accuracy: Is That Subpixel Accuracy or Not?"; Advanced Imaging, January 1993 pp. 44-67
17. Menta, Terry. "Realizing the Potential of Electronic Imaging"; Government Imaging, November/December 1992 pp 5-6
18. Seecof, Benjamin R. "Scanning Into the Future of Copyrightable Images: Computer-Based Image Processing Poses a Present Threat"; High Technology Law Journal, Vol 5, No. 2, Fall 1990 pp. 371-400