BIOMETRIC AUTHENTICATION SYSTEM FOR SECURE DIGITAL CAMERAS

BY

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DISSERTATION

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ABSTRACT

Digital camera images are not easily accepted as evidence because it is difficult for law enforcement, insurance, news, and other such agencies to authenticate their integrity, origin, and authorship. The integrity of digital images as evidence rests on the accurate answering of a simple question: Who did what when?

The unique (Proof of concept) research, presented in this dissertation involved developing the first of its kind, Biometric Authentication System (BAS), for a Secure Digital Camera (SDC), to solve the following significant problems currently associated with the use of digital images as evidence, such as:

Verifying the digital camera image was not damaged or tampered with. (Integrity)

Identifying exactly what camera captured the digital image. (Origin)

Exact identification of the digital photographer. (Authorship)

The concept of this invisible, inside the camera solution, involves losslessly embedding a biometric identifier (The photographer's iris), with cryptographic hashes, and other forensic data, concurrently into the original scene image.

The biometric identifier (The photographer's iris) is captured through the SDC viewfinder when the shutter release button is depressed to take the original scene image.

The motivation for this concept was a presentation given by Dr. Jessica Fridrich, at Binghamton University (September, 2000). Fridrich referenced a scenario of a special tamper–proof watermarking chip inside a digital camera that would secretly watermark the image data before it is stored in the camera's memory [i].

An overview of the concepts behind the SDC is given, and previous research summarized. The solutions to problems encountered in developing a SDC are detailed.

To My Parents

Gerald and Helen Blythe

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It is with respect and appreciation that I acknowledge my committee members, Hal Lewis, Jessica Fridrich, George Klir, and Rebecca Bussjager for their invaluable support, assistance, and encouragement, throughout my dissertation research project. I also wish to thank my Professors Hal Lewis, Jessica Fridrich, and George Klir, for providing me the opportunity to attend their enlightening and enjoyable courses, as well as tailoring my independent study courses to support and guide me in my research efforts.

I am especially indebted to Jessica Fridrich, for the inspiration her enlightening presentations and innovative publications [i, v, xx] in the fields of digital watermarking, steganography, and data encryption gave me. For they initiated my intense, interest in their applications to digital forensics and security. Her support and encouragement enabled me to acquire the knowledge necessary to pursue my interests. This dissertation incorporates one of the unique lossless watermarking embedding and extraction techniques she pioneered [xxix].

I am equally indebted to Professor Lewis, for his extraordinary dedication and love of teaching. During my first year at Binghamton University, Professor Lewis voluntarily offered me a study plan to refresh my knowledge in applied calculus. He offered this same opportunity to another “math rusty” student, and my good friend, Roberto Duran–Rodriguez. He then regularly returned to the campus during his summer break to assist both of us in successfully achieving our summer study goals.

To my family and friends, who I have seen so little during the past several years, I offer to them all a big “Thank You” for their continuing patience and understanding. I am very fortunate to have so many dear friends. However, I cannot list you all, for this section would read like a telephone book. Each of you knows how much your support has meant to me. No words can properly express my sincere gratitude.

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To Dr. John Daugman go my very sincere thanks. Not only for his encouragement and patience. But for his expert opinions, and helpful suggestions. Daugman made the difficult task of capturing an iris image with the resolution and contrast necessary for iris recognition, a reality.

In conclusion, I wish to thank my committee members for taking the time to review this dissertation and for their help and support at my defense.

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ACRONYMS

A/D	Analog to Digital Converter
AC	Alternating Current
AES	Advanced Encryption Standard
AfB	Association for Biometrics
AKEP	Authentication Key Exchange Protocol
ANSI	American National Standards Institute.
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuits
BAS	Biometric Authentication System
BMP	Bitmap
CA	Certification Authority
CCD	Charge–Coupled Device
CD	Compact Disc
CD–ROM	Compact Disc–Read–Only Memory
CMOS	Complementary Metal Oxide Semiconductor
CMY	Cyan, Magenta, Yellow
CMYK	Cyan, Magenta, Yellow, Black
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DC	Direct Current
DCT	Discrete Cosine Transform
DES	Data Encryption Standard
DIGIC	Digital Image Core
DOF	Depth of Field
ECF	Eye Controlled Focus
EFL	Effective Focal Length
EPS	Encapsulated PostScript
EXIF	Exchangeable Image File
FAR	False Acceptance Rate
FIPS	Federal Information Processing Standards
FOV	Field Of View
FTP	File Transfer Protocol
GB	Gigabyte
GIF	Graphic Interchange Format
H	Embedded Hash (digital)
H’	Calculated Hash (digital)
HTML	Hyper Text Markup Language
ICC	International Color Consortium
IR	Infrared Radiation
JEIDA	Japan Electronic Industry Development Association
JFET	Junction Field Effect Transistors
JPEG	Joint Photographic Experts Group
KB	Kilobyte

LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light–Emitting Diode
SB	Least Significant Bit
MA, (ma)	Milliamphere
MAA	Message Authenticator Algorithm
MAC	Message Authentication Code
MB	Megabyte
MD5	Message Digest 5
MP	Megapixel
MSB	Most Significant Bit
NIR	Near Infrared
NIST	National Institute of Standards and Technology
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PNG	Portable Network Graphics
POTS	Plain Old Telephone Service
PRNG	Pseudo Random Number Generator
RAM	Random Access Memory
RGB	Red, Green, and Blue
ROM	Read Only Memory
RSA	Data Security (Inc.) Algorithm (Initials of the 3 co–developers)
SDC	Secure Digital Camera
SOP	Standard Operating Procedures
SSD	Solid State Disk
TIFF	Tagged Image File Format
USB	Universal Serial Bus
V	Voltage or Volts
VAC	Volts (of) Alternating Current
VDC	Volts (of) Direct Current
VGA	Video Graphics Array
VLSI	Very Large Scale Integration (Electronic circuit chip)
WORM	Write Once, Read Many
WWW	World Wide Web
WYSIWYG	What You See Is What You Get

NOTATIONAL CONVENTIONS

$\mathbf{a_i}$, $\mathbf{a_o}$ Angular half field of view in infinite conjugate systems.

D Distance between two elements.

F Effective focal length of the entire lens system.

F/# F/# is the lens' ability to focus light.

$\boldsymbol{F_i}$, $\boldsymbol{F_o}$ Focal length of the lens closest to the image and object, respectively.

$\boldsymbol{H_i}$, $\boldsymbol{H_o}$ Image and object height, respectively. This represents HALF of the actual full image and object size. In afocal systems, this represents half of the full beam waist.

I* , *O Image and object distance measured from the lens closest to the image and object respectively.

M Magnification is the system's ability to produce an enlarged/reduced image or projection of an object.

q FULL angle of the cone of light accepted or emitted by a lens system (closely linked to numerical aperture).

TP Throughput is the system's ability to transfer light.

Superscripts

Superscripts are used as indicate by the symbol or text below:

( )♥ A references a footnote at end of the page.

$( )^{\text{ii}}$ A sequentially numbered bibliography reference.

$\{\ \}^{\{\text{Appendix X }\}}$ A cross–linked reference, used to further describe a new or uncommon term not previously mentioned. It could be a cross–link to a Glossary term, Bookmark, Section, Page number, etc.

Other:

[ ] A cross–link to a Figure or Table, in this Dissertation i.e. [Figure 2.1]

1. Introduction

1.1. Motivation and Background

According to Blond's Evidence [iii], photographic evidence can be authenticated by two methods, depending on the type of imagery. The traditional method is to consider images as "illustrative of a witness testimony". Given the advances in imaging technology, many jurisdictions have adopted an alternative method based upon the silent witness theory. This states that photographic evidence "speaks for itself" and is thus admissible through testimony that establishes how it was produced.

In today's world, not only is the general public rapidly replacing classical analog cameras (film) with digital cameras, law enforcement agencies are doing so as well. Increasingly, agencies are relying on digital photography to preserve a visual record of crime scenes, physical evidence, and victim's injuries. This is quite understandable because a digital camera image gives the photographer immediate visual feedback of each picture taken. Digital images can be readily shared via computer networks and conveniently processed for queries in databases. In addition, properly stored digital images do not age or degrade with usage. On the other hand, thanks to powerful editing programs, it is very easy even for an amateur to maliciously modify digital media and create "perfect" forgeries. An example of an illegitimate forensic application is the "burning in "of O. J. Simpson's mug shot to make the stubble on his face appear darker, as shown in [Figure 1.1]. This is a deliberate effort to appeal to a viewer's prejudice [iv].

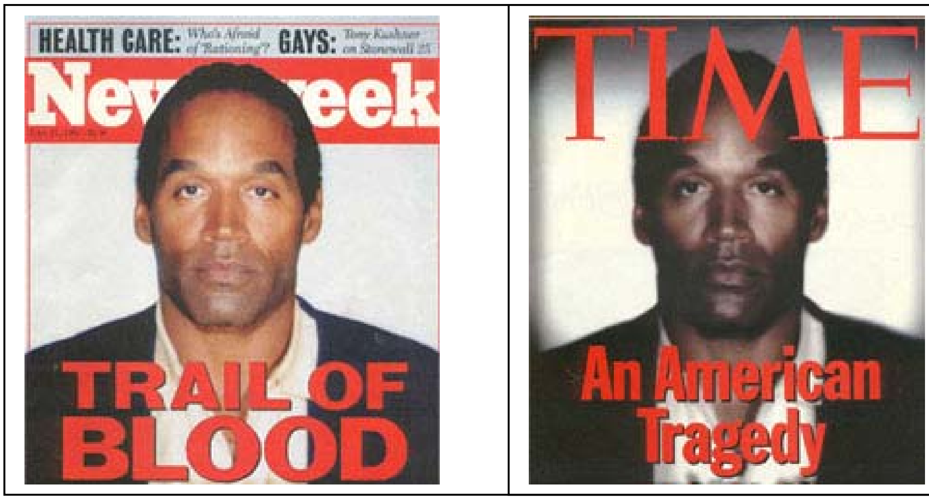


Figure 1.1 O. J. Simpson Image Forgery Example

The legal requirements for traditional photographs (Silver halide) to be acceptable as evidence, one must establish their integrity, origin, and authorship. The courts are now applying these standards to digital photographs. Although digital (photographs) images may be easier to manipulate than traditional photographs, the nature of their digital format facilitates the development of scientifically proven techniques for detecting many of these manipulations [v,vi,vii,viii].

The solutions to these problems will not only contribute to the understanding of this fast moving complex world of digital image technology, but will provide the courts with a needed solution for digital image authentication. This dissertation addresses the issues regarding the use of digital images as evidence, and their applications in the courts evidentiary system.

In our "Proof of Concept" research, we proposed a Secure Digital Camera [ix] (SDC) system as a solution to the significant problems associated with use of digital camera images as evidence in a court of law. A Secure Digital Camera (SDC) can verify image integrity, exactly who the photographer was, and what camera was used.

Forensic tools that help verify the integrity, establish the origin, and authenticate a digital image are thus very essential to the forensic examiner. These tools may prove to have additional benefits, such as decreasing the possibility for human error, in the chain of custody process. These forensic tools can prove to be vital whenever questions of digital image integrity are raised.

Chain of custody[♥] can be one of the most difficult issues faced by the forensic professional trying to introduce a digital image as evidence in a criminal case.

1.2. Scope and Contributions

1.2.1. Scope

The work presented in this dissertation addresses the evidentiary problems associated with the integrity, verification, and authentication of digital images in a court of law. We offer a unique, first of its kind biometric authentication solution using our secure digital camera. In the context of lossless authentication watermarking, we address biometric watermarking, and detail the various techniques and technologies that were involved.

1.2.2. Contributions

The particular contributions of this dissertation are as follows:

- Identified, detailed, and summarized the significant problems currently associated with the use of digital images as evidence in a court. No system currently exists that can verify the integrity, origin, and authorship of digital images.
- Proposed the first of its kind, Biometric Authentication System (BAS), for a Secure Digital Camera (SDC), as a solution to these evidentiary issues.

[♥] Chain of Custody: A process used to maintain and document the chronological history of the evidence.

- Designed and developed an iris capture system for iris recognition, that is located inside of a standard camera viewfinder.
- Tested and explored the capacity vs. image quality issues associated with the lossless data embedding technique implemented in our SDC, using the algorithms developed by Fridrich, et al [xxix].
- Designed and developed a working bench top prototype of a secure digital camera system, using a novel approach, based on lossless watermarks for digital images with a bioforensic identifier.

1.3. SDC Basic Design Concept Overview

The overall concept of a secure digital camera is to offer a solution to the problems associated with the chain of custody for digital images presented to the court.

The SDC system consists of a secure digital camera that contains a unique fragile watermarking chip, and a secret hard–wired embedding key inside of it. This watermarking chip securely, losslessly, and invisibly embeds the photographer's JPEG compressed iris image, the hash of the scene image, date, time, and other camera/picture information into the image of the scene photographed. This watermarked image is then stored on the camera's memory card for off line extraction and verification using the secret camera key as diagramed in [Figure 1.2].

The problem of authorship is solved by the using the iris as a biometric identifier of the photographer. Image integrity is guaranteed by the use of secure cryptographic hashes (e.g., MD5) that detect any image modification. The secret camera ID key identifies the exact camera used. Once authenticated, the SDC image is transferred to a read only memory (ROM) type of archival storage system, such as a CD–ROM.

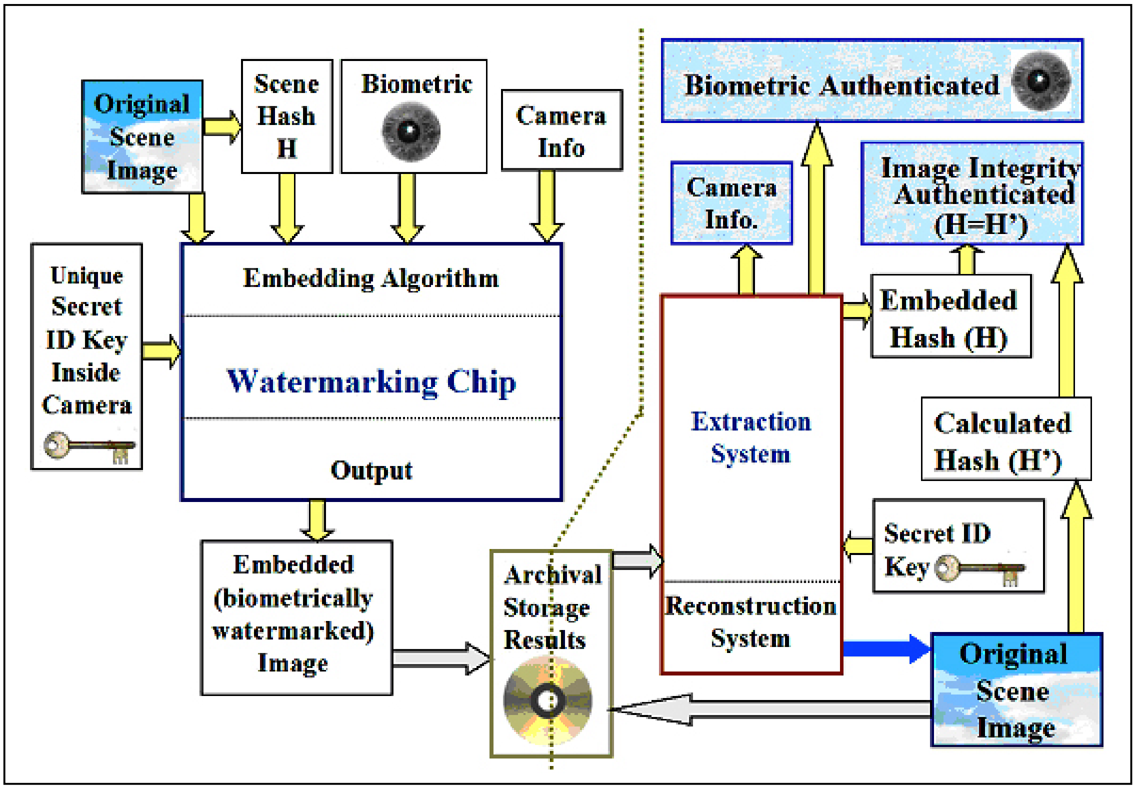


Figure 1.2 Overall SDC Concept Block Diagram

1.3.1. The Internal Camera Design Concept

[Figure 1.3] illustrates our basic concept of how a secure digital camera automatically captures a digital image of the human iris, through the viewfinder with every digital photograph taken.

This iris image is then JPEG compressed and combined with a hard–wired secret camera identification key, the hash of the original scene image being photographed, and additional digital camera specifics, e.g. a time stamp. The result is a digital bioforensic authentication signature losslessly embedded by the watermarking chip, inside the secure digital camera.

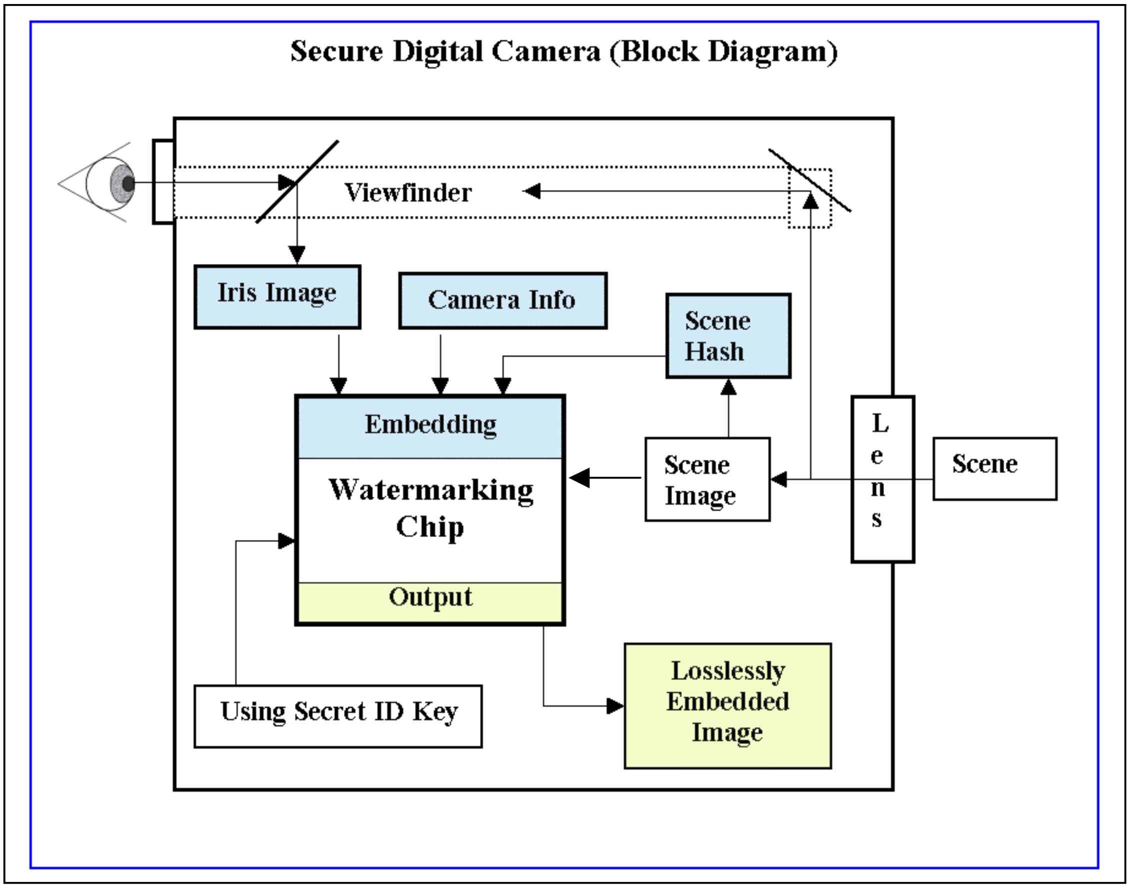


Figure 1.3 Internal Camera Concept – Block Diagram

1.4. Prior Art

1.4.1. Digital Watermarking Cameras

Epson:

The following are the Epson cameras that have watermarking capabilities. They are all discontinued camera models, as is the corresponding IAS software:

- Epson PhotoPC 700/750Z (1.2Mp)
- Epson PhotoPC 800/800Z (2.1Mp)
- Epson PhotoPC 3000Z (3.1Mp)

Epson uses a system called the "image authentication system"(IAS). The user must purchase the software as an option and then upload it to the camera from a personal computer. Once the IAS is installed in the camera, it will transparently add a digital watermark (encrypted fingerprint) to each image captured. This still allows viewing of images using any software that can read JPEGs, but the IAS software can verify the authenticity of images. It can also detect any tampering, even if a single pixel has been changed.

While not likely to be an essential feature for most users, it has clear forensic benefits in many applications. If the camera is opened, the IAS system must be installed again. The offline software allows one to verify the image integrity, as well as show the areas that have been modified on a personal computer.

Kodak:

The following are the Kodak cameras that have watermarking capabilities. They are all discontinued camera models:

- Kodak DC–200 (0.9Mp)
- Kodak DC–260 (1.3Mp)
- Kodak DC–290 (2.1Mp)

The Kodak DC–290 was the only camera Kodak made with digital watermarking capabilities built in. It is also discontinued from manufacturing. The watermark settings allow one to place any or all of the following watermarking options: date, time, text, or logo visibly into the pictures. One can also select the watermarks characteristics, such as left and top offset in picture, transparency level, text color, and background color as shown in [

Figure 1.4].

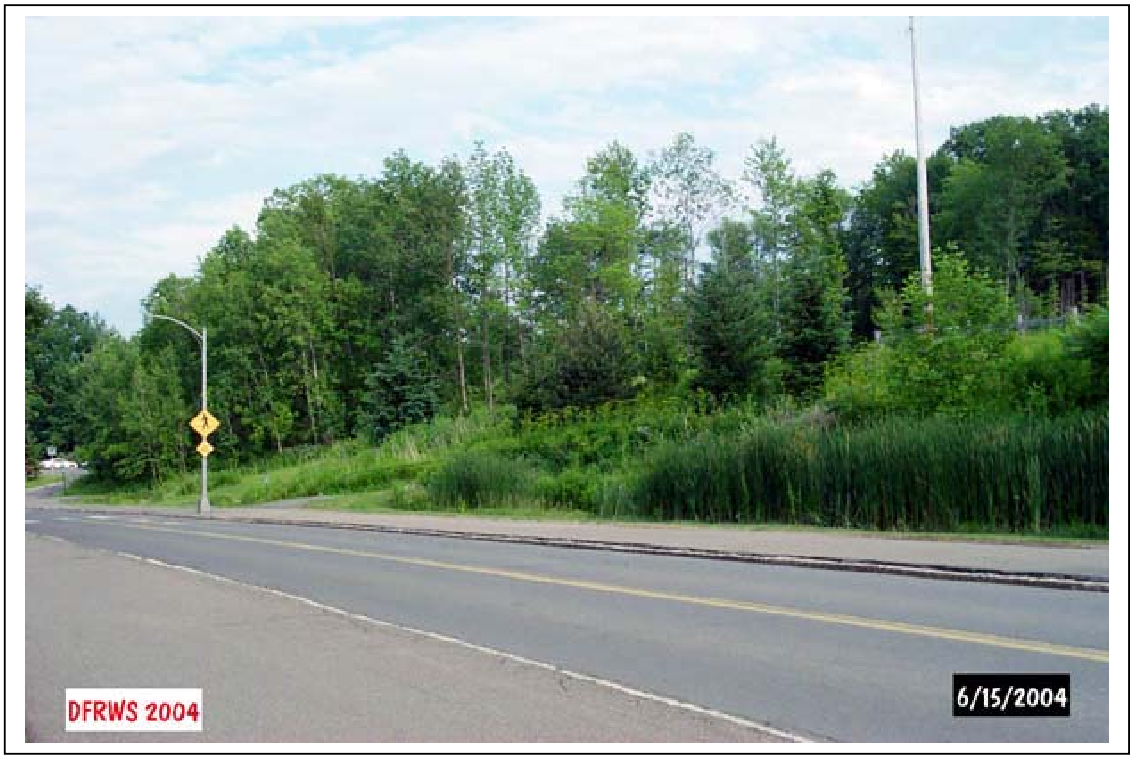


Figure 1.4 Kodak Watermarked Image

The main difference between the Epson and the Kodak cameras is that the Epson is better suited to camera image verification. It has an invisible watermark and can detect a change in a single pixel.

The Kodak camera has a visible watermark. The watermark logo can be added after the picture is taken with Kodak software. This has limited forensic use.

1.4.2. Digital Data Verification Cameras

Although the two previous cameras are obsolete, the strong need for law enforcement, insurance, news and other agencies for a system capable of at least verifying the originality of digital photographs has been recognized and addressed by the Canon Corporation Inc., a camera manufacturing company.

Canon:

Canon now offers the data verification kit shown in Figure 1.5. This kit consists of a dedicated SM (secure mobile) card reader/writer and verification software that quickly scans image files from the following cameras:

- EOS–1D Mark II, & EOS–20D (8.2 Mp)
- EOS–1Ds (11.0 Mp)
- EOS–1Ds Mark II (17.2 Mp)

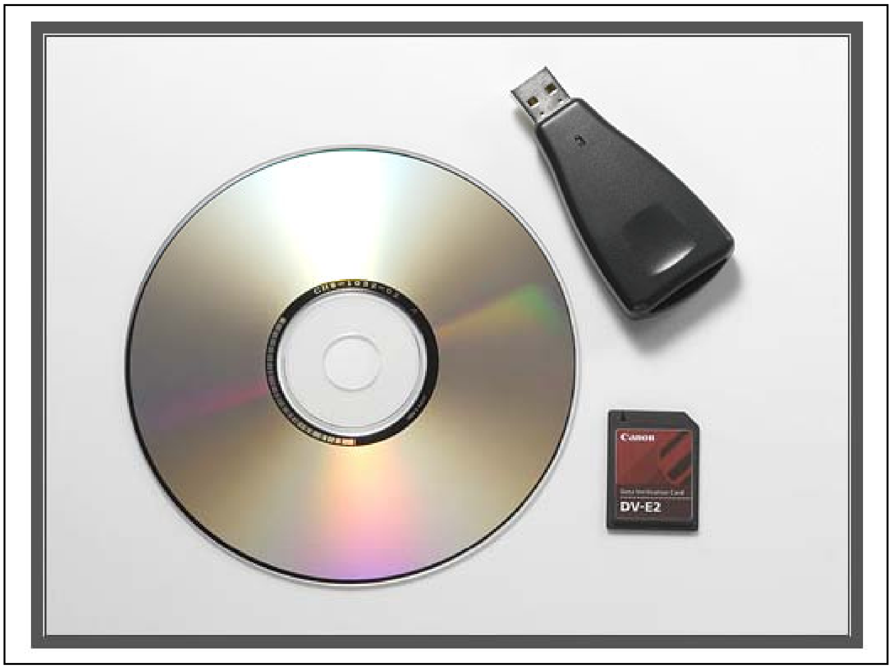


Figure 1.5 Canon Data Verification Kit {Appendix B.}

When the personal function (# 31) on the above cameras is activated, a code based on the image contents is generated and appended to the image. When the image is viewed, the data verification software determines the code for the image and compares it with the attached code. If the image contents have been manipulated in any way, the codes will not match and the image cannot be verified as the original.

1.5. Digital Biometric Camera Patents

Searching the U.S. Patent Office database and other on–line resources, such as the biometric consortium, we located only two patents that were close in design. However, neither one had the unique features of our SDC. The following are the details for the two patents and their abstracts:

1. **Application Number: US2001000900370**, as shown in [Figure 1.6].

Abstract: (Verbatim) An iris camera module includes an image pickup optical system and a target optical system and the optical path is divided by a half mirror. An image of an iris is picked up by an image pickup element of an image pickup section. The iris image thus picked up is compared with a reference iris image stored in storage in advance and the comparison result is output. The iris camera module has a configuration fit for a compact design. The reference iris image as a reference for comparison is stored in the storage of the comparison chip. It is thus difficult to falsify the reference iris image thereby providing a high security.

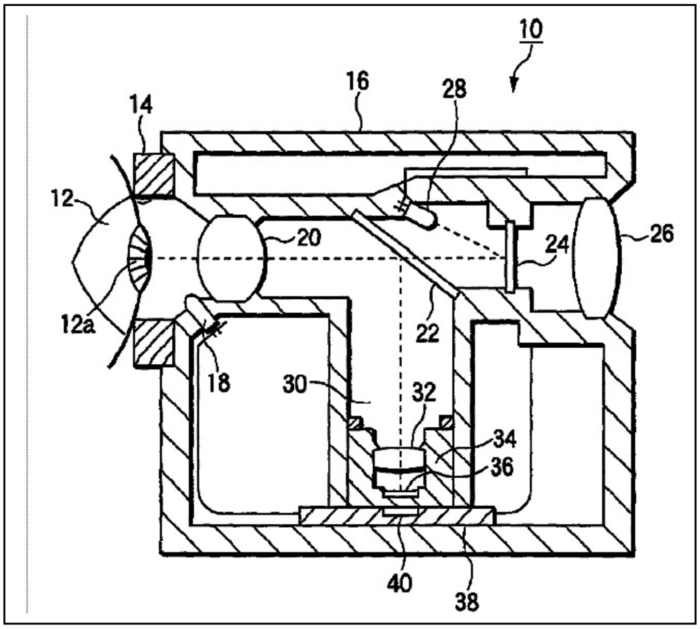


Figure 1.6 Patent Application Number: US2001000900370

In the first referenced patent (US2001000900370), the only similarity to our SDC is the viewfinder iris image system. The concept of this camera is for use as a security camera. It does not allow unauthorized users to operate the camera based on a reference iris image that was stored in advance. This not only limits the number of users, it does not append or insert the iris image into the scene. This camera does not offer a solution to the evidentiary problems of digital images.

2. **Application Number: US20020080256A1:** Digital camera apparatus with biometric capability, as shown in [Figure 1.7].

Abstract: (Verbatim) A digital camera contains biometric capability to identify a photographer, which is preferably provided by the camera's own optical sensors. The biometric feature is preferably the iris of a photographer's eye, which is recognized as unique for each individual. The camera captures an image of an iris, abstracts a set of distinguishing features, and matches this set to an on–board database. The iris image is preferably captured when the photographer brings his eye in the vicinity of the camera's viewing window, through a combination of mirrors, lenses, prisms, and the like. This capability may be used to record the identity of a photographer with the image, as an anti–theft or privacy device, or to personalize the camera settings.

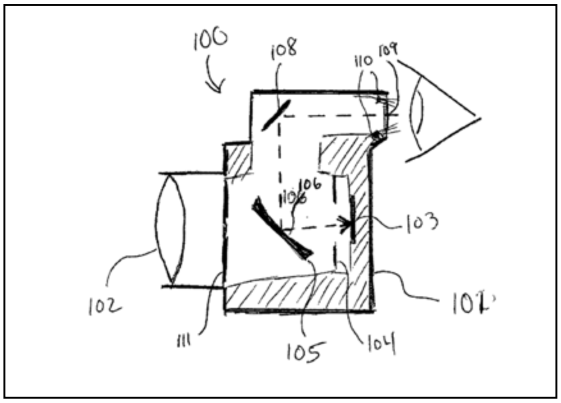


Figure 1.7 Patent Application Number: US20020080256A1

In the second referenced patent (US20020080256A1), the only similarity to our SDC is the viewfinder iris image system. The concept of this camera is as an anti–theft deterrent, privacy device, or to personalize the camera settings. This camera performs the feature extraction and matching of the iris image done on–board (within) the camera. The on–board database is costly. It would reduce camera performance time, with current technology, in addition to limiting the number of camera users.

Both of the referenced patents are conceptually similar, since they focus on personal security issues of camera's use. They both use on board recognition systems that severely limit the number of users.

Unlike the SDC, neither patent offers a solution to the evidentiary problems associated with the use of digital image as evidence.

1.6. Related Works

In this section, we refer to works concerned with iris recognition since, to our knowledge, no one has attempted to losslessly embed the iris into a digital image. Most of the existing papers deal with converting an acquired iris image into a suitable code that can be easily manipulated. The iris recognition systems of Boles, Daugman, and Wildes, are compared by author Lim, S., in the following abbreviated summary of an article in the ETRI Journal [x].

1.6.1. ETRI Journal Summary

As briefly stated in the ETRI Journal, Daugman [xiv] developed the feature extraction process based on information from a set of 2–D Gabor filters. He generated a 256byte code by quantizing the local 2,048 bit phase vectors according to the outputs of the real and imaginary parts of the filtered image. A test of statistical independence is implemented by the simple Boolean Exclusive-OR operator (XOR) applied to the 2,048 bit phase vectors that encode any two iris patterns. The norms (|| ||) of the resultant XOR'ed phase bit vectors and of the filtered (AND'ed mask) vectors are then measured in order to compute a fractional Hamming Distance as the measure of the dissimilarity between any two irises

On the contrary, the Wildes' [xi] system made use of a Laplacian pyramid constructed with four different resolution levels to generate iris code. It also exploited a normalized correlation based on goodness–of match values and Fisher's linear discriminant for pattern matching. Both iris recognition systems make use of band pass image decompositions to get multi–scale information.

Boles [xii] implemented the system operating the set of 1–D signals composed of normalized iris signatures at a few intermediate resolution levels and obtaining the iris representation of these signals via the zero crossing of the dyadic wavelet transform. It made use of two dissimilarity functions to compare the new pattern with the reference patterns.

Boles' approaches have the advantage of processing 1–D iris signals rather than a 2–D image used by both Daugman and Wildes. They both proposed and implemented a whole system for personal identification or verification, including the configuration of image acquisition device. Boles' only focused on the iris representation and matching algorithm without an image acquisition module.

The ETRI paper identifies some of the problems that the author, Shin Young Lim, experienced in his attempts to acquire a human iris image. Many similar problems had to be considered when designing the SDC viewfinder capture (Acquisition) module.

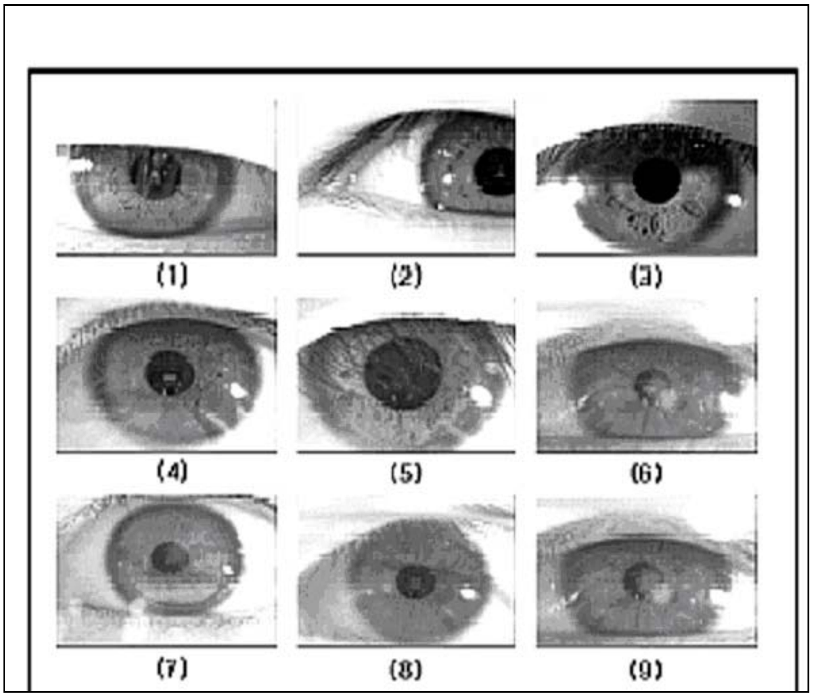


Figure 1.8 Failure Examples for Iris Recognition

For explanations of the types of errors (Numbers 1–9) below each iris image in Figure 1.8], refer to their tabulated failure analysis shown in [Table 1.1].

Cause of Failure		# of Data	Ratio (%)
Data Without Glasses and with Lens	**(1) Occlusion by eyelids**	**178**	**31**
	(2) Inappropriate eye positioning	**127**	**22**
	(3) Shadow of eyelids	**121**	**21**
	(4) Noises with pupil	**34**	**6**
	(5) Etc	**115**	**20**
	Total	**575**	**100**
Data With Glasses	**(6) Noises of dirt on the glasses**	**49**	**37**
	(7) Reflection of glasses	**28**	**21**
	(8) Shadow of the rim of glasses	**20**	**15**
	(9) Etc	**36**	**27**
	Total	**133**	**100**

Table 1.1 Failure Causes for Iris Recognition

In the ETRI experiments, the iris image was obtained at a distance of 200mm. Many of the iris capture problems would be significantly reduced or eliminated in the SDC, due to the close proximity of the iris to the camera's viewfinder capture system.

1.7. Digital Images as Evidence

We believe that the legal concerns raised by digital images, as opposed to traditional photographs, are not as different as one may believe. Currently, the courts accept traditional photography as a process that is known to be a "trustworthy" one. There are many similarities that exist between traditional and digital photographs.

For example, traditional cameras use photographic film to record an image using light–sensitive collectors called silver halide. A digital camera records an image using light–sensitive collectors called pixels. As light strikes the surface of the film, individual particles of silver halide change chemically. As light strikes the surface of the digital camera sensor, individual pixels change (Opto) electronically. The longer the exposure, the greater is the change with both photographic film, and digital image sensors.

The accuracy and detail of traditional camera images are dependent upon the resolution of the optical system used in the camera, as well as the film density (grain), and physical size. The larger the film size is, the greater the image resolution will be. Just as with traditional cameras, the accuracy and detail of digital camera images are dependent upon the resolution of the cameras optical system, as well as the size of the image sensor. The larger the physical size of the image sensor (In Mp), the greater the image resolution will be. In general, the better the optics, the higher the light intensity, and the larger the size of the film, or image sensor, the more accurate and detailed the images will be with either technology.

The actual process of capturing an image on photographic film, or digital image sensor is more complex than our simplified explanation, but for the purposes of this dissertation, it should be adequate to show the similarities between a typical digital image and photographic film.

These similarities should be clear to anyone who has used a camera from believing a digital camera image is the result of some novel scientific process. With recent advances in digital camera sensor sizes and image processing technology, the ability of photographic film to record an image more accurately is now being questioned.

The world has taken photographs for granted since the first daguerreotype was presented on August 19, 1839 [xiii]. Digital images, on the other hand, still represent a mystique when shown to the average citizen. The origin and validity of digital images are looked upon with some suspicion. This is especially true when the image is introduced into legal proceedings. Defense attorneys and judges tend to be distrustful of technology; and jurors get easily confused by technical explanations.

1.7.1. Photographs as Evidence

The principal requirements to admit a photograph (digital or film–based) into evidence are relevance and authentication. Unless the photograph is admitted by the stipulation of both parties, the party attempting to admit the photograph into evidence must be prepared to offer testimony that the photograph is an accurate representation of the scene. This usually means someone must testify that the photograph accurately portrays the scene as viewed by that witness.

Evidence that is merely illustrative of verbal testimony and carries no independent probative value may be used as demonstrative evidence to aid a witness' testimony or to help counsel in opening or closing arguments. Demonstrative evidence has been an effective courtroom tool; litigators have used chalkboards, maps, diagrams, photographs, films, and videos to help the jury understand and remember witness testimony.

The Courts also recognize that “general admissibility” is not the sole admissibility factor for scientific evidence; trial courts should also look to peer review and publication, the known or potential rate of error (i.e. FAR) of the process or technique, and whether the process or technique has been tested. [♥]The Courts stress the importance of “testing” [scientific techniques] to see if they can be “falsified” and mentioned “the criterion of the scientific status of a theory is its falsifiability. This “testing” will be a requirement for our SDC system to be a useful and accepted tool.

In addition to the methods of authentication listed in Rule 901(b), the common law sets forth various authentication procedures. By examining common law authentication tests for types of evidence similar in nature to digital images, focusing on trends in the courts and the explanations for those trends, one might better judge the nature of the authentication requirements to which digital images may be subjected.

From the extensive legal research we performed, it appears that the current evidentiary system is not equipped to authenticate digital images. The SDC will help the courts by eliminating the many obstacles that traditional photographs now face.

Despite the fact that digital images are a different media form than traditional photographs, courts often use the same methods to authenticate digital images that they use to authenticate traditional photographs.

[♥] Quoting: Popper, K., Conjectures and Refutations, “The Growth of Scientific Knowledge”, 37 (5th ed. 1989).

2. Biometric Systems

Introduction

The term ‘Biometric’ is derived from the Greek words bio (life) and metric (the measure of). ‘Biometrics’ can been defined as: “A pattern recognition system that recognizes a person by determining the authenticity of a specific physiological and/or behavioral characteristic possessed by that person.” The most commonly used form of biometrics in use today is a fingerprint. Fingerprints are a good choice for biometric identification because they possess two very important characteristics required for biometric identification. The first characteristic is that fingerprints are unique for each individual. The second characteristic is that fingerprints are permanent, since they do not change over time. It is for these two reasons that fingerprints were the first legally accepted biometric technique used for identification.

Biometric–based authentication applications include cell phones, computers, transaction security (ATM), remote and local resource access, and web security.

Common physical biometric technologies include the following:

- Finger Print (dactylogram) Identification
- Hand or palm Geometry Identification
- Voice Recognition
- Signature Recognition
- Retina Identification
- Facial Recognition
- Iris Identification

2.1. Choosing a Biometric Identifier

Of the many biometric technologies available, only the following two met the physical size constraints of our (SDC) camera, and possessed the biometric characteristics our SDC design required; uniqueness, and permanency:

- Fingerprint Patterns: The analysis of an individual's unique fingerprints.
- Iris: The analysis of the colored ring that surrounds the eye's pupil
    1. **Uniqueness:** Is the characteristic that a biometric identifier is unique for each individual.
    2. **Permanency:** Is the characteristic that a biometric identifier remains permanent, since it does not change over time (I.e. a person's face does change over time).

The fingerprint identification systems currently under testing were proving to be difficult to use due to moisture problems. A glove would hamper its use as well.

We considered many variables when we compared the two technologies. They included, but were not limited to implementation and integration time and costs, user friendliness, reliability, and legal acceptability. The iris was selected to be the biometric identifier that the SDC watermarking chip losslessly embeds into the cover image.

2.2. Anatomy of the Eye

The very front of the eye is essentially made up of two parts: the sclera, or "white" of the eye, and cornea. The sclera consists of closely interwoven fibers and covers the entire surface of the eye, except for a small section in the back, where the optic nerve leaves the eye, and a small section directly in front and centered, known as the cornea as shown in [Figure 2.1].

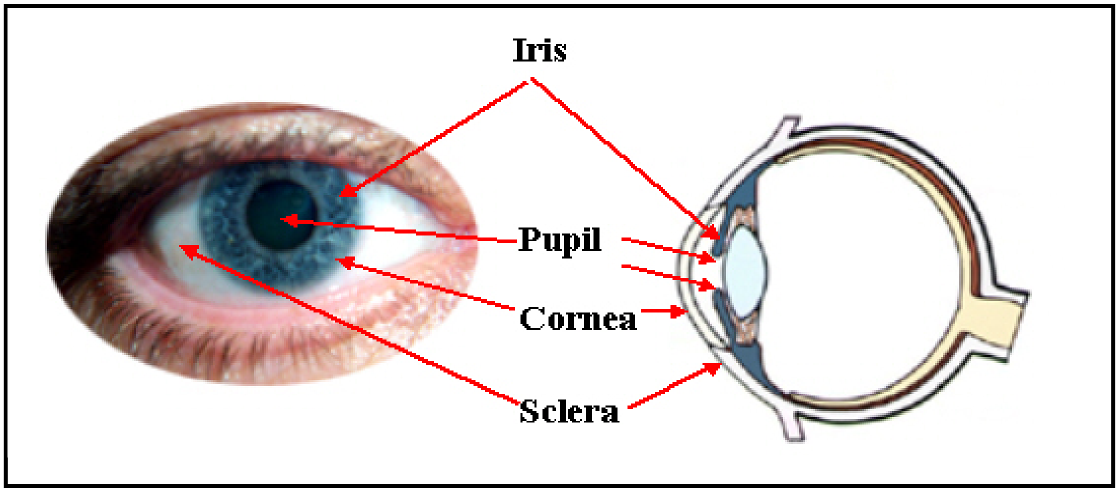


Figure 2.1 Basic Eye Components Cross Reference Diagram

The cornea consists of fibers arranged in a regular fashion. Conveniently, this makes the cornea transparent, allowing light to filter in. Behind the cornea is the anterior chamber. It is filled with a fluid known as the aqueous humor. This fluid is primarily responsible for carrying oxygen and nutrients to the organs submerged in it, as well as carrying away their waste.

Normally, this is a function for the blood vessels. However, the blood vessels are opaque and would block the transmission of light. A spongy tissue, the ciliary bodies, arranged around the edge of the cornea, constantly produces the aqueous humor. Immersed in the aqueous humor is a ring of muscles commonly referred to as the iris.

2.3. Introduction to the Iris

The word iris is most likely derived from the Latin word for rainbow. It appears the term was first applied in the sixteenth century, referring to this multicolored portion of the eye. The iris shown in [Figure 2.2] is the plainly visible colored ring that surrounds the pupil.

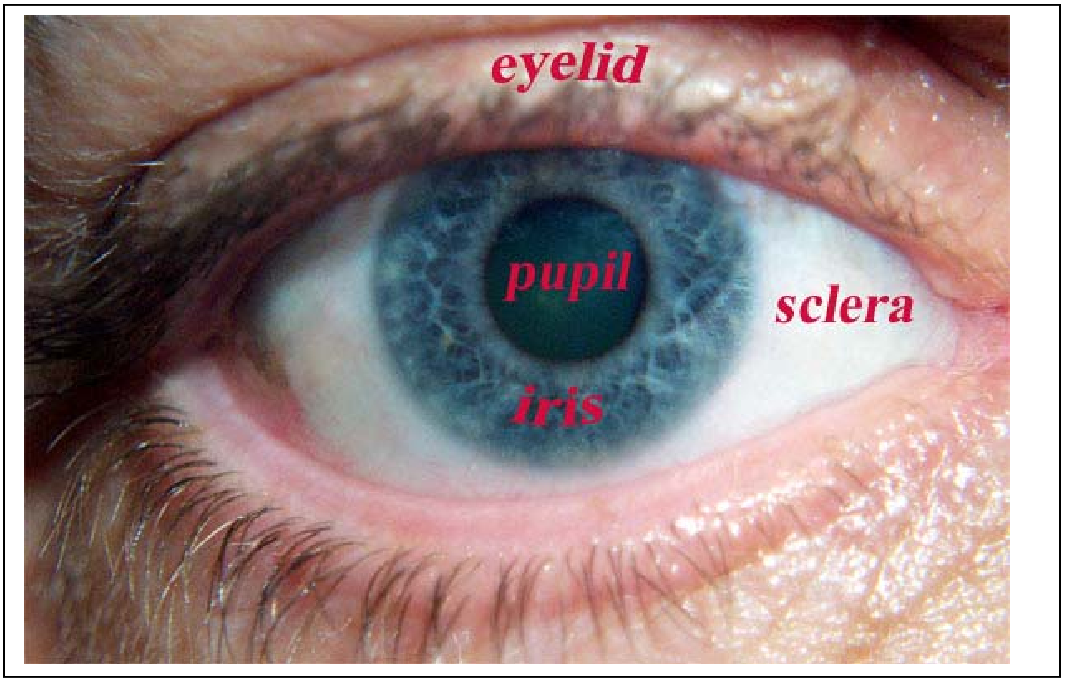


Figure 2.2 Key Eye Components for Iris Recognition Systems

The function of the iris is to control the amount of light entering through the pupil. The sphincter and the dilator muscles adjust the size of the pupil accordingly to the amount of light entering the eye. The average diameter of the iris is 12mm [xiv], and the pupil size can vary from 10% to 80% of the iris diameter.

The pupil may not be exactly circular in shape. The centers of the iris and pupil are different, and can differ from each other of about 20% [xv].

2.4. The Individuality of the Iris

No two irises are alike. There is no detailed correlation between the iris patterns of even identical twins or the right and left eye of an individual. The amount of information that can be measured in a single iris is much greater than fingerprints. It is extremely difficult to surgically tamper the texture of the iris. Further, it is rather easy to detect artificial irises [xvi] (e.g., designer contact lenses). Developmental biology further suggests that, while the general structure of the iris is genetically determined, the particular aspects of its details are dependent upon circumstance, like the conditions in the embryonic precursor to the iris. Developmental biology also supports the lack of variance through life idea. The human iris begins to form during the third month of gestation. The structures creating its distinctive pattern are complete by the eighth month of gestation. But pigmentation continues into the first years after birth.

The only marked exceptions are the pigmentation, which does not fully mature until adolescence, and the size of the pupil, which is also not fully determined until puberty. However, once out of the teenage years, a person's iris variations will likely remain the same for the rest of his/her life (thus the enormous interest in utilizing iris variation in a biometric system).

2.5. Iris Functionality

The actual physical functionality of the iris is quite remarkable. It is often compared to the diaphragm (Opening for light to pass) of a camera, as it shares some characteristics. A typical iris has an f–number around f/2 or f/3, ideal for maximum exposure to light. An f-number is the diameter of a camera lens diaphragm aperture in terms of the effective focal length of the lens. For example, f/11 represents a diaphragm aperture diameter that is one-eleventh of the focal length (or the focal length is 11 times the aperture) The iris can change the amount of light coming into the eye in about a fifth of a second, but the reduction amount is minuscule – less than a factor of 20 (about another f–stop). This obviously points out that the iris is not responsible for control of light intensity, for this is primarily the job of the rods and cones in the back of the retina. However, like changing the f–stop on a camera, the iris can seriously reduce aberrations, especially in bright conditions, and increase depth of field [DOF].

When using a manual camera in bright light situations, you decrease the (iris size) f–stop, for proper exposure. The human eye functions in a manner by decreasing the pupil size to allow less light in, which makes it easier to identify incoming images. When focusing in on close objects, such as a book, computer monitor, or watch, the iris stops down to increase the depth of field.

This is also the case in photography, where decreasing the f–stop (Opening for light), sharpens the resulting image. During low light levels, however, the iris serves the opposite purpose. Much like one would do for night photography, increasing the f–stop to let in more light, the iris opens as much as possible to allow the faintest light to enter the eye. Once the rods have adjusted to current light levels, a small amount of light is all they need to perform basic image detection.

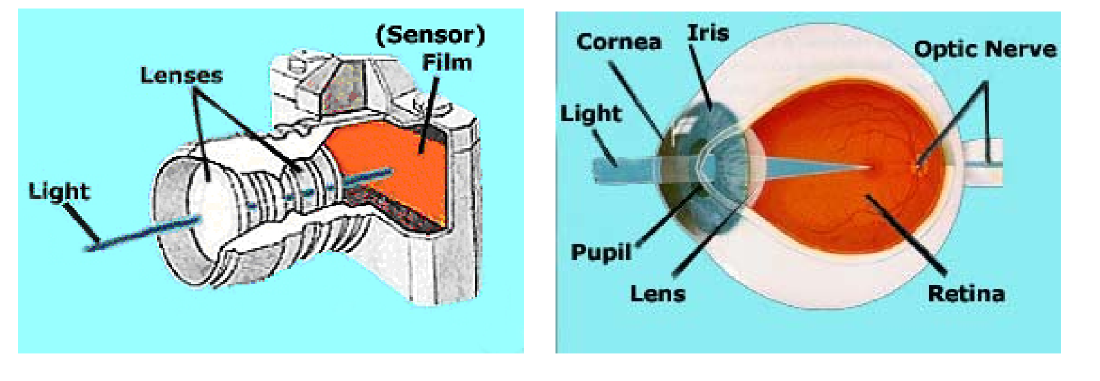


Figure 2.3 Camera and Eye Comparisons

To summarize in a simple manner, the individual components of the eye work in a manner similar to a camera as shown in [Figure 2.3]. The cornea’s function is similar to a camera lens cover. The eye's main focusing element, the cornea, takes widely diverging rays of light and bends them through the pupil, the dark, round opening in the center of the colored iris. The iris and pupil act like the aperture of a camera. The function of the eye lens, like the camera lens, is to focus light to the back of the eye.

The very back of the eye is lined with a layer called the retina. The retina acts very much like the film of the camera, or the image sensor in a digital camera. The retina is a membrane containing photoreceptor nerve cells that lines the inside back wall of the eye. The photoreceptor nerve cells of the retina change the light rays into electrical impulses. The optic nerve transmits these electrical impulses to the brain, where an image is perceived. The macula, the center 10% of the retina, is responsible for sharp vision, such as when reading. The peripheral retina is responsible for the peripheral vision.

2.6. Iris Recognition – The Current Technology

Daugman's (University of Cambridge) research patents on iris recognition form the basis of this section (Iridian Technologies, Inc. of Moorestown, NJ, formerly IrisScan Corporation). This section (2.6.) summarizes the iris recognition information obtained from Daugman's web page. {Appendix B.}.

2.6.1. Iris Characteristics

Iris recognition is based on visible (via regular and/or infrared light) qualities of the iris. Expressed simply, iris recognition technology converts these visible characteristics into a 512 byte IrisCode®, a template stored for future verification attempts. 512 bytes is a compact size for a biometric template, but the quantity of information derived from the iris is massive.

From the 11mm diameter iris, Daugman's algorithms provide 3.4 bits of data per square mm. This density of information is such that each iris can be said to have 266 unique "spots", as opposed to 13–60 for traditional biometric technologies (I.e. fingerprint). Daugman concludes that 173 "independent binary degrees–of–freedom" can be extracted from his algorithm–an exceptionally large number for a biometric.

2.6.2. The Algorithms

The first step is location of the iris by a dedicated camera no more than 3 feet from the eye as shown in [Figure 2.4]. After the camera situates the eye, the algorithm narrows in from the right and left of the iris to locate its outer edge. This horizontal approach accounts for obstruction caused by the eyelids. It simultaneously locates the inner edge of the iris (at the pupil), excluding the lower 90 degrees, because of inherent moisture and lighting issues.

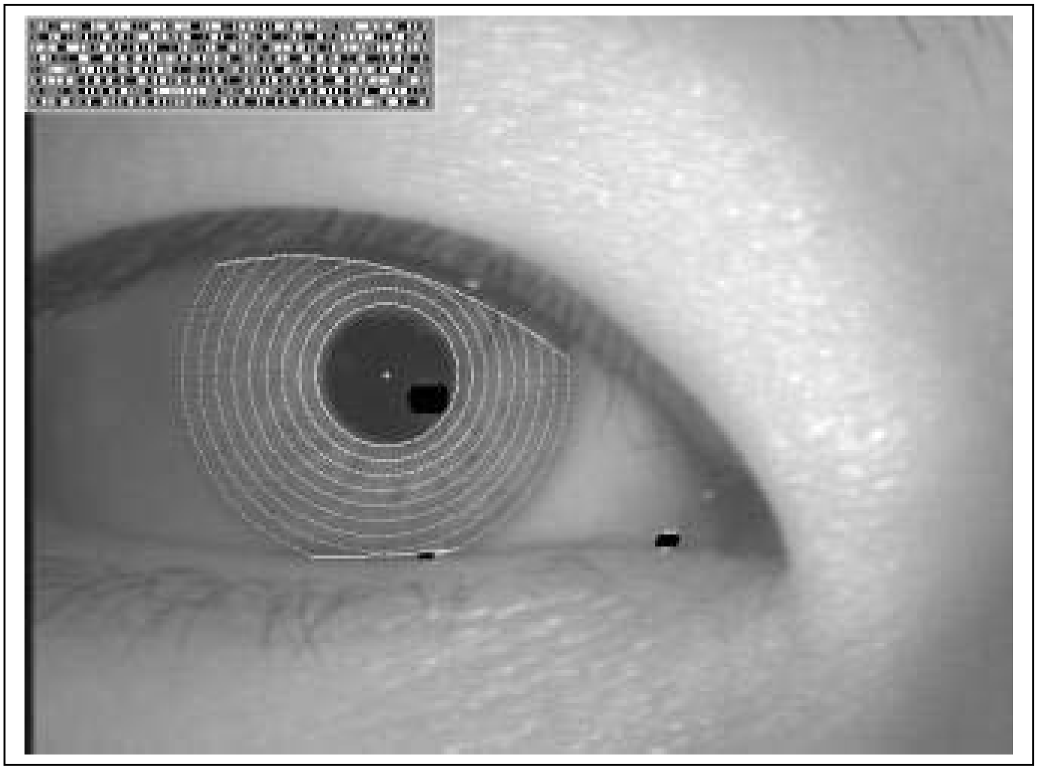


Figure 2.4 Iris Area Algorithm

The monochrome camera uses both visible and infrared light, the latter of which is located in the 700–900nm range. Upon location of the iris, as seen above, an algorithm uses 2–D Gabor wavelets to filter and map segments of the iris into hundreds of vectors (known here as phasors). Not the entire iris is used, a portion of the top, as well as 45deg. of the bottom, are unused to account for eyelids and camera–light reflections. For future identification, the database will not be comparing images of irises, but rather hexadecimal representations of data returned by wavelet filtering and mapping.

2.6.3. Accuracy

The IrisCode® constructed from these complex measurements provides such a tremendous wealth of data that iris recognition offers levels of accuracy orders of magnitude higher than other biometrics. Some statistical representations of the accuracy are as follows [{Appendix B.}].

- The odds of two different irises returning a 75% match (i.e. having a Hamming Distance of 0.25): 1 in 10^{16}.
- Equal Error Rate (the point at which the likelihood of a false accept and false reject are the same): 1 in 1.2 million.
- The odds of 2 different irises returning identical Iris Codes: 1 in 10^{52}.

Other numerical derivations demonstrate the unique robustness of these algorithms. A person's right and left eyes have a statistically insignificant increase in similarity: 0.00048 on a 0.5 mean. This serves to demonstrate the hypothesis that iris shape and characteristics are phenotypic–not entirely determined by genetic structure.

The algorithm can also account for occlusion (blocking) of the iris: even if 2/3 of the iris were completely obscured, accurate measure of the remaining third would result in an equal error rate of 1 in 100,000.

Iris recognition can also account for those ongoing changes to the eye and iris, which are defining aspects of living tissue. The pupil's expansion and contraction, a constant process separate from its response to light, skews and stretches the iris. The algorithm accounts for such alteration after having located the boundaries of the iris.

Daugman draws the analogy to a “homogenous rubber sheet” which, despite its distortion, retains certain consistent qualities. A question asked of all biometrics is their ability to determine fraudulent samples. Iris recognition can account for this in several ways: the detection of papillary (pupil) changes, reflections from the cornea, detection of contact lenses atop the cornea, and use of infrared illumination to determine the state of the sample eye tissue.

2.6.4. Advantages and Disadvantages of Iris for Identification:

Advantages of the Iris for Identification:

- Highly protected, internal organ of the eye
- Externally visible; patterns imaged from a distance
- Iris patterns possess a high degree of randomness
  - Variability: 244 degrees–of–freedom
  - Entropy: 3.2 bits per square–millimeter
  - Uniqueness: set by combinatorial complexity
- Changing pupil size confirms natural physiology
- Pre–natal morphogenesis (7th month of gestation)
- Limited genetic penetrance of iris patterns
- Patterns apparently stable throughout life
- Encoding and decision–making are tractable

Disadvantages of the Iris for Identification :

- Small target (1 cm) to acquire from a distance (1 m)
- Moving target ...within another... on yet another
- Located behind a curved, wet, reflecting surface
- Obscured by eyelashes, lenses, reflections
- Partially occluded by eyelids, often drooping
- Deforms non–elastically as pupil changes size
- Illumination should not be visible or bright.
- Some negative (Orwellian) connotations.

2.7. Electromagnetic Spectrum

The electromagnetic spectrum covers the total range of possible wavelengths of photons from the shortest “gamma rays” through x–rays, the ultraviolet, the visible, infrared, and microwave to the longest “radio waves” [Figure 2.5]

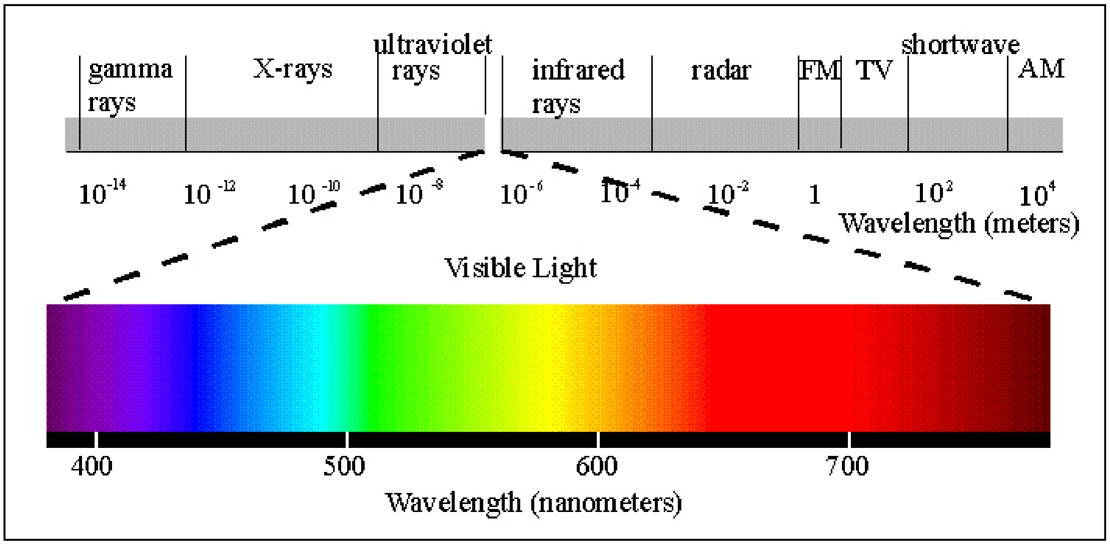


Figure 2.5 The Electromagnetic Spectrum

2.8. Light

The main characterization of light is by its wavelength, most often specified in nanometers (nm). We can also define a frequency for each wavelength by dividing the speed of light by the wavelength.

The range of light wavelengths we see are called the “visible spectrum”. It covers a range from about 400nm to 555nm to 750nm (violet to green to red). The human eye is most sensitive to light at a wavelength of 555nm, which is equal to 5.4 × 10^{14} Hz.

The range just above the visible, the near infrared (NIR), is most commonly used in infrared (IR) remote controls and is the dominant wavelength in the night sky spectrum.

In the SDC, the NIR LED's (850nm) utilize this non–visible feature to illuminate the iris. This feature provides for a less intrusive biometric (iris) acquisition system.

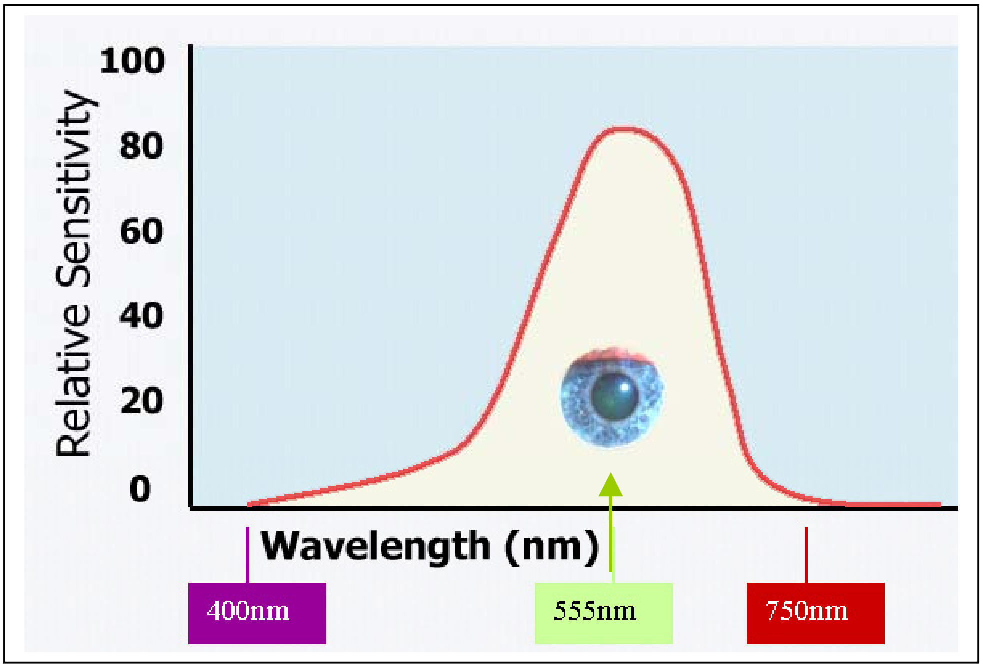


Figure 2.6 Eye Sensitivity and Visible Light Wavelengths

3. Digital Data Authentication

Introduction

The concepts behind data authentication are well stated in the following definition on the Cisco web site's {Appendix B.} glossary:

It states that data authentication includes two concepts:

1. Data integrity (verify that data has not been altered).
2. Data origin authentication (verify that the data was actually sent by the claimed sender).

Data authentication can refer either to integrity alone or to both of these concepts (although data origin authentication is dependent upon data integrity).

We begin with the technical history of digital data verification by describing the original concepts, and specific terms, or techniques required for a thorough understanding of data authentication. Data verification began with the use of digital signatures.

3.1. Digital Signatures for Verifying Data Authenticity

Historically, digital data authenticity was verified by the use of digital signatures. The integrity and authenticity of digital data relied upon the use of digital signatures [xvii]. A digital signature is binary information (Digital) that is appended to a (digital) message to assure the recipient of the authenticity and integrity of the message.

Digital signatures use public–key cryptography **{Cryptography}**, in which the signer has a private key used for creating signatures and a public key used for signature verification. Digital signatures and their cryptographic properties have been well studied. A number of algorithms, such as RSA {RSA algorithm } and DSA {DSA algorithm}, are used extensively in the various authentication techniques [xvii]. A hash function is used to create and verify a digital signature. A hash function is an algorithm which creates a standard length digital representation (Fingerprint) of the document called a hash value. Hashing algorithms are "one–way" since you are able to create a hash from a document, but you are unable to recreate the document from a hash. A hash is usually smaller than the document, but it is not an encryption of the document. The main disadvantage of a digital signature over a digital watermark is a digital signature is appended in the header of an image file and it may be easily stripped off, such as when opening a document, or when saving it under a different format.

3.1.1. Digital Watermarking

Introduction

A digital watermark is best described by comparing it to a traditional watermark. Traditional watermarks are added to some types of paper to offer proof of authenticity.

They are imperceptible, except when the paper is held up to a light for inspection. Similarly, digital watermarks are added to still images in a way that can be seen by a computer but is imperceptible to the human eye under normal observation conditions. This is possible by taking advantage of imperfections in the human senses, such as masking, and other properties of the human visual system[xviii, xix].

3.2. Watermark Classification and Terms for SDC

Watermarks can be visible or invisible depending on their application and their relationship to the cover media.

Visible watermarks are designed to convey visual message indicating proof of ownership such as a company logo. Visible watermarks should not detract from the content of the digital data.

Invisible watermarks are imperceptible/inaudible under normal viewing/listening conditions. The existence of such a watermark is determined only by using a watermark extraction or detection algorithm.

A further classification of watermarks is into fragile, semi–fragile, and robust.

Fragile watermarks detect every possible modification of the image with high certainty. Fragile watermarks are usually realized by embedding a cryptographic hash into the image [xx xxviii, xxx] .

Semi–fragile watermarks are supposed to be insensitive to “allowed” manipulations, such as lossy compression or small amount of common processing, but react sensitively to malicious content–changing manipulations, such as adding or removing objects [xxi, xxii].

Robust watermarks are detectable even after attempts are made to remove them. Robust hashes [xxiii], and robust watermarks [xxiv], are employed to facilitate content authentication of digital images.

It is doubtful a universal watermarking technique will ever exist that can satisfy all the requirements of all applications. Watermarking systems are designed within the context of their application, which in turn dictate the applicable watermarking technique(s). The use of the terms, “digital watermarking”, “data embedding”, and “data hiding”, and are often interchanged. For example, the term data hiding only implies that the embedded information is imperceptible to a human observer, as opposed to a reference to steganography or covert communications, where statistical undetectability is an additional requirement. A watermarking system consists of two basic components, a watermark embedding system, and a watermark extraction (Authentication) system.

3.3. Application Classification of Digital Watermarks

In [Table 3.1], the following classifications are based upon the type of information conveyed by the watermark [xxv]

Application Class	**Purpose of the Embedded Watermark**	**Application Scenarios**
Protection of Intellectual Property Rights	Conveys information about content ownership (Sender and/or receiver) and intellectual property rights	Copyright Protection, Copy Protection, Fingerprinting
Content Verification	Ensures that the original multimedia content has not been altered, and/or helps determine the type and location of alterations	Authentication Integrity Checking
Information Hiding	Represents side channel used to carry additional information	Broadcast Monitoring System Enhancement

Table 3.1 Classes of Watermarking Applications

The majority of the early authentication watermarking designs introduced some small amount of non–invertible distortion into the digital image [xxvi]

In some applications, such as watermarking of medical images or sensitive military imagery, distortion is unacceptable due to legal and other reasons. Forensic imagery also belongs to the category of sensitive images. Consequently, the distortion due to embedding of an authentication watermark will violate evidence integrity.

3.4. Authentication Watermarks

Authentication watermarks are broken down into two categories, fragile and semi–fragile watermarks. Since semi–fragile watermarks allow authorized image modifications, we will restrict our attention to fragile watermarks, which address the issues of image authentification and verification.

A fragile watermarking system consists of the two common components of all watermarking systems, a watermark embedding system and a watermark extraction system.

Authentication watermarks embedded by a watermarking chip inside the digital video and still cameras have been proposed in the past [xxvii, xxviii]. However, because the authentication process invariably modifies the image, the legal problems associated with watermarking prevented the spread of watermarking technology. To overcome this problem of authentication watermarks, the novel scheme of "lossless watermarking" was proposed [xxix]. In lossless watermarking, the embedding distortion is completely removed from the watermarked image and thus one can obtain the unmodified original image

3.5. Biometric Watermarking

Biometric Watermarking is the process that creates a link between a human subject and the digital media by embedding biometric information into the digital object as shown in [Figure 3.1].

Using a secret key, the SDC combines a fragile watermarking scheme with a biometric watermark (The iris) to produce a watermarked image inside of the camera.

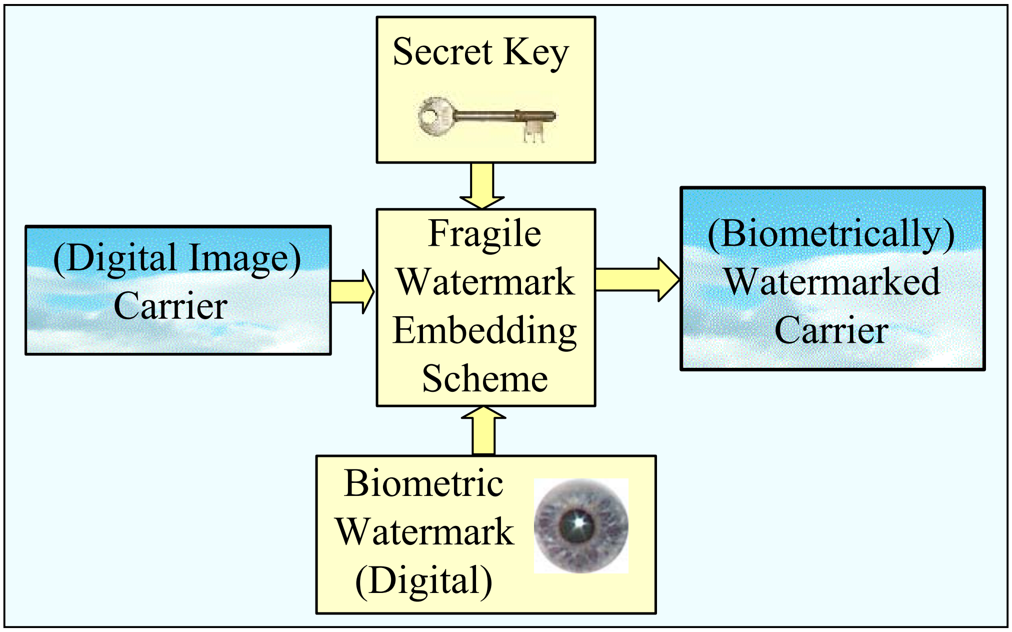

Secret Key
(Digital Image) Carrier
Fragile Watermark Embedding Scheme
(Biometrically) Watermarked Carrier
Biometric Watermark (Digital)

Figure 3.1 SDC Biometric Watermarking Scheme Block Diagram

Within the limited context of image authentication, and the lossless watermark–embedding scheme of our SDC, we can define lossless biometric watermarking as:

<u>Lossless Biometric Watermarking</u>

“***The process of losslessly embedding biometric authentication information into the cover image, without introducing visible artifacts, and subsequently utilizing the inserted information to validate the authenticity and integrity of the cover image***.”

3.6. JPEG

Introduction

The main goal of this dissertation is to prove the feasibility of our proposed concept. Therefore, we did not implement the lossless watermark embedding technique in hardware. Instead, we simulated the Watermarking Chip inside of the camera using a software implementation of a lossless data embedding technique for JPEG images described in [xxix], the paper that is the basis of this section.

In this section, we describe two watermarking techniques for JPEG files that embed a MAC (Message Authentication Code)[{MAC}] in quantized DCT coefficients in a lossless manner so that anyone who possesses the authentication key can revert to the exact copy of the original image before authentication occurred. The first technique described in section [{3.7.1}], is based on lossless compression of biased bit–streams derived from the quantized coefficients. In [{3.7.4}], we introduce another very simple technique in which one entry of the quantization table is modified to obtain a completely biased sequence of coefficients that can be readily used for lossless data embedding and authentication. A summary is given in Section [{3.7.5}].

3.6.1. JPEG Concepts

We will begin with a definition, and then a description of the JPEG compression process.

JPEG stands for Joint Photographic Experts Group, the original name of the committee that wrote the standard. JPEG is a standardized image compression algorithm.

JPEG is designed for compressing either full–color or gray–scale images consisting of natural, real world scenes. JPEG is "lossy", meaning that the decompressed image isn't the same as the uncompressed image. A photograph actually contains considerable information that the human visual system cannot detect and that can be safely discarded.

There are lossless image compression algorithms, but JPEG achieves much greater compression than is possible with lossless methods. JPEG is designed to exploit known limitations of the human visual system, notably the fact that small color changes are perceived less accurately than small changes in brightness. A useful property of JPEG is that adjusting compression parameters can vary the degree of lossiness. That allows the trade off of the file size, against the output image quality.

Since the majority of JPEG files use the Baseline Sequential compression technique as a standard, this dissertation will address JPEG compression within that context. The lossless embedding method as part of the JPEG compression is illustrated in [Figure 3.2], and a description given in section {3.7.4}.

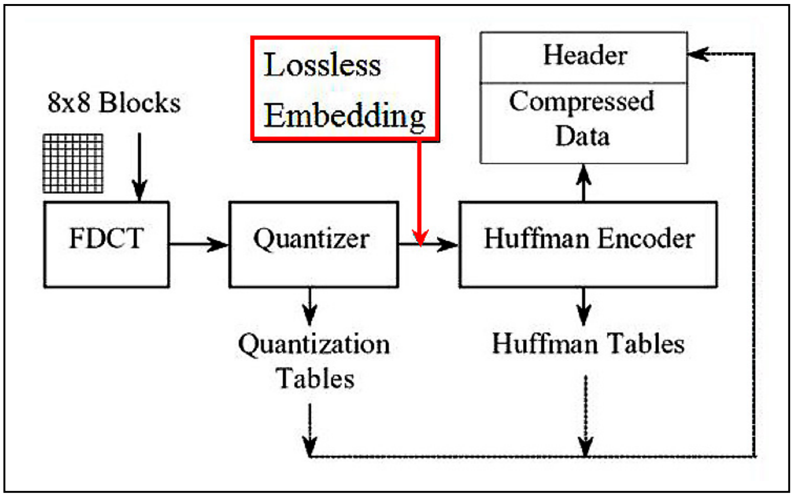


Figure 3.2 Lossless JPEG Embedding Method 2, *Q* (*i,j*)→ *Q* (*I,j*)/2

3.6.2. The JPEG Encoder Steps:

1) The linear transformation in color space: [R G B] –> [Y Cb Cr]

(R, G, B are 8–bit unsigned values) The following is the formula for the transformation:

$$\mathbf{Y = 0.2990 \times R + 0.5870 \times G + 0.114 \times B \text{ (Luminance)}}$$

$$\mathbf{Cb = -0.1687 \times R - 0.3313 \times G + 0.5 \times B + 128 \text{ (Chrominance)}}$$

$$\mathbf{Cr = 0.5 \times R - 0.4187 \times G - 0.0813 \times B + 128 \text{ (Chrominance)}}$$

2) Sampling: The JPEG standard takes into account the fact that the eye seems to be more sensitive to luminance than to color (the white–black view cells have more influence than the day view cells). On most JPEG's, luminance is taken in every pixel while the chrominance is taken as a medium value for a 2x2 block of pixels images.

3) Level shift: All 8–bit unsigned values (Y, Cb, and Cr) in the image are "level shifted": they are converted to an 8–bit signed representation, by subtracting 128 from their value.

4) The 8 × 8 Discrete Cosines Transform (DCT)

The image is divided into 8×8 blocks of pixels, then for each 8x8 block is applied the DCT transform. The 8×8 blocks are processed from left to right and from top to bottom.

5) The zig–zag reordering of the 64 DCT coefficients

After we are done with traversing in zig–zag the 8×8 matrix we have now a vector with 64 coefficients (0….63) The reason for this zig–zag traversing is that we traverse the 8×8 DCT coefficients in the order of increasing the spatial frequencies. Therefore, we get a vector sorted by the criteria of the spatial frequency: The first value in the vector (at index 0) corresponds to the lowest spatial frequency present in the image – it's called the

DC term. As we increase the index in the vector, we get values corresponding to higher frequencies (The value at index 63 corresponds to the amplitude of the highest spatial frequency present in the 8×8 block). The rest of the DCT coefficients are called AC terms.

6) Quantization

We now have a sorted vector with 64 values corresponding to the amplitudes of the 64 spatial frequencies present in the 8×8 block. These 64 values are quantized: Each value is divided by a specified 64 value vector — the quantization (Q) table. It is then rounded to the nearest integer.

7) The Zero Run Length Coding (RLC)

The quantized vector is losslessly compressed using run length encoding..

The JPEG decompression is done in a reverse order as previously listed.

3.7. Lossless Authentication Watermark for JPEG Images

Note: This section $^{\{3.7\}}$ is taken from a paper titled "Invertible Authentication Watermark for JPEG Images", Fridrich (et all).

The advantage of having the authentication code embedded in the image rather than appended is obvious. Lossless format conversion leads to a different representation of the image data but does not change the visual appearance of the image and its authenticity status. In addition, if the authentication information can be lumped and localized in the image, potentially enabling localization of modifications as well as verification of content integrity of image fragments after cropping. Another advantage of fragile watermarks is that authentication based on invisible watermarking is less obvious.

One possible drawback of authentication based on watermarking is the fact that the authenticated image will inevitably be distorted by some small amount of noise due to the authentication itself. In virtually all previously proposed authentication watermarking scheme's [xx, xxx], this distortion cannot be completely removed even when the image is deemed authentic. Although the distortion is often quite small, it may be unacceptable for medical imagery (for legal reasons) or images with a high strategic importance in certain military applications. In the case of JPEG files, the extent of the modifications must be obviously higher than for uncompressed image formats, which makes the issue of distortion more pressing.

The general paradigm of authentication based on watermarking assumes that the image can be divided into two disjoint sets: The set that determines the Message Authentication Code or MAC (hash or some other derived image features) and the set that will hold the MAC. It is important that these two sets do not interact, so that the act of embedding the MAC does not change the MAC itself. These two sets may consist of the seven most significant bits and the set of all least significant bits. In algorithms that work directly with JPEG streams, certain subset of coefficients or blocks is assigned to one set while a different set of coefficients (or blocks) holds the authentication bits [xxx] This paradigm, however, always seems to introduce some additional weakness into the algorithm and makes it vulnerable to attacks. This seems to be especially true when pairs of original and authenticated images become available or when an attacker can submit his image for authentication or for integrity verification[xxxi].

The concept of invertible (or lossless) authentication and data embedding enables us to design watermarks that do not follow the above–mentioned paradigm. The MAC will be calculated from the *whole* image and embedded, together with other data, in a lossless (invertible) manner in the image. After a positive integrity check, the extracted data can be used to completely remove the authentication watermark from the watermarked image. Even though the watermark is lossless (Erasable), one must still pay close attention to the distortion introduced to the image and try to keep it as small as possible.

3.7.1. Lossless Authentication of JPEG Files (Method 1)

Following the methodology for lossless authentication first described in [xxix], let us assume that we have an object X represented in a discrete form using bits. For example, X could be a JPEG file, a complex multimedia object, an audio file, a digitized hologram, a representation of a 3D structure, or any other digital object that needs to be authenticated. Let us further assume that it is possible to identify a subset $E \subset X$ that has a structure and that can be randomized without changing the essential properties of X or its semantic meaning. For authentication, the subset E needs to have enough structure to allow lossless compression by at least 128 bits (the hash of X). One can then authenticate X in an invertible manner by replacing the subset E with an encrypted version of its compressed form concatenated with the hash $H(X)$.

We note that if the set E is easily compressible, we do not need to work with the whole set E but only with a smaller portion of it that would give us enough space for the hash after lossless compression. We use this general authentication principle to develop lossless authentication of JPEG files.

In this chapter, we will focus only on grayscale images, although the technology can be extended to color images in a straightforward manner. JPEG compression starts with dividing the image into disjoint blocks of 8×8 pixels. For each block, the discrete cosine transform (DCT) is calculated, producing 64 DCT coefficients. Let us denote the (i,j)–th DCT coefficient of the k–th block as $d_k(i,j)$, $1 \le i, j \le 8$, $k = 1, \ldots, B$, where B is the total number of blocks in the image. In each block, all 64 coefficients are further quantized to integers $D_k(i,j)$ with a JPEG quantization matrix Q

$$D_k(i,j) = integer\_round\left(\frac{d_k(i,j)}{Q(i,j)}\right).$$

The quantized coefficients are arranged in a zig–zag manner and compressed using the Huffman coder. The resulting compressed stream together with a header forms the final JPEG file.

The largest DCT coefficients occur for the lowest frequencies (small i and j). Due to properties of typical images and due to quantization, the quantized DCT coefficients corresponding to higher frequencies have a large number of zeros or small integers, such as 1's or −1's.

For example, for the classical grayscale test image "Lenna" with 256×256 pixels, the DCT coefficient (5,5) is zero in 94.14% of all blocks. In 2.66% cases, it is a 1, and in 2.81% cases, it is equal to −1, with less than 1% of 2's and −2's.

Thus, the sequence $D_k(5,5)$ forms a subset E that is easily compressible with a simple Huffman or arithmetic coder. Furthermore, if we embed message bits (the hash) into the LSBs of the coefficients $D_k(5,5)$, we only need to compress the original LSBs of the sequence $D_k(5,5)$ instead of the whole sequence. We can further improve the efficiency of the algorithm if we define the LSB of negative integers $D_k < 0$ as $\mathrm{LSB}(D_k) = 1 - (|D_k| \bmod 2)$. Thus, LSB(−1)=LSB(−3)=0, and LSB(−2)=LSB(−4)=1, etc. Because

DCT coefficients D_k have a symmetrical distribution with zero mean, this simple measure will increase the bias between zeros and ones in the LSB bit–stream of original DCT coefficients.

DCT coefficients $D_k(i,j)$ corresponding to higher–frequencies will produce a set E with a larger bias between zeros and ones, but because the quantization factor $Q(i,j)$ is also higher for such coefficients, the distortion in each modified block will also be higher. To obtain the best results, one should use different DCT coefficients for different JPEG quality factors to minimize the overall distortion and avoid introducing easily detectable artifacts.

Below, we give a pseudo–code for lossless authentication of grayscale JPEG files.

3.7.2. Algorithm for Invertible Authentication of JPEG Files

1. Based on the JPEG quality factor, determine the set of L authentication pairs (i_1,j_1), (i_2,j_2), …, (i_L,j_L), $1\leq i_l, j_l \leq 8$, in middle frequencies.

2. Read the JPEG file and use Huffman decompressor to obtain the values of quantized DCT coefficients, $D_k(i,j)$, $1 \leq i, j \leq 8$, $k = 1, \ldots, B$, where B is the total number of blocks in the image.

3. Calculate the hash H of the Huffman decompressed stream $D_k(i,j)$.

4. Seed a PRNG with a secret key and follow a random non–intersecting walk through the set $E=\{D_1(i_1,j_1), \ldots, D_B(i_1,j_1), D_1(i_2,j_2), \ldots, D_B(i_2,j_2), \ldots, D_1(i_L,j_L), \ldots, D_B(i_L,j_L)\}$. There are $L\times B$ elements in the set E.

5. While following the random walk, run the adaptive context–free lossless arithmetic compression algorithm for the least significant bits of the coefficients from E. While compressing, check for the difference between the length of the compressed bit–

stream C and the number of processed coefficients. Once there is enough space to insert the hash H, stop running the compression algorithm. Denote the set of visited coefficients as E_1, $E_1 \subseteq E$.

6. Concatenate the compressed bit–stream C and the hash H and insert the resulting bit–stream into the least significant bits of the coefficients from E_1. Huffman compress all DCT coefficients $D_k(i,j)$ including the modified ones and store the authenticated image as a JPEG file on a disk.

3.7.3. Integrity Verification:

1. Based on the JPEG quality factor, determine the set of L authentication pairs (i_1,j_1), (i_2,j_2), …, (i_L,j_L), $1 \le i_l, j_l \le 8$.

2. Read the JPEG file and use Huffman decompressor to obtain the values of quantized DCT coefficients, $D_k(i,j)$, $1 \le i, j \le 8$, $k = 1, \ldots, B$.

3. Seed a PRNG with a secret key and follow a random non–intersecting walk through the set $E=\{D_1(i_1,j_1), \ldots, D_B(i_1,j_1), D_1(i_2,j_2), \ldots, D_B(i_2,j_2), \ldots, D_1(i_L,j_L), \ldots, D_B(i_L,j_L)\}$.

4. While following the random walk, run the context–free lossless arithmetic decompression algorithm for the least significant bits of the coefficients visited during the random walk. Once the length of the decompressed bit–stream reaches $B+|H|$ (the number of 8×8 blocks in the image plus the hash length), stop the procedure.

5. Separate the decompressed bit–stream into the LSBs of visited DCT coefficients and the extracted candidate for hash H'. Replace the LSBs of all visited coefficients with the decompressed bit–stream and calculate the hash H of the resulting stream of all quantized DCT coefficients $D_k(i,j)$, $1 \le i, j \le 8$, $k = 1, \ldots, B$.

6. Compare H' with H. If they agree, the JPEG file is authentic and the original JPEG image is obtained. If $H \neq H'$, the image is deemed non–authentic.

7. The selection of the L authentication coefficients can be adjusted according to the quality factor to minimize the distortion and other artifacts. For example, using L=3 coefficients (5,5), (4,6), and (6,3) in a random fashion will contribute to the overall security of the scheme because the statistical artifacts due to lossless authentication will be more difficult to detect.

For color JPEG images, it is advisable to use the chrominance instead of the luminance as it introduces much less visible distortion into the image. [Table 3.3] shows the distortion measured using the PSNR.. In the experiments, 128 (4,000) bits were embedded using one fixed DCT coefficient (6,6), and three color test images; P1, P2, and P3. The JPEG images in [Figure 3.3], were obtained by saving raw bitmaps as JPEGs with four different quality factors in PaintShop Pro 7.0.

Test Image	**Distortion (dB)**			
	JPEG 90%	**JPEG 85%**	**JPEG 75%**	**JPEG 50%**
P1	55.0	52.0	48.0	43.0
(512×330)	(42.0)	(38.8)	(34.6)	(28.8)
P2	50.5	47.8	44.0	37.6
(256×256)	(38.6)	(35.3)	(30.0)	(25.2)
P3	59.7	56.6	53.6	47.2
(878×586)	(46.4)	(43.3)	(39.2)	(33.4)

Table 3.2 Distortion for Lossless Embedding of 128 (4,000) Bits

Figure 3.3 Three Test Images P1, P2, and P3

3.7.4. Lossless Authentication of JPEG Files (Method 2)

The idea for the second method is quite simple. If for a given DCT coefficient (*i*,*j*) the quantization factor *Q*(*i*,*j*) is even, we could divide it by two and multiply all coefficients $D_k(i,j)$ by two without changing the visual appearance of the image at all. Because now all $D_k(i,j)$ are even, we can embed any binary message into the LSBs of $D_k(i,j)$ and this LSB embedding will be trivially invertible.

If *Q*(*i*,*j*) is odd, we replace it with *floor*(*Q*(*i*,*j*)/2) and multiply all $D_k(i,j)$ by two. In this case, we need to include a flag to the hash telling us that *Q*(*i*,*j*) was originally odd in order to be able to reconstruct the original JPEG stream during verification. Because this method uses a non–standard quantization table, the table must be included in the header of the authenticated image. Because the table entry *Q*(*i*,*j*) will not be compatible with the rest of the table, this authentication method is steganographically obvious.

Method 2 *Q(i,j)*→ 1				
Image	**QF**	**(6,6)**	**(5,4)**	**(4,2)**
P1 **512×330**	50	66.6 (54.4)	66.2 (54.6)	66.6 (54.2)
	75	66.9 (55.0)	66.5 (55.2)	67.0 (54.8)
	85	66.5 (55.0)	66.0 (55.0)	66.6 (54.8)
	90	66.9 (55.1)	66.7 (55.1)	67.0 (54.7)
P2 **256×256**	50	62.0 (53.5)	61.8 (53.1)	62.0 (52.7)
	75	62.7 (53.5)	62.2 (53.0)	62.5 (52.5)
	85	62.3 (53.5)	61.8 (53.0)	62.5 (52.6)
	90	62.5 (53.5)	62.3 (53.1)	62.2 (52.5)
P3 **878×586**	50	70.8 (56.8)	70.3 (56.4)	70.6 (56.7)
	75	71.4 (57.8)	71.4 (57.4)	71.8 (57.7)
	85	71.4 (58.0)	70.6 (57.6)	71.2 (57.9)
	90	71.7 (58.1)	71.5 (57.7)	71.6 (57.9)

Table 3.3 Method 2 *Q(i,j)*→ 1

For Method 2, $Q(I,j)\rightarrow 1$: The distortion for lossless JPEG authentication and for embedding 4000 bits in an invertible manner (numbers in parenthesis) is shown in [Table 3.4]. Three test images P1, P2, P3, and different JPEG quality factors were used.

For Method 2, $Q(i, j)\rightarrow Q(i,j)/2$: The distortion for lossless JPEG authentication and for embedding 4,000 bits in an invertible manner (numbers in parenthesis) is shown in [Table 3.4]. Three test images P1, P2, P3, and different JPEG quality factors used.

Method 2 $Q(i,j)\rightarrow Q(i,j)/2$				
Image	**QF**	**(6,6)**	**(5,4)**	**(4,2)**
P1 **512×330**	50	49.3 (34.7)	46.5 (32.3)	49.2 (33.2)
	75	54.6 (40.4)	52.0 (38.0)	52.9 (39.1)
	85	58.0 (44.4)	55.6 (42.1)	57.0 (43.1)
	90	60.4 (47.1)	58.6 (45.1)	58.7 (46.3)
P2 **256×256**	50	43.7 (31.1)	40.8 (28.2)	43.2 (27.1)
	75	50.8 (37.1)	48.1 (34.3)	49.0 (32.9)
	85	54.1 (41.2)	51.5 (38.5)	53.1 (37.2)
	90	56.0 (44.3)	54.0 (41.8)	54.7 (40.7)
P3 **878×586**	50	53.6 (39.4)	50.7 (36.4)	53.3 (38.4)
	75	59.2 (44.8)	56.6 (42.0)	57.6 (44.2)
	85	62.7 (48.4)	60.3 (45.8)	61.7 (47.5)
	90	64.9 (50.5)	63.0 (48.5)	61.7 (50.4)

Table 3.4 Method 2 $Q(i,j)\rightarrow Q(i,j)/2$

One can imagine several other possible implementations of the above idea. For example, we could replace $Q(i,j)$ with a 1 instead of its half and multiply each $D_k(i,j)$ with $Q(i,j)$. This version of the method will introduce very small distortion because the DCT coefficients used for embedding have a quantization factor equal to 1. On the other hand, the modified stream of quantized coefficients will be less compressible using the Huffman code thus worsening the overall compression ratio.

[Table 3.5] shows the file sizes before and after embedding the image hash (128 bits), using the coefficient (6,6).

Image	QF	Original Size	Method 1	Method 2 ***Q*(*i,j*)→ 1**	Method 2 ***Q*(*I,j*)→ *Q*(*i,j*)/2**
P1	**50**	19,413	19,617	19,608	19,627
	75	30,451	30,711	30,713	30,674
	85	41,865	42,138	42,119	42,065
	90	53,292	53,574	53,551	53,478
P2	**50**	7,969	8,181	8,169	8,172
	75	11,782	11,997	11,990	11,948
	85	15,818	16,025	16,019	15,986
	90	19,839	20,060	20,045	20,008
P3	**50**	52,864	53,452	53,126	53,089
	75	81,281	81,606	81,597	81,513
	85	110,441	110,721	110,748	110,692
	90	140,098	140,389	140,392	140,332

Table 3.5 File Size Comparisons – Before and After Embedding Hash

3.7.5. Summary

In this section, we reviewed two new methods for authentication watermarks for JPEG files. Both methods can be conveniently added to JPEG compressors and de–compressors. The distortion due to watermarking is very small and can be completely removed from the watermarked image if it is deemed authentic.

In the first method, the original LSBs of selected middle frequency coefficients are losslessly compressed and inserted with the hash of the whole image into the LSBs of the same coefficients.

Of the two variations of method 2, we selected the *Q*(*i,j*)→ *Q*(*i,j*)/2 technique for implementation in the SDC watermarking chip. As it gave us the high embedding capacity and lower distortion we desired.

This method is more steganographically obvious than the first one, but that is not a concern in our application.

4. Experimental (SDC)

Introduction

This section discusses the process of designing, implementing, and testing an iris image capture device that is located within the viewfinder of a standard camera. We detail the procedure of integrating a standard viewfinder into a working bench top prototype of an iris capture device. The hardware, mechanics, optics, and software of the SDC bench top prototype are detailed, and the experimental result summarized.

4.1. Capturing the Iris Image

Introduction

Goal of the SDC Iris Image Capture System is: “To capture an iris image that meets the technical specifications, and image quality[♥] of existing iris recognition systems (FAR of 1 in 1.2 million).

Capturing a well defined, high contrast image of the iris through the viewfinder was one of the major challenges we encountered in development of our SDC. The Canon ECF viewfinder system contained several key components that are required in the SDC, such as the NIR LED illumination system, NIR dichroic mirror (beam–splitter), and a viewfinder housing.

[♥] Some of the components of imaging quality are resolution, image contrast, perspective errors, geometric errors (such as distortion), and depth of field

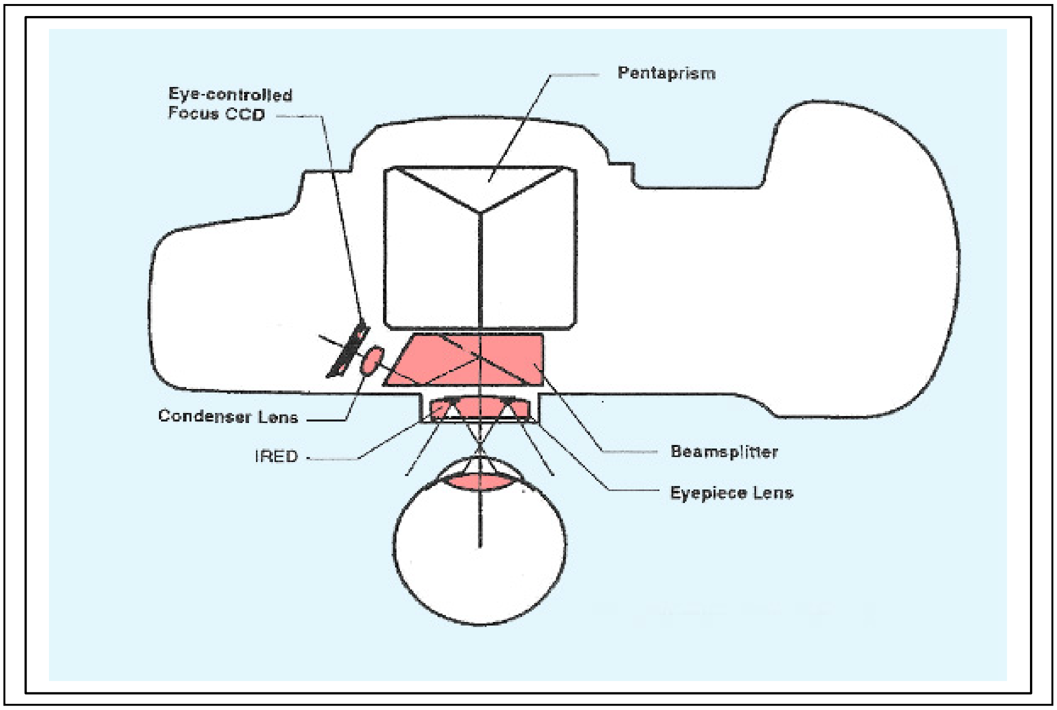


Figure 4.1Canon ECF Components

The simplified diagram of the Canon ECF system [Figure 4.1], made it appear that replacing the Canon view sensor with a Kodak CMOS image sensor would require only a moderate amount of design, implementation, and testing. Unfortunately, this proved not to be the case, since it proved to be a significantly more difficult task than first estimated.

4.2. Canon Eye Controlled Focus System

Canon first introduced their ECF system in 1999, but it did not get much attention until 2004. That is when Canon greatly increased the speed of many of their camera functions by improving the DIGIC (Digital Image Core) processor. They introduced the new DIGIC II, as an in the camera hardware based, image processor. Canon transferred the knowledge gained from the development and incorporation of Application Specific Integrated Circuits (ASIC) for use on their digital cameras to the analog 35mm cameras.

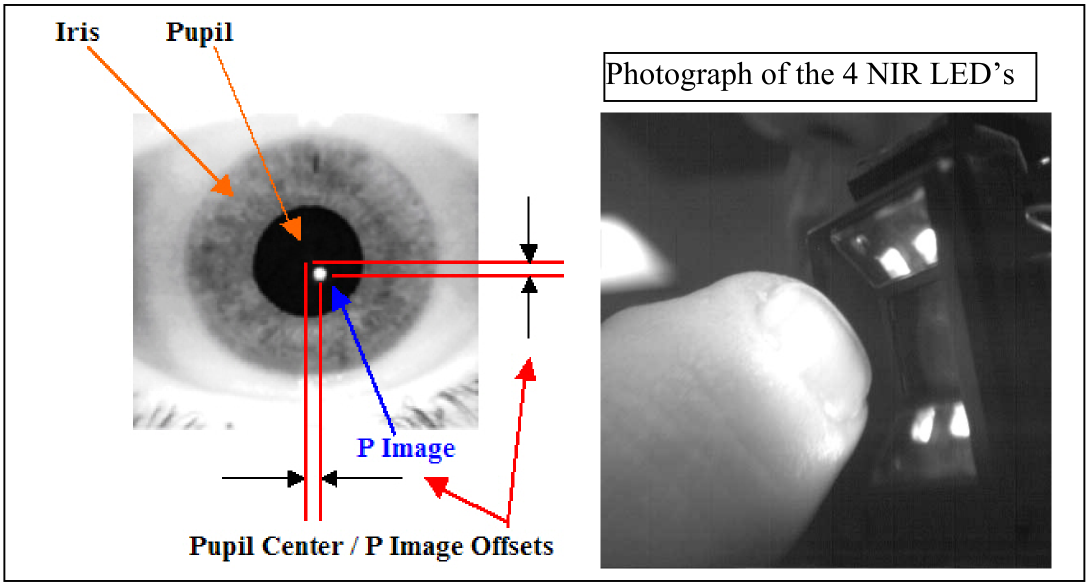


Figure 4.2 Canon EOS 3 Purkinje (P) Image, and Modified Viewfinder

4.2.1. Theory of Operation

The Canon (ECF) system operates by illuminating the eye with NIR LED’s. The reflected light from the eye forms an image on the CCD area sensor. Canon uses this reflected light to form a Purkinje (P) image and then calculate the distance to the center of the pupil from the P image, as shown in [Figure 4.2].

4.2.2. Canon EOS 3 Actual ECF Theory of Operation Testing

Since there was no technical data to be obtained on the Canon ECF system, a Canon EOS 3 camera was purchased and partially disassembled to understand its operation. The “bare” camera electronic circuitry was modified to allow the camera to function the same as if it were still assembled as shown in [Figure 4.3]. This allowed us to determine the characteristics and operation of the Canon EOS 3 ECF system.

Once we understood the theory and operation of the Canon ECF system, we felt confident that it could be adapted to meet our requirements, while realizing it would be a challenging task. The purchase of an electrical wiring schematic, and a Canon viewfinder assembly for the Canon EOS 3 camera, were helpful in the SDC hardware design phase.

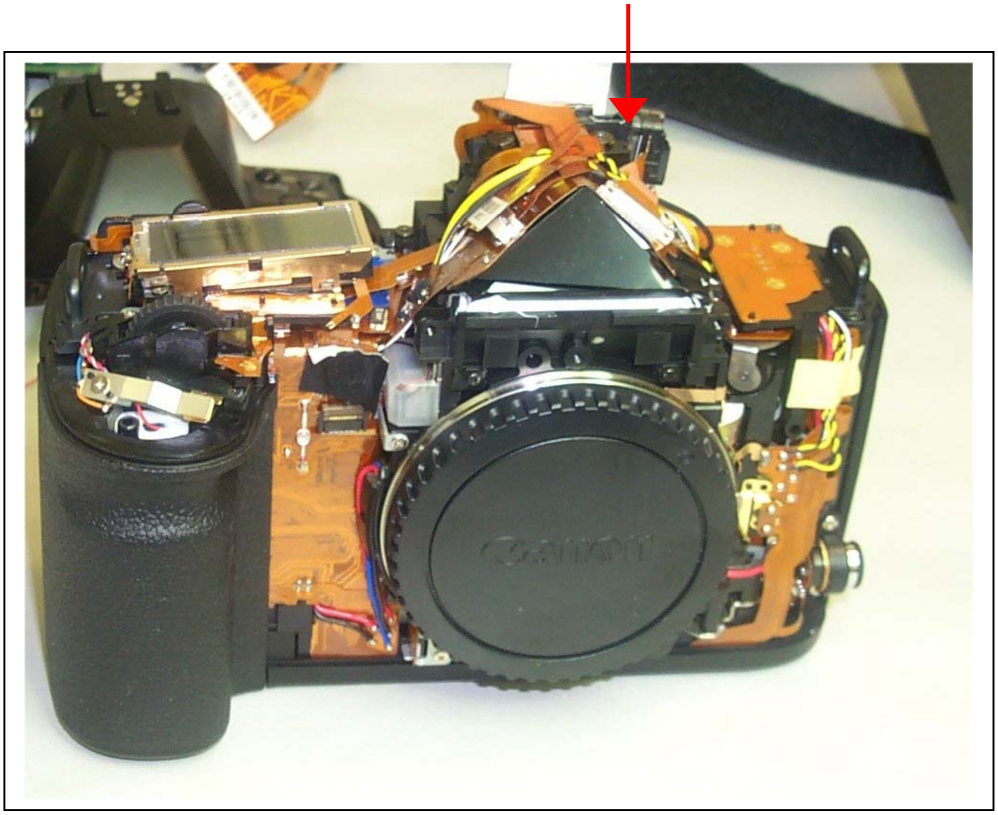


Figure 4.3 Disassembled Canon EOS 3

4.3. Iris Image Representation

After choosing the iris image as our SDC biometric identifier, we were faced with a digital format decision. Which of two possible techniques to transform the image of the iris into its representative digital form we should choose? The two possibilities were:

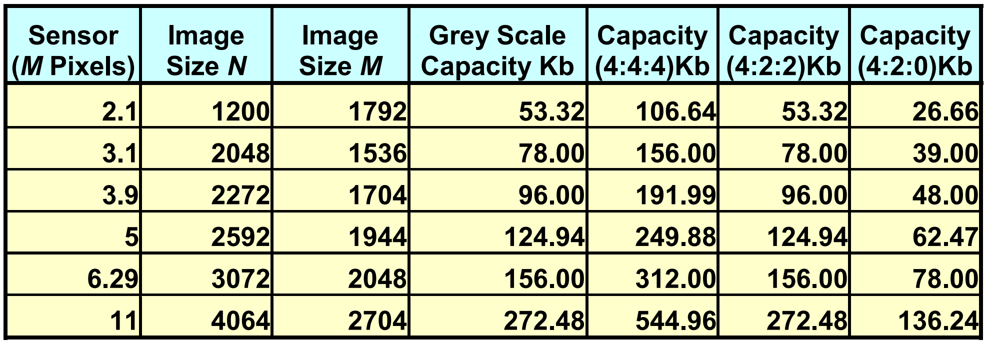
1. To losslessly embed the actual iris image [xxix].
2. losslessly a bit stream representation of the iris image [iii].

Both approaches have certain advantages and disadvantages. A Bit stream representation could embed the information in a robust manner, allowing the user to verify the image author from a processed image. The need to extract a digital fingerprint from the iris is a difficult task that involves feature extraction and processing. This may be too time consuming, expensive, and it will require additional computing power and memory. This could slow down the picture–taking process and increase the price of the camera beyond an acceptable level. If a fast and cheap iris recognition module became available in the future, this approach would certainly be the best solution.

4.4. Embedding Capacity

We decided to use the iris image and lossy compress it using JPEG to make its file size fit within the available lossless capacity of our camera images. This eliminates the need for a real time iris image signal–processing chip inside the camera. Another advantage is that it uses JPEG format, a commonly used existing technology.

In [Figure 4.4] the last four columns indicate the embedding capacity for JPEG lossless method Q(*i,j*)→ Q(*i,j*)/2, for various image sensor sizes.



Sensor (*M* Pixels)	Image Size *N*	Image Size *M*	Grey Scale Capacity Kb	Capacity (4:4:4)Kb	Capacity (4:2:2)Kb	Capacity (4:2:0)Kb
2.1	1200	1792	53.32	106.64	53.32	26.66
3.1	2048	1536	78.00	156.00	78.00	39.00
3.9	2272	1704	96.00	191.99	96.00	48.00
5	2592	1944	124.94	249.88	124.94	62.47
6.29	3072	2048	156.00	312.00	156.00	78.00
11	4064	2704	272.48	544.96	272.48	136.24

Figure 4.4 Lossless JPEG Image Capacity Calculations

The capacity for JPEG *Q(i,j)→Q(i,j)/2* (SDC embedding scheme) is calculated as is shown in [Figure 4.5].

Note: (L= Luminance Channel, C=Chrominance Channel):

Capacity Calculations for JPEG Q(*i,j*)→ Q(*i,j*)/2 Embedding

For gray scale images: Capacity=$L\times N/8\times M/8$

*(See note: 5.1) **For color images:**

If the sample ratio is L:U:V=1:1:1 (i.e. format 4:4:4):

Capacity=$2\times C\times N/8\times M/8$

If the sample ratio is L:U:V=2:1:1 (i.e. format 4:2:2):

Capacity=$2\times C\times N/8\times M/16$

If the sample ratio is L:U:V=4:1:1 (i.e. format 4:2:0):

Capacity=$2\times C\times N/16\times M/16$

*Note: 5.1: Only the two chrominance channels are used to embed data. Both L and C equal (64–51) =13, (i.e. 13 DCT coefficients in one 8 block are used for data embedding).

Figure 4.5 Capacity Calculations for JPEG *Q(i,j)→ Q(i,j)/2* Embedding

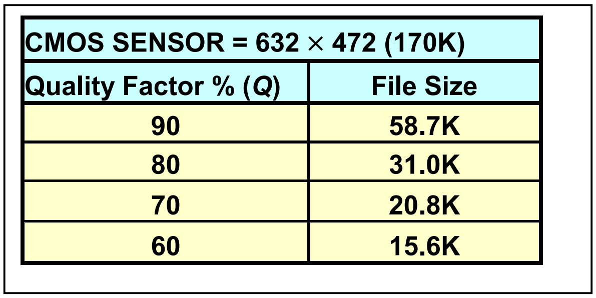
The SDC watermarking chip was simulated using software that incorporates the above capacity formulas, as well as the implementation of Fridrich's lossless watermarking embedding and extraction algorithm [xx].

4.4.1. Image Size vs. Compression Factor

In the context of iris recognition, we need to know which method of iris image file size reduction is the best fit for an iris recognition system. Should we decrease the iris image file size by downsizing the image or by decreasing the quality factor (JPEG compression ratio)?

With the continuing increase in image sensor sizes, the embedding capacity will soon be less of a factor. The largest iris image size obtained was 170Kb.

The following [Figure 4.6] illustrates the results of compressing a 170Kb gray scale iris image file, with actual $N \times M$ dimensions of 632 pixels 472 pixels (Paint Shop Pro software was used):



CMOS SENSOR = 632 × 472 (170K)	
Quality Factor % (*Q*)	File Size
90	58.7K
80	31.0K
70	20.8K
60	15.6K

Figure 4.6 Compressed Iris Image File Sizes Experiment Results

According to Daugman[xxxii], if there is a decision between image size and compression, we should always maintain the largest image size possible. That is because successful iris recognition is possible with very large compression ratios. Both iris image quality and detail are important, but without sufficient iris image details, a high quality image is of little use in an iris recognition system.

4.5. Viewfinder System Design Concept

Before beginning any lens system design, we must consider the constraints and assumptions made about the existing Canon viewfinder assembly. Canon could not furnish us with detail specific camera technical specifications. We had to solve the unknown questions by physical, electrical, and optical testing and actual measurements.

Our initial concept was to design and test a basic iris capture system consisting of a CMOS sensor and a single lens, as shown in [Figure 4.7].

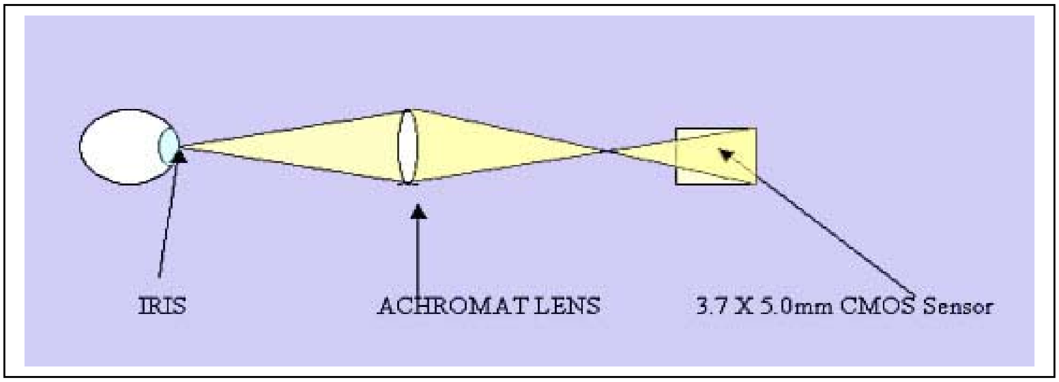


Figure 4.7 Initial Iris Capture Design Concept

Some of the unknown specifications included items, such as the NIR LED wavelength, types of glass used in the viewfinder lenses, their focal lengths and their lens spacing, and dichroic mirror specifications, as shown in [Figure 4.8]. These are but a few the initial design considerations, constraints, or assumptions we encountered in the modification of the viewfinder assembly.

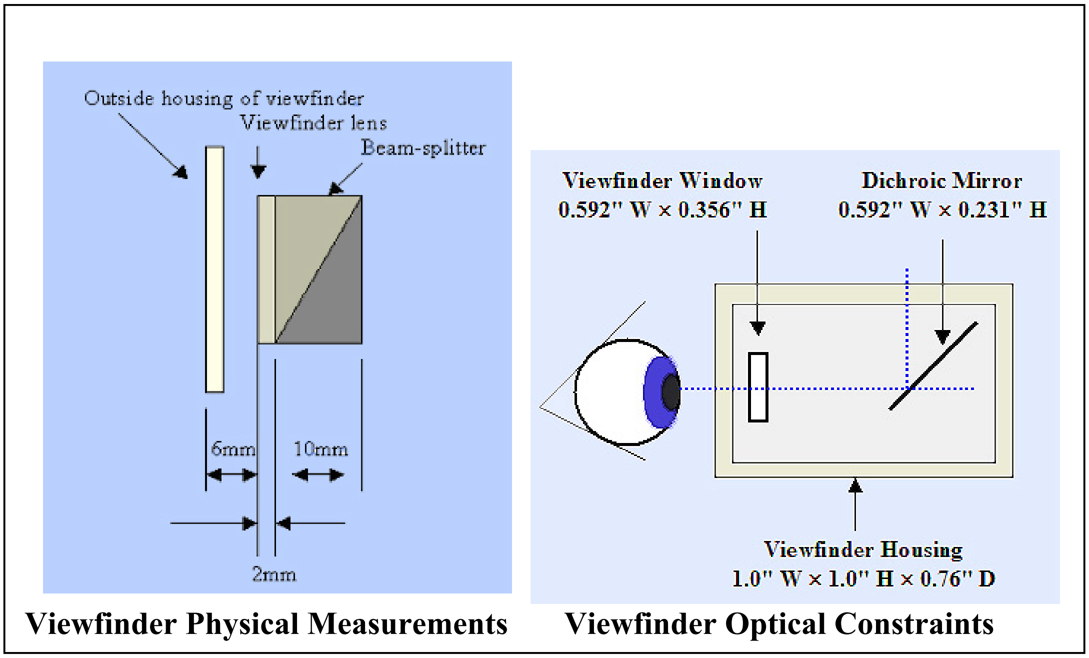


Figure 4.8 Examples of Viewfinder Design Constraints

The viewfinder was disassembled and measurements taken to design the simple lens system within the constraints of the viewfinder assembly, as shown in [Figure 4.10]

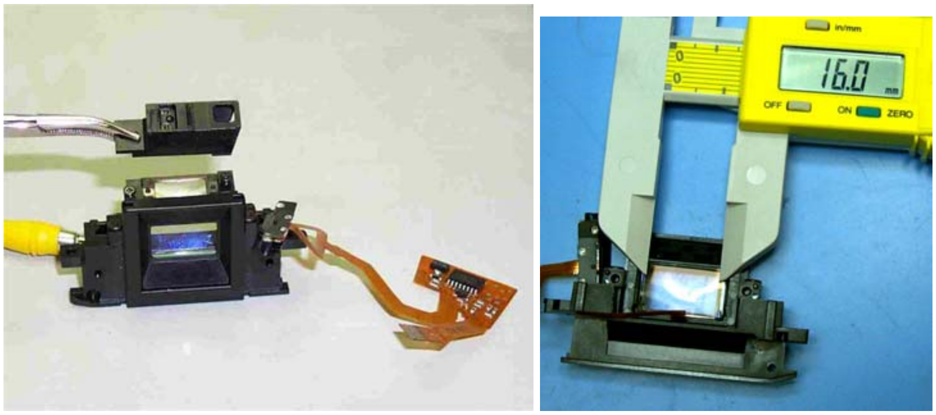


Figure 4.9 Disassembled Viewfinder

[Figure 4.10] illustrates that even a simple lens system has many factors that must be considered before we can begin the design of our SDC.

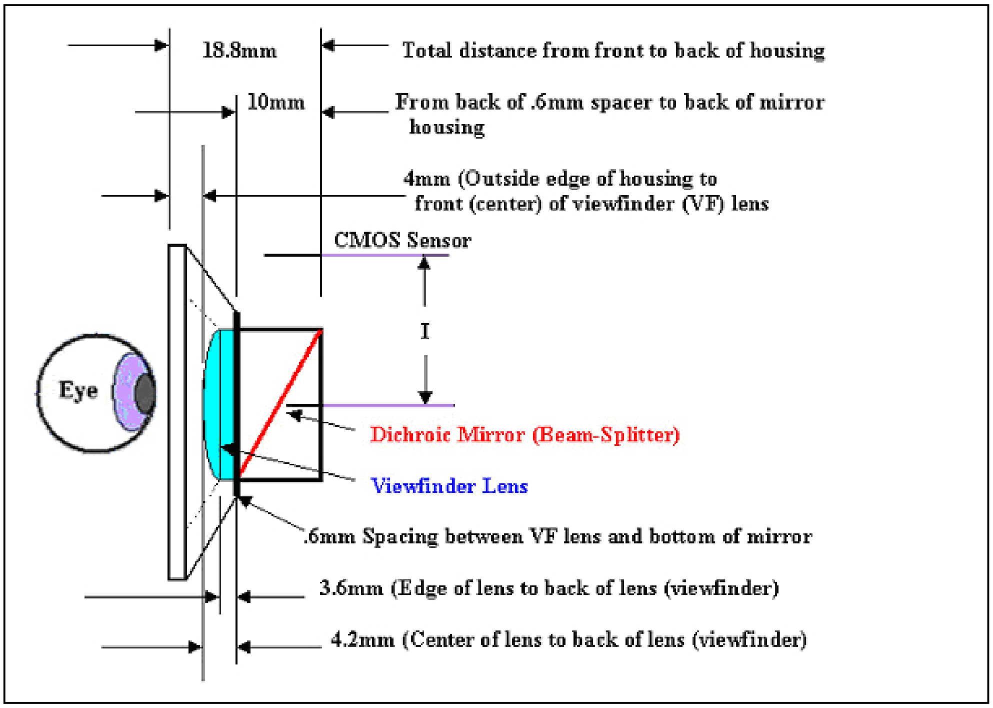
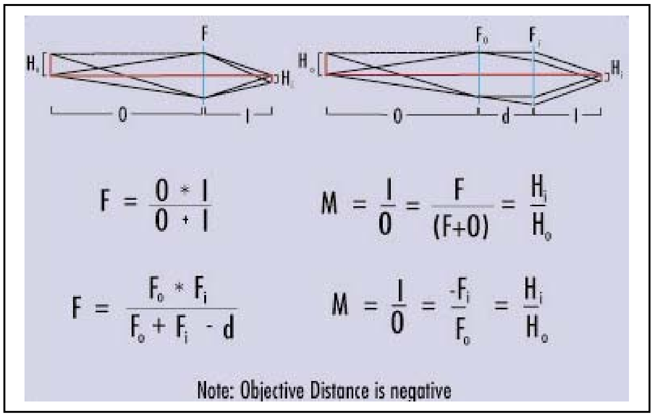

18.8mm
Total distance from front to back of housing
10mm
From back of .6mm spacer to back of mirror housing
4mm (Outside edge of housing to front (center) of viewfinder (VF) lens
CMOS Sensor
I
Eye
Dichroic Mirror (Beam-Splitter)
Viewfinder Lens
.6mm Spacing between VF lens and bottom of mirror
3.6mm (Edge of lens to back of lens (viewfinder)
4.2mm (Center of lens to back of lens (viewfinder)

Figure 4.10 Viewfinder Component Measurements

Using the formulas in [Figure 4.11], from the Edmunds Optics web site {Appendix B.}, we calculated our optical parameters.



$$F = \frac{O * I}{O + I} \qquad M = \frac{I}{O} = \frac{F}{(F+O)} = \frac{H_i}{H_o}$$

$$F = \frac{F_o * F_i}{F_o + F_i - d} \qquad M = \frac{I}{O} = \frac{-F_i}{F_o} = \frac{H_i}{H_o}$$

Note: Objective Distance is negative

Figure 4.11 Magnifications and Focal Length Formula

A description of the formula nomenclature is shown in [Figure 4.12].

H_i,H_o	Image and object height, respectively. This represents HALF of the actual full image and object size. In afocal systems, this represents half of the full beam waist.
I, O	Image and object distance measured from the lens closest to the image and object respectively.
F_i F_o	Focal length of the lens closest to the image and object, respectively.
F	Effective focal length of the entire lens system.
M	Magnification is the system's ability to produce an enlarged/reduced image or projection of an object.
D	Distance between two elements.
θ	FULL angle of the cone of light accepted or emitted by a lens system (closely linked to numerical aperture).
α_i, α_o	Angular HALF field of view in infinite conjugate systems.
TP	Throughput is the system's ability to transfer light.
F/#	F/# is the lens' ability to focus light.

Figure 4.12 Optical Formula Nomenclature

4.6. Viewfinder System Design Calculations

The SDC viewfinder is a typical Finite/Finite Conjugate lens application (Refer to Edmunds web site for detailed information {Appendix B.}). We can begin by stating our problem: We want to capture an object (iris) of 10mm in size (***H_o***) on a CMOS image sensor that has a horizontal (Iris) sensing distance (***H_i***) of 3.7mm (Max).

Let us begin by calculating the required magnification (***M***) of the system:

$M= H_i/H_o$*,** (3.7mm/10.0mm = –0.37). This gives us an overall system magnification of (M***) **= –0.37** (All objective distances are negative). Clarifying the above formula in [Figure 4.11] is as follows:

$F = O \times I / O + I$

$F = F_o \times F_i / F_o + F_i - d$

(Note: All objective distances are negative).

$M = I / O = F / (F + O) = H_i / H_o$

$M = I / O = -F_i / F_o = H_i / H_o$

Since we now know ***M*** = –0.37, our viewfinder housing size is our major limiting design restriction. We simply measured the maximum distance in the viewfinder to current ECF sensor to be approximately 50mm

Substituting in the above formula, $F = O \times I / O + I$, for ***I***=50mm, and ***O***=10mm, gives us a first lens choice of 8.3mm Effective Focal Length (EFL).

We now had enough information to design and build a simple iris capture system, and begin the initial proof of concept experiments. The major issue remaining was iris illumination. The Canon viewfinder was equipped with eight NIR LED's that were properly positioned to reflect off of the pupil of the eye, which is perfect for our SDC application. The only unknown was their operational wavelength. We checked with many sources in the electronic/optics industry and were not able to identify the part by number or physical characteristics. Based on recommendations from the manufactures, we estimated their wavelength to be over 900nm. This proved to be correct, however, subsequent testing indicated that that was not the ideal wavelength for maximum iris image contrast.

Edmunds Optics have a large off the shelf selection of Near IR Achromat doublet lenses that are designed to provide the smallest spot size possible for polychromatic light between 700 and 1100nm. [Figure 4.13]

Three NIR Achromat doublet lenses with focal lengths of 5mm, 10mm, and 15mm, with D=3mm were ordered for the initial iris image capture system experimentation.

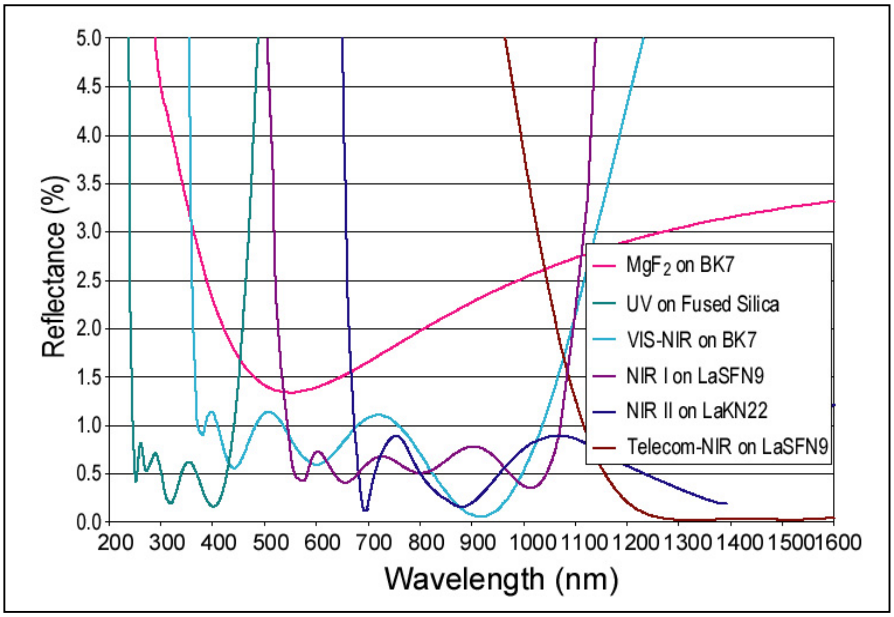


Figure 4.13 Near IR Achromat Doublet Lens Reflection Curve Chart

4.7. Focal Length Experimentation Results

The image was encouraging, but they all had magnification issues:

The F=5 mm, lens had too much magnification and very poor image quality, as shown in [Figure 4.14], the first iris image that we captured..

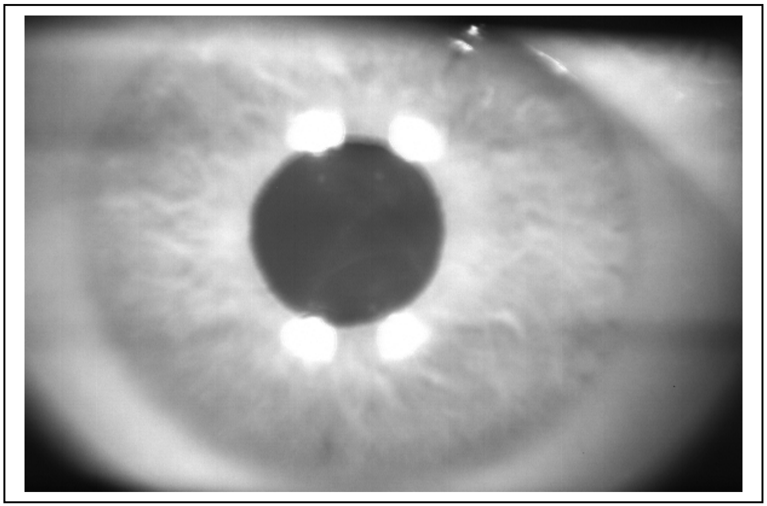


Figure 4.14 First Single Lens Iris Image Captured (F=5mm, D=3mm)

Neither the 10mm and 15mm lenses had enough magnification, but appeared to have better image details.

4.8. A Multiple Lens Design Solution

We now faced a more complex lens design problem. We needed a multiple lens system to meet our previously mentioned iris image constraints and requirements, yet still obtain the image quality needed for an accurate iris recognition system.

We could no longer use a few basic formulas to design such a system. A multiple lens system has a much higher degree of complexity as well as the possibility of addition optical defects. An optical engineer, (Ms. R. Bussjager) with the USAF Research Lab at Rome, NY, was willing to use their sophisticated lens design software to assist us with the multiple lens design.

The simulation software, trace results indicate, why our initial iris images had magnification, and quality issues as shown if [Figure 4.15].

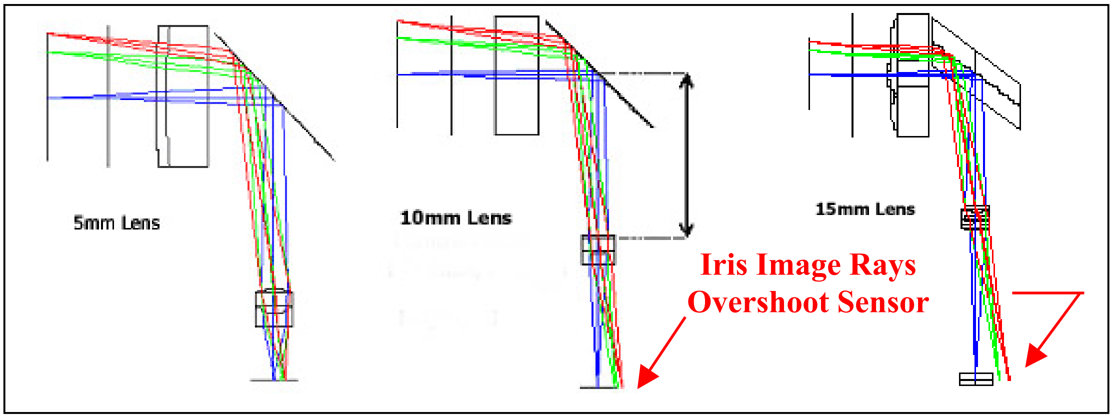


Figure 4.15 Ray Trace Results for Single Element Lens Designs

In [Figure 4.15], the 5mm lens is shown with too much magnification (–0.19), however the rays from the object plane (Iris image) do not overshoot the image sensor.

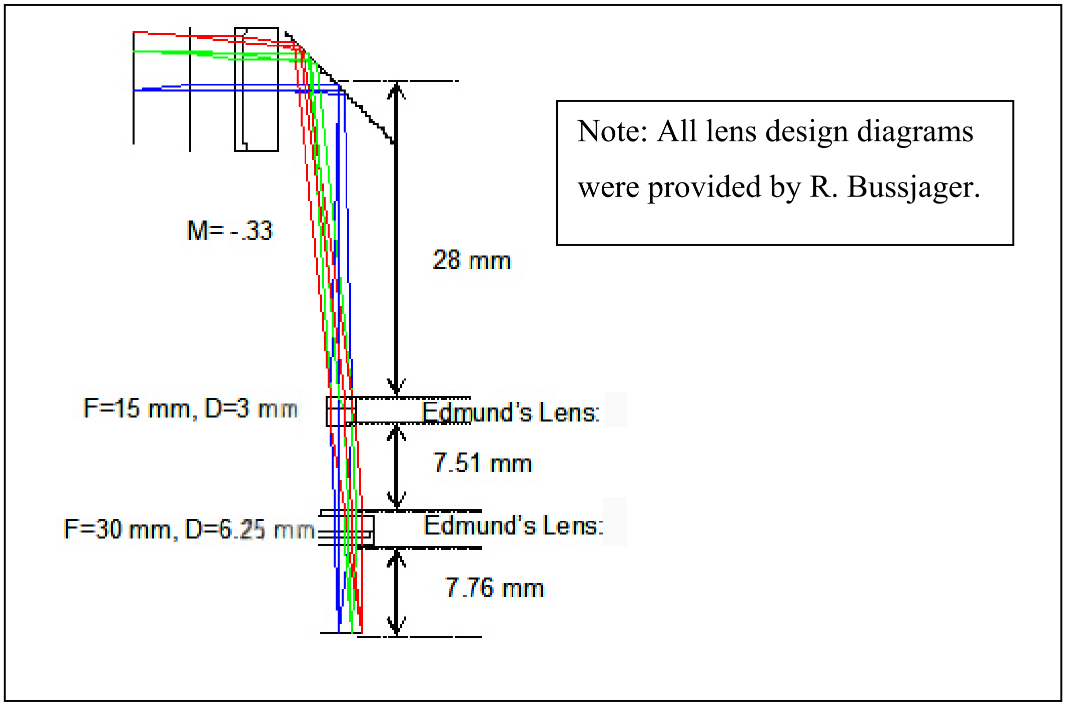
The 10mm lens does not provide enough magnification (–0.478), and one can notice that rays from the top of the iris overshoot the area on the CMOS image sensor.

The 15mm lens performance is as expected, showing an even larger CMOS image sensor overshoot.

Figure 4.16 Obtaining the Solution

Software simulations were performed on alternative single lens types for use in the viewfinder, but no good choices were found. When using only a single lens, the ray tracing analysis showed large effects of aberrations, such as spherical, coma, and field curvature.

Additional software simulations were performed using a two–lens system in conjunction with the viewfinder lens. For our "proof of concept" purposes, an intense lens combination design is not necessary. The diagram in [Figure 4.17] shows a first cut analysis for a dual lens system.



Note: All lens design diagrams were provided by R. Bussjager.

Figure 4.17 Ray Trace Diagram for a Dual Lens System

To keep the costs down, we desired to use our existing Edmund lenses with F=15 mm and D=3mm, combined with an Edmund lens with F=30 mm and D=6.25mm. The ray trace diagram illustrated in [Figure 4.17] indicated that this combination would yield a magnification of –0.33. This is slightly less than the necessary –0.37 magnification needed, so the image of a 10 mm iris should just under-fill the camera sensor, leaving room for a slightly larger iris.

If our calculations and the necessary assumptions were correct, there should be no vignetting of the iris image. With this encouraging information, we decided to implement the lens design as our initial test system.

In conclusion, after significant design modifications, additional simulations, and optical parts fabrication, we implemented the recommend initial multi–element lens combination with the following specifications:

- Lens 1 is a NIR Achromat doublet lens: F=30 mm and D=6.25 mm lens.
- Lens 2 is a NIR Achromat doublet lens: F=15mm and D=6.25mm lens.
- The type of glass used in both of these lenses is BK7 and SF5.

The initial results of the above lens design were encouraging, as shown in the first dual lens iris image obtained through the SDC viewfinder [Figure 4.18].

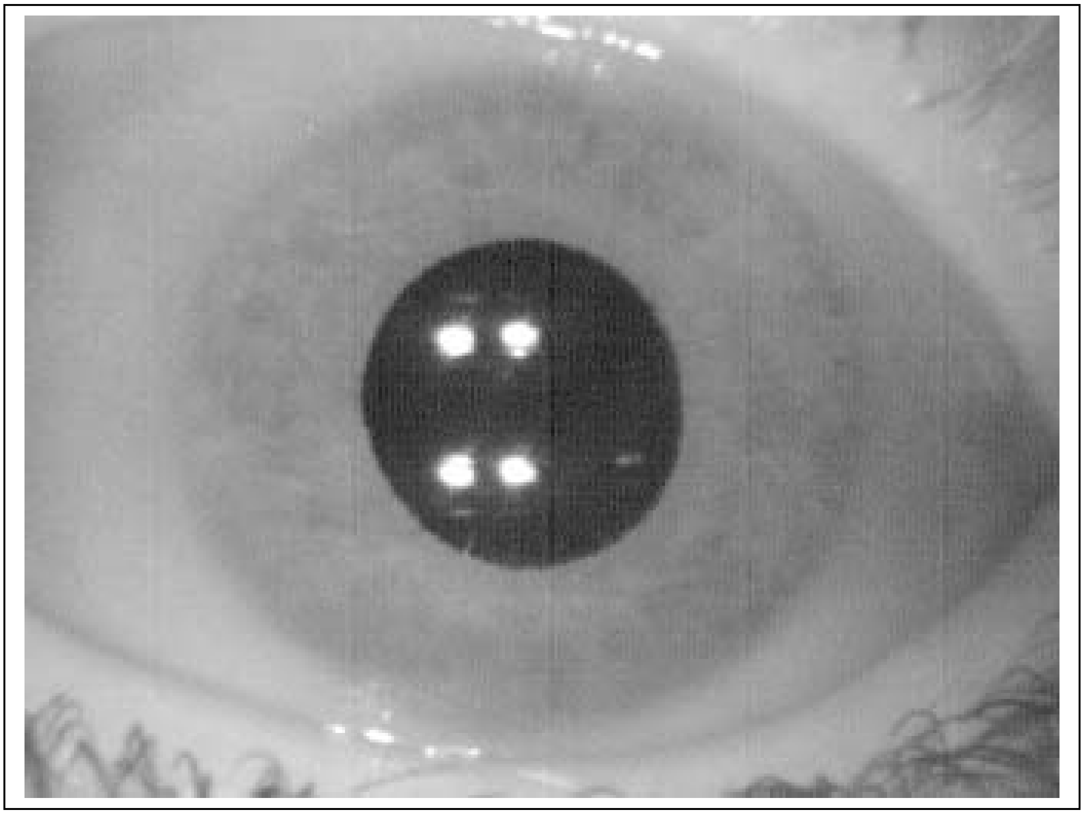


Figure 4.18 First Dual Lens Image (F=15mm, D=6.25mm & F=30mm, D=6.25mm)

The following is an illustrated parts diagram of the components that were replaced in the Canon viewfinder [Figure 4.19] to construct the SDC Iris Image Capture viewfinder [Figure 4.20]:

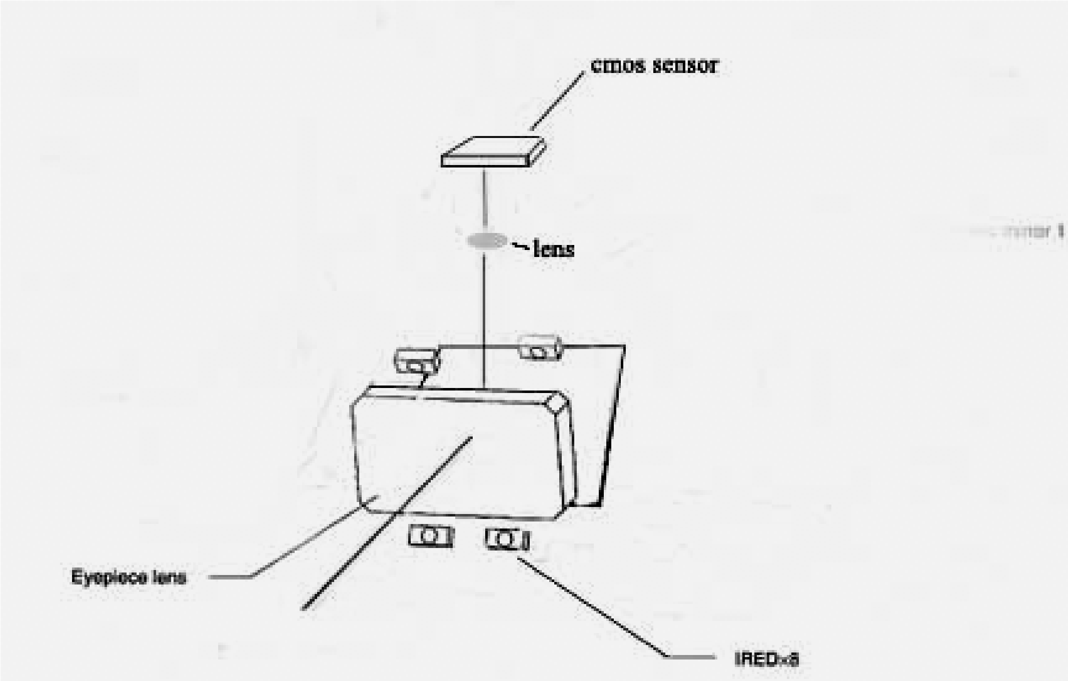


Figure 4.19 SDC Modified Viewfinder

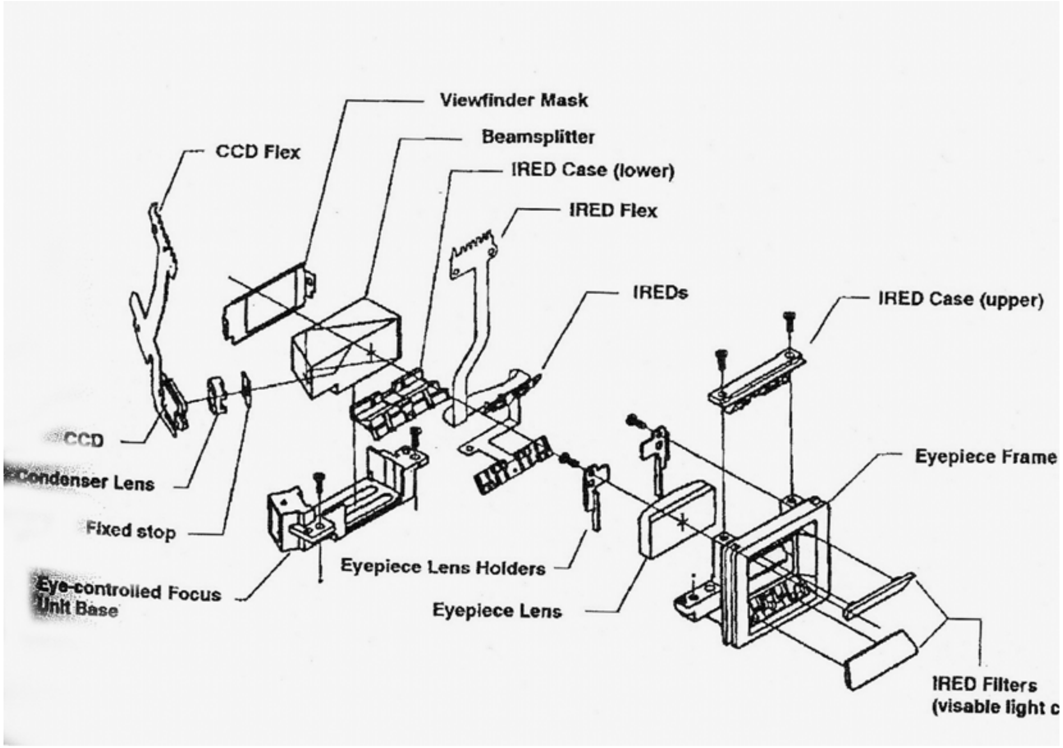
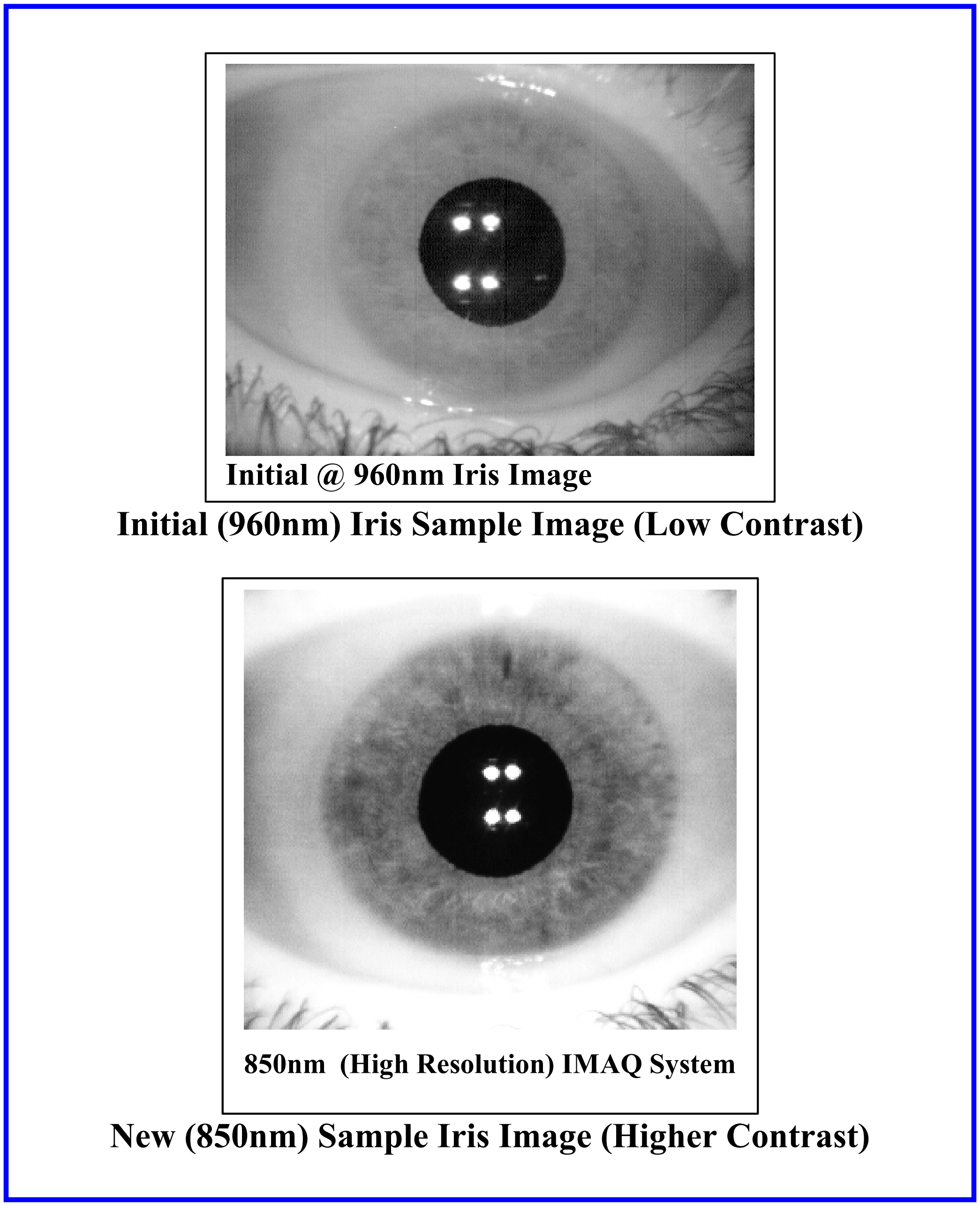


Figure 4.20 Viewfinder Assembly Parts

4.9. The NIR LED Experiments

After our initial meeting, and several e–mail follow up questions with Professor Daugman, he indicated that the initial iris images that we sent to him for image compression questions, were of too low a contrast level to achieve reliable iris identification.



Initial @ 960nm Iris Image

Initial (960nm) Iris Sample Image (Low Contrast)

850nm (High Resolution) IMAQ System

New (850nm) Sample Iris Image (Higher Contrast)

Figure 4.21 NIR LED 960nm and 850nm Wavelength Comparisons

Daugman suspected the low contrast was a result of the high wavelength (Approximately 960nm) of the NIR LED’s in the original Canon viewfinder. Additional experiments were performed with lower wavelength (850nm) NIR LED’s, and the results sent to Daugman for his evaluation. The new 850nm NIR LED iris images were now deemed to be of high enough quality for use in an iris recognition system [Figure 4.21].

4.10. A New Prototype Viewfinder Assembly

Although the new prototype viewfinder assembly was quickly constructed to be functional, but not esthetically pleasing [Figure 4.22], the resulting images it obtained exceeded our expectations. The holes for the NIR LED’s were made with a hot soldering iron, and then we centered the 4 new (850nm) NIR LED’s to the top and bottom of a spare viewfinder housing. We held them in an approximate alignment by melting the viewfinder housing plastic around them.

Adding two additional NIR LED’s, to the left and right side of the viewfinder, they would provide a more uniform illumination for the iris images. We plan to perform additional testing of even lower wavelength NIR LED’s.

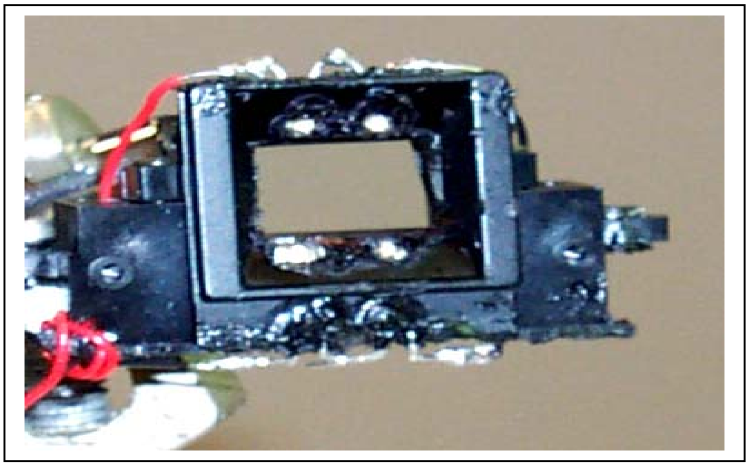
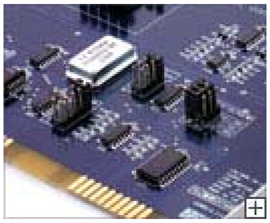


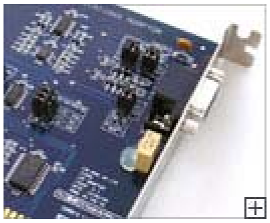
Figure 4.22 New Prototype Viewfinder Assembly

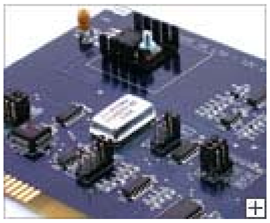
5. SDC System Specifications

5.1. Hardware

Calibre UK I2C–Bus Adapter
ICA90–5V I2C– Bus Comms Adapter for ISA–Bus PCs







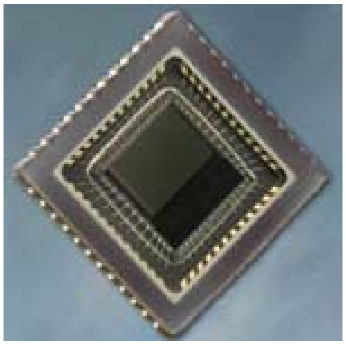
The Original I2C Communications Adapter to Plug into your PC

Features:

- **True I2C Compatibility**
- **Operates as Master, Slave or Real–Time Monitor**
- **Fits any PC, AT or ISA/EISA bus computer**
- **Software Function Libraries & User Manual included**
- **I2C Configuration through software**
- **Link selection of I/O Addresses**
- **I2C Connection via 9 way D socket**
- **5V Power output to run external devices under test**
- **WINI2C/ICA application software available as an optional extra**

5.2. Kodak—CMOS Image Sensor

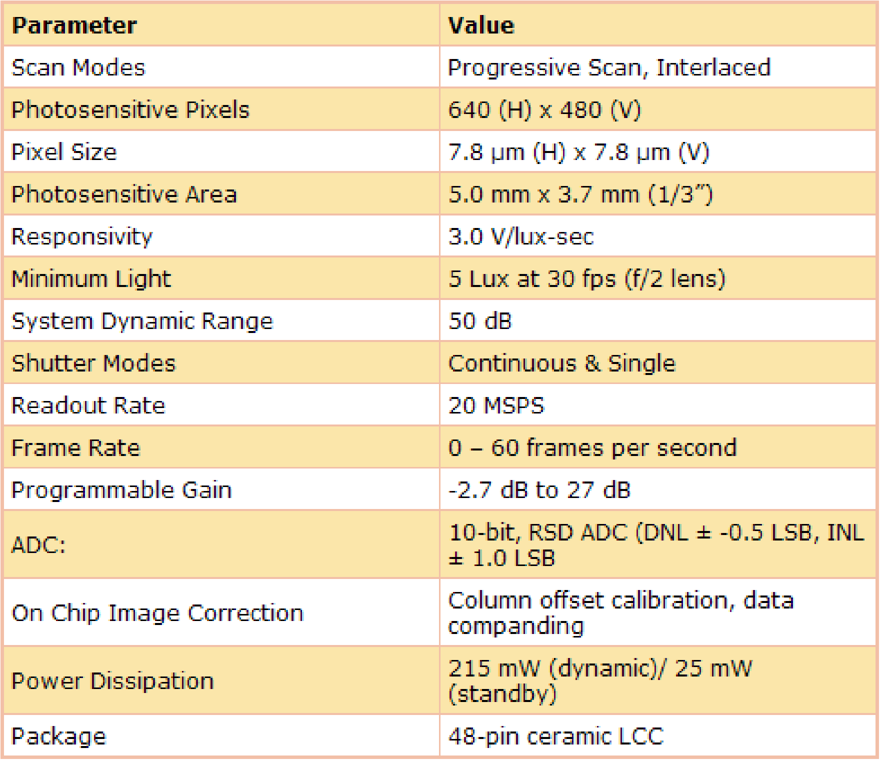
KAC—0311 Is a High–Performance CMOS Image Sensor



The sensor comprises a 1/3” format pixel array with 640×480 active elements. The 7.8 µm square pixels use a pinned photodiode architecture for high sensitivity and low noise for superior image quality. Incorporating the functionality of a complete analog image acquisition, digitizer and digital signal processing system on a single chip, the on–chip processing pipeline includes Correlated Double Sampling (CDS), a Frame Rate Clamp (FRC), Digitally Programmable Amplifiers (DPGAs) for real time color gain correction, and a

10–bit Analog to Digital Converter (ADC) that converts the analog data to a 10–bit digital word stream. This fully differential analog signal–processing pipeline provides improved noise immunity, signal to noise ratio, and system dynamic range.

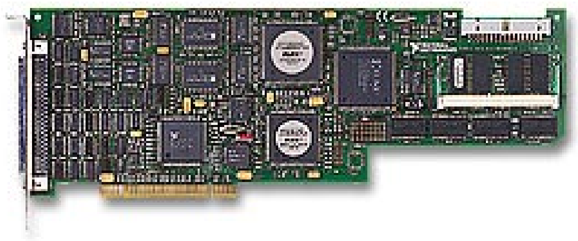
Kodak KAC—0311 Image Sensor Specifications



Parameter	Value
Scan Modes	Progressive Scan, Interlaced
Photosensitive Pixels	640 (H) x 480 (V)
Pixel Size	7.8 µm (H) x 7.8 µm (V)
Photosensitive Area	5.0 mm x 3.7 mm (1/3")
Responsivity	3.0 V/lux-sec
Minimum Light	5 Lux at 30 fps (f/2 lens)
System Dynamic Range	50 dB
Shutter Modes	Continuous & Single
Readout Rate	20 MSPS
Frame Rate	0 – 60 frames per second
Programmable Gain	-2.7 dB to 27 dB
ADC:	10-bit, RSD ADC (DNL ± -0.5 LSB, INL ± 1.0 LSB
On Chip Image Correction	Column offset calibration, data companding
Power Dissipation	215 mW (dynamic)/ 25 mW (standby)
Package	48-pin ceramic LCC

5.3. National Instruments

NI PCI—1424 (Frame Grabber)



The National Instruments PCI–1424 digital image acquisition boards are designed to acquire color and grayscale images and to control digital cameras. Designed for high–speed, large–image, high–resolution digital image capture, they can capture into onboard memory up to 32 bits of data at a clock speed of 50 MHz, for a total acquisition rate of 200 Mbytes/s.

Features:

- **Image acquisition boards for digital area and line–scan cameras**
- **Easy–to–use camera configuration utility**
- **50 MHz pixel clock rate with up to 200 Mbytes/s acquisition**
- **RS–422/TTL or LVDS/TTL camera compatibility**
- **4 external triggers (digital I/O lines)**
- **Full 8, 10, 12, 14, 16, 24 and 32–bit resolution (grayscale or color)**

5.4. SDC System Hardware Configuration

The current iris capture system consists of the hardware components shown in [Figure 5.1].

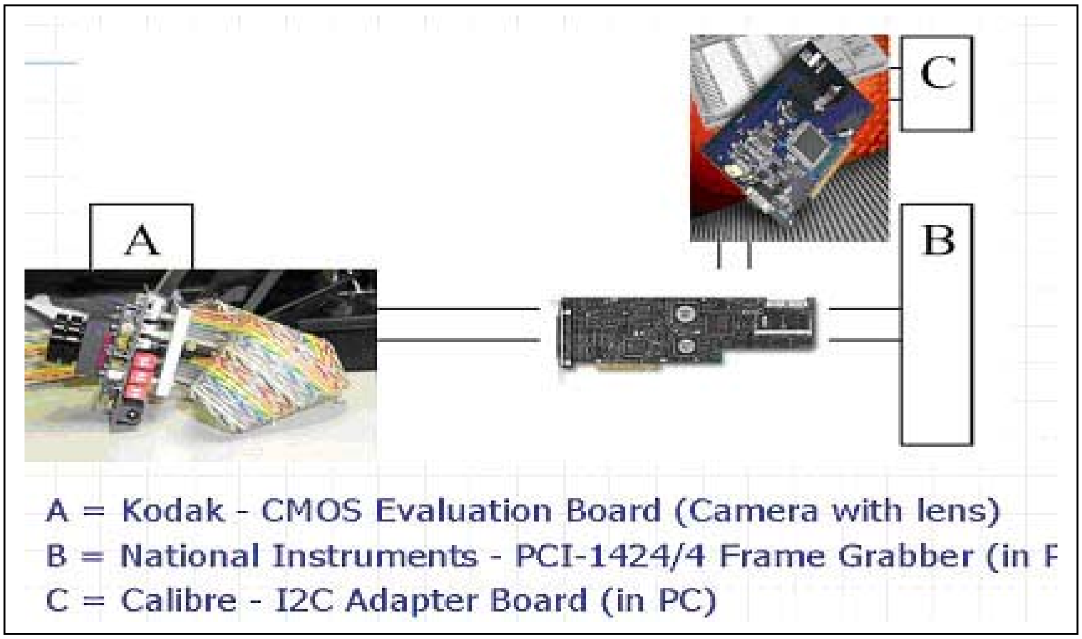

C
A
B
A = Kodak - CMOS Evaluation Board (Camera with lens)
B = National Instruments - PCI-1424/4 Frame Grabber (in F
C = Calibre - I2C Adapter Board (in PC)

Figure 5.1 Basic Iris Capture System Hardware Configuration

[Figure 5.2] is a picture of the Kodak Mother/Daughter Evaluation Image Sensor Board with a two–element lens and f–stop control (F=15mm & F=30mm). The iris capture system was focused using an artificial eye to aid in the lens spacing experiments.

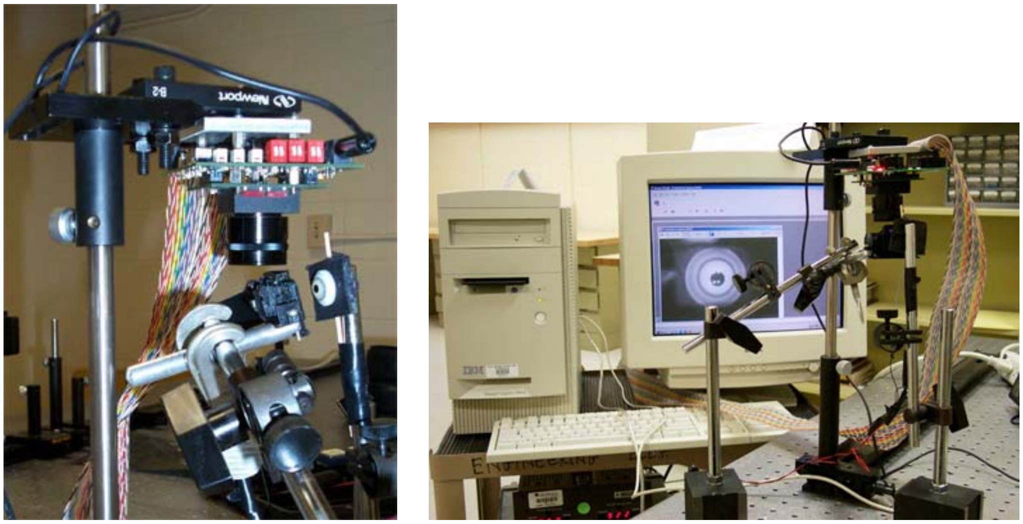


Figure 5.2 SDC Bench–Top Prototype

5.5. Software

The following is a list of the software used on this SDC project:

- Microsoft Windows 2000 Professional
- Microsoft Office 2000 Professional
- Adobe Photoshop 7.0
- Paint Shop Pro 7.0
- Kodak Sensor Solutions
- National Instrument IMAQ
- Secure Stego

6. Conclusions and Future Work

6.1. Conclusions

In this dissertation we proposed a new concept of a Secure Digital Camera that offers a solution to the evidentiary problems associated with verifying the integrity, establishing the origin, and authenticating a digital image. The SDC will not only eliminate the current evidentiary problems, but will simplify and strengthen the chain of custody procedures for digital images.

We explained how the camera (SDC) losslessly embeds the photographer's iris image, the hash of the scene image, date, time, and other camera/picture information into the image of the scene. The embedding process depends on a secret camera key. The embedded data can be later extracted to verify the image integrity, establish the image origin and verify the image authenticity (identify the camera and the photographer). The watermark is not only invisible but also completely removable (lossless). The use of the iris as a biometric reliably verifies the photographer. Secure cryptographic hashes (e.g., MD5) guarantee that no modifications can be made to the image that cannot be detected.

Our Secure Digital Camera (SDC) provides a scientifically verifiable authentication method for its digital images by proving that they:

- Were not tampered with **(Integrity)**.
- Were taken by this particular camera **(Origin)**
- Were taken by a specific person **(Authorship)**.

6.2. Future Work

We would like to automate as much of the manual SDC process as possible. By taking it from a bench–top prototype to a system that resembles a camera would make a more impressive demonstration for my supporters as well as potential manufacturers.

We would also like to make additional experiment with various wavelength NIR LED's, in addition to the many small issues, such as the effects larger diameter lenses have on image quality.

If current trends in electronic miniaturization and increased computing power continue, it would be interesting to actually implement the watermarking chip in hardware. The SDC watermarking chip seems feasible with current technology.

To implement a real time "in the camera" hardware iris recognition system would be challenging with current technology, but foreseeable in the near future.

GLOSSARY

Achromat Lens (Achromatic Doublet): Two lenses, usually one of crown glass and one flint glass, cemented together. Corrects for chromatic and spherical aberrations. Can also be air spaced.

Acquire: A method of locating images on peripheral devices (such as scanners and digital cameras) and adding them to your hard disk drive; taking screen captures.

Additive Colors: When the colors red, green, and blue are added together, they become white.

Advanced Encryption Standard (AES): New encryption standard to be approved by NIST for next 20–30 years use.

Afocal: Refers to an optical system that does not form an image. A telescope with an eyepiece is afocal, because it does not form an image of its own (the optics of the eye must be used as a "re–imager"). Literally, "without a focal length"; an optical system with its object and image point at infinity.

Algorithm: A set of mathematical rules (logic) used in the processes of encryption and decryption. The specific process in a computer program used to solve a particular problem.

Alias: An assumed name (dummy) mail address that routes the message to all real addresses associated with the assumed name.

Aliasing: An effect caused by sampling an image (or signal) at too low a rate. It makes rapid change (high texture) areas of an image appear as a slow change in the sample image. Once aliasing occurs, there is no way to accurately reproduce the original image from the sampled image.

American National Standards Institute (ANSI): Represents the U.S. in the ISO. A private standards body that develops industry standards through various Accredited Standards Committees (ASC). The X9 committee focuses on security standards for the financial services industry.

American Standard Code for Information Interchange (ASCII): The standard code, using a coded character set consisting of 7–bit coded characters (8 bits including parity check), used for information.

Analog to Digital Converter (A/D Converter): A device that converts analog information (a photograph or video frame) into a series of numbers that a computer can store and manipulate.

Analog: Analog transmitted data can be represented electronically by a continuous wave form signal. Examples of analog items are traditional photographed images and phonograph albums.

Anonymity: Of unknown or undeclared origin or authorship, concealing an entity's identification.

Application: Information processing according to a set of instructions to accomplish a given end. Application examples: electronic mail, credit card verification, electronic data interchange, database search, LAN/WAN connections, remote computing services, distributed data processing, information gateways, international access services, frame–relay services, ATM networks, electronic publishing, electronic trading, authentication, database SQL, etc.

Archive: Long–term storage of data or images. Archiving is generally accomplished on some form of magnetic media; such as disk or tape, or optical media; such as Writable CD.

Artifact: An undesirable degradation of an electronic image. Usually occurs during the electronic capture, manipulation, or output of an image.

Aspect Ratio: The ratio of horizontal to vertical dimensions of an image (35mm slide frame is 3:2, TV 4:3, HDTV 16:9, 4X5 film 5:4).

Asymmetric Key Encryption: A separate but integrated user key pair comprised of one public key and one private key. Each key is one way meaning that key used to encrypt information and can not be used to decrypt information.

Asymmetric: Do not need the same key on each end of a communication link.

Asynchronous: Character–by–character or cell–by–cell or data unit–by–data unit transfer. Data units from any one source need not be periodically spaced within the overall data unit stream.

Audit: The process of examining the history of a transaction to find out what happened. An operational audit can be an examination of ongoing activities to determine what is happening.

Authentication Key Exchange Protocol (AKEP): Key transport based on symmetric encryption allowing two parties to end up with a shared secret key, secure against passive adversaries.

Authentication: The process of ensuring the identity of the connecting user or participants exchanging electronic data. Makes sure the person or server at either end of a connection is who they/it claim to be and not an impostor.

Authorization: To convey official sanction, access or legal power to an entity.

Bayer Filter: A color filtering array for RGB colors. It uses subunits of four pixels. There are two green sites for every red or blue site. This is because cone cells in the human eye are more sensitive to green light than other colors.

Beamsplitter: An optical component that divides light (i.e., a beam) into two separate portions (beams). When the component is inserted into an optical path at a specific angle (typically 45 degrees), a portion of the beam will be diverted (reflected) in a different direction (typically 90 degrees from the input beam). A beamsplitter will reflect a portion of the incident energy, absorb a relatively small portion, and transmit the remaining energy. It is essentially an optical window (clear glass or film) that has a metallic or dielectric coating on one side with specific reflecting and transmitting characteristics. A plate beamsplitter is the most common type and has a thin glass substrate. They are also known as "mirror–type" beamsplitters due to the reflective nature of the coatings used.

Bi–Level: An image containing only two colors–a background color and a foreground color, for example, a black and white image.

Binary Digit: One of the two symbols (0 & 1) commonly used to represent numerical entries in the binary number system.

Binary: A mathematical base 2, which uses only 1's and 0's to represent numbers. 0001 represents 1 decimal, 0010 represents 2 decimal and so forth. Binary numbers are used indirectly to refer to color depth, as in 24–bit or 8–bit color.

Biometric Accuracy: There are two different methods to rate biometric accuracy: False–Acceptance Rate (FAR) and False–Rejection Rate (FRR). These measures can vary significantly, depending on how you adjust the sensitivity of the mechanism that matches the biometric. For example, you can require a tighter match between the measurements of hand geometry and the user's template (increase the sensitivity). This will probably decrease the false–acceptance rate, but at the same time can increase the false–rejection rate.

Birthday Attack: A particular class of attack against one–way functions. The technique does not allow the function to be completely inverted, but it does find two inputs that correspond to the same output. It does this by computing the function value of many different randomly generated inputs and searching for identical pairs in the set of outputs. If some function, when supplied with a random input, returns one of k equally–likely values, then by repeatedly evaluating the function for different inputs, we expect to obtain the same output after about $1.2k^{1/2}$ trials. If we are trying to find a collision, then by the birthday paradox we would expect that after trying $1.2(2^{n/2})$ possible input values we would have some collision.

Bit: A binary digit, a fundamental digital quantity representing either 1 or 0, on or off.

Bitmap (BMP): An image made up of dots, or pixels. Refers to a raster image, in which the image consists of rows or pixels rather than vector coordinates.

Block Cipher: Block algorithms–algorithms that operate on plain text in blocks (strings or groups) of bits.

Block: A string or group of bits that a block algorithm operates on; typical values are 40, 50, 64, 128, 512, 1024, …

Brightness: The value of a pixel in an electronic image, representing its lightness value from black to white. Usually defined as brightness levels ranging in value from 0 (black) to 255 (white).

Brute Force Cracking: The process of trying to recover a crypto key by trying all reasonable possibilities.

Byte: A set of Bits that represent a single character. Usually there are 8 Bits in a Byte, sometimes more, depending on how the measurement is being made (See also Bit).

Cache: A high–speed storage mechanism. The ACD Systems database is a cache.

Calibration: The act of adjusting the color of one device relative to another, such as a monitor to a printer, or a scanner to a film recorder. Or, it may be the process of adjusting the color of one device to some established standard.

Caption: A comment or description added to an image. Captions above images are called headers, while captions below are referred to as footers.

Capture: The method of taking a biometric sample from the end user.

CBR–Constant Bit Rate: A type of encoding that maintains a fixed bit rate throughout a file, so that data is sent in a steady stream.

Central Processing Unit (CPU): The chip in a computer where virtually all information is processed.

Certificate (Digital Certificate): An electronic document attached to a public key by a trusted third party which provides proof that the public key belongs to a legitimate owner and has not been compromised.

Certificate Authority: A trusted third party who issues, revokes, and manages certificates, validating that public keys are not compromised and that they belong to the correct owners.

Certification Authority (CA): A trusted third party that creates certificates that essentially notarize the association of an identified entity with a public key and other attributes.

Certification: The process of testing a biometric system to ensure that it meets certain performance criteria. Systems that meet the testing criteria are said to have passed and are certified by the testing organization. The administrative act of approving a computer system, component, product, etc., for use in a particular application; endorsement of information by a trusted entity.

Chain of Custody: A process used to maintain and document the chronological history of the evidence. (Documents should include name or initials of the individual collecting the evidence, each person or entity subsequently having custody of it, dates the items were collected or transferred, agency and case number, victim’s or suspect’s name, and a brief description of the item).

Channel: A piece of information stored with an image. True color images, for example, have three channels–red, green and blue.

Charge–Coupled Device Sensor (CCD): The device in a digital camera or scanner that converts light into proportional (analog) electrical current.

Checksum: A numeric value used to verify the integrity of a block of data. The value is computed suing a checksum procedure. A crypto checksum incorporates secret information in the checksum procedure so that it can’t be reproduced by third parties that don’t know the secret information.

Chi–Square Test: Is a statistical test which computes the probability that there is no significant difference between the expected frequency of an occurrence with the observed frequency of that occurrence. Any statistical hypothesis test in which the test statistic has a chi–square distribution if the null hypothesis is true.

Chroma: The color of an image element (pixel) made up of saturation and hue values, but separate from the luminance value.

Chrominance: The color portion of an image comprised of a mixture of hue and saturation or the combination of three primary colors, such as red, green, and blue.

Cipher System (Cryptosystem): The hardware and/or software making up the means to encrypt and decrypt plaintext. Encryption and decryption can be implemented in software on the host computer or in hardware devices placed on the links between computers.

Ciphertext: Data that has been encrypted with a cipher, as opposed to plaintext.

Claim of Identity: When a biometric sample is submitted to a biometric system to verify a claimed identity.

Claimant: A person who is submitting a biometric sample for verification or identification whilst claiming a legitimate or false identity.

Closed–Set Identification: When an unidentified end–user is known to be enrolled in the biometric system. Opposite of 'Open–Set Identification'.

C–MOUNT: The first standard for CCTV lens screw mounting. It is defined with the thread of 1"(2.54mm) in diameter and 32 threads/inch, and the back flange–to–sensor (CCD, CMOS, JFET) distance of 17.526mm (0.69"). The C–mount description applies to both lenses and cameras. C–mount lenses can be both, C–mount and CS–mount cameras, only in the later case an adaptor is required.

Color Correction: The process of correcting or enhancing the color of an image.

Color Matching/Management System (CMS): Software meant to ensure color matching and calibration between video or computer monitors and any form of hard copy output.

Compact Disc (CD): The abbreviation for, a laser–encoded plastic medium designed to store a large amount of data. A variety of CD formats are available for use by computers.

Compact Disc Drive: A drive mechanism for recording or playing CDs. The most common types are CD–ROM, and WORM (Write Once, Read Many).

Compact Disc, Read–Only Memory (CD–ROM): A non–rewritable CD used by a computer as a storage medium for data. Once written, the data on a CD–ROM can only be read, not changed or altered.

Compact Flash: A type of storage card used in digital cameras to store images captured by the camera. The Compact Flash can then be erased when the images have been transferred or are no longer needed, and reused.

Complementary Metal Oxide Semiconductor (CMOS) Sensor: A type of imaging sensor that capture images taken by digital cameras. A type of semiconductor technology that uses both NMOS (negative polarity) and PMOS (positive polarity) circuits. Since only one of the circuit types is on at any given time, CMOS chips require less power than chips using just one type of transistor sensors (I.e. CCD).

Composite Image: An image made up of two or more sub–images stored separately in a file.

Compression: The reduction of data to reduce file size for storage. Compression can be "lossy" (such as JPEG) or "lossless" (such as TIFF LZW). Greater reduction is possible with lossy compression than with lossless schemes.

Conjugate Distances: Is the distance from the lens to the object/source (object distance) and the distance from the lens to the detector/image (image distance). For example, in an infinite conjugate design one of these distances approaches infinity.

Conjugate Sizes: is the size of the object/source (object size) and the size of the detector/image plane (image size). For example, in systems with an infinite conjugate, the conjugate "size" can be expressed as an angle.

Continuous Tone: An image where brightness appears consistent and uninterrupted. Each pixel in a continuous tone image file uses at least one byte each for its red, green, and blue values which permits 256 density levels per color or more than 16 million mixture colors.

Contouring: A visual effect in an image as a result of low brightness resolution which appears as bands of sharp, distinct, brightness change–similar to banding.

Contrast: The relationship between the lightest and the darkest areas of an image. An image with deep shadows, bright highlights and few steps between the two is said to be high contrast. An image with weak shadows, dim highlights and many smooth steps between the two is said to be low contrast. High contrast implies dark black and bright white content. Medium contrast implies a good spread from black to white. Low contrast implies a small spread of values from black to white.

Convert: To change a file from one format to another.

Cropping tool: The cropping tool simulates the traditional method for cropping–that is, trimming photographs.

Cryptanalysis: The art or science of transferring ciphertext into plaintext without initial knowledge of the key used to encrypt the plaintext.

Cryptography: (From Greek *kryptós*, "hidden", and *gráphein*, "to write") Traditionally, the study of means of converting information from its normal, comprehensible form into an incomprehensible format, rendering it unreadable without secret knowledge – the art of *encryption* The branch of cryptographic science which deals with the means, methods, and apparatus of converting plain text messages into secret messages and visa versa.

CS–MOUNT: A newer standard for lens mounting. It uses the same physical thread as the C–mount, but the back flange–to–CCD distance is reduced to 12.5mm in order to have the lenses made smaller, more compact and less expensive. CS–mount lenses can only be used on CS–mount cameras.

Cyan, Magenta, Yellow, Black (CMYK): One of several color encoding system used by printers for combining primary colors to produce a full–color image. In CMYK, colors are expressed by the "subtractive primaries" (cyan, magenta, yellow) and black. Black is called "K" or keyline since black, keylined text appears on this layer.

Cyclic Redundancy Check (CRC): An algorithm used to detect data transmission errors.

Data Compression: The process of converting data from one format to another format that is physically smaller in size. The same logical information is stored using less physical information.

Data Encryption: The process of changing data from an intelligible format to an unintelligible, but decryptable, format.

Data Integrity: Ensuring information has not been altered by unauthorized or unknown means.

Data key: A crypto key that encrypts data as opposed to a key that encrypts other keys.

Data: Digital information or just information, depending on the context.

Database: An electronic filing system for data–a collection of data organized by fields, records, and files such that a computer program can select desired pieces of the collection. The generic name for anything input to, output from, or stored in a computer. All data must be in digital format.

Decode: To read (or view) a file format. That section of a code book in which the code groups are in alphabetical order, or other systematic order. To convert by codebook, not cryptanalysis.

Decrypt: To convert cipher text into the original plain text using a cryptosystem. Decryption (and encryption) can be implemented in software on computers or in hardware devices placed on the links between computers.

Default Setting: A preset parameter in computer programs which will be used unless changed by the operator.

Degrees of Freedom: The number of statistically independent features in biometric data.

Densitometer: A tool used to measure the amount of light that is reflected or transmitted by an object.

Depth of Field (DOF): The difference between the closest and farthest distances an object may be shifted before an unacceptable blur is observed at a particular resolution. The DOF is also the amount of object movement (into and out of focus) allowable while maintaining an acceptable focus. With a greater the depth of field, more of the scene near to far is in focus. Lens aperture and scene lighting will greatly influence the DOF.

DES–Data Encryption Standard : National Bureau of Standards. A mathematical algorithm for encrypting (enciphering) and decrypting (deciphering) binary coded information. Encrypting data converts it to an unintelligible form called cipher. Decrypting cipher converts the data back to its original form called plaintext.

Dichroic Coating: A filter or mirror coating that transmits or reflects light depending on wavelength rather than upon polarization.

Dichromatic Mirror, (Chromatic Beam–Splitter): A semi–transparent band pass filter that reflects light shorter than a specific wavelength and transmits light that is longer than that wavelength.

Dictionary Attack: A calculated, brute–force attack to reveal a password by trying obvious combinations.

Digital Camera (Still): A camera that records images in digital form on a CCD (Charged Coupled Device), CMOS (Complimentary Metal Oxide Semiconductor) or JFET (Junction Field Effect Transistors) sensor, and stores it on an electronic media such as a flash card. It might also be called a film–less camera. All image sensors use an electronic chip which is comprised of a grid of phototransistors to sense the light intensities across the plane of focus of the camera lens. Unlike traditional analog cameras that record infinitely variable intensities of light, digital cameras record discrete numbers for storage.

Digital Camera Software: Software intended to support users of digital cameras to manage their digital photos.

Digital Certificate: A signed electronic document (digital ID) that notarizes and binds the connection between a public key and its legitimate owner. Similar to how a drivers license or passport proves the owner's identify. Its purpose is to prevent unauthorized impersonation and provide confidence in public keys.

Digital Image: An image composed of pixels.

Digital Scripts: These are coding commands that turn complex digital imaging tasks into menu options that can be executed with a few steps. Scripts can be written for capture, post–processing, and application–related tasks.

Digital Signature Algorithm (DSA): A public–key digital signature. The DSA algorithm was proposed by NIST for use in DSS. DSA was developed by the US National Security Agency (NSA) to generate a digital signature for the authentication of electronic documents. It can not be used for encryption, only for digital signatures.

Digital Signature Standard (DDS): A NIST proposed standard (FIPS) for digital standards using DSA.

Digital Signature: Information that is encrypted with an entity private key and is appended to a message to assure the recipient of the authenticity and integrity of the message. The digital signature proves that the message was signed by the entity that owns, or has access to, the private key or shared secret symmetric key. Computed by using a set of rules and a set of parameters such that the identity of the signer and the integrity of the data can be verified. An electronic identification of a person or thing created by using a public–key algorithm, intended to verify to a recipient the integrity of the data and the identity of the sender of the data.

Digital Time Stamp: A digital signature, which includes a time and date thereby certifying that the content was signed at a given time. Time Stamps may be made of the data being certified it or on a sufficiently strong hash value of that data.

Digital vs. Analog Information: Digital data is represented by discrete values. Analog information is represented by ranges of values, and is therefore less precise.

Digital Zoom: Allows the user to zoom in on a subject beyond the range provided by the optical zoom lens. Digital zooming crops the center of the digital picture and resizes the new cropped picture to the size of the selected resolution. Because digital zoom removes image information it is preferable not to use it when taking photos meant for enlarged printing.

Digital: A system or device in which information is stored or manipulated by on/off impulses, so that each piece of information has an exact or repeatable value (code).

Digitalization: The process of converting analog information into digital format for use by a computer.

Disc: Term used to describe optical storage media (video disc, laser disc, compact disc), as opposed to magnetic storage systems.

Discrete Cosine Transform (DCT): Is used in the JPEG and MPEG image compression algorithms. Refers to the coding methodology used to reduce the number of bits for actual data compression. DCT transforms a block of pixel intensities into a block of frequency transform coefficients. The transform is then applied to new blocks until the entire image is transformed.

Disk: Term used to describe magnetic storage media (floppy disk, diskette, hard disk), as opposed to optical storage systems.

Dots Per Inch (DPI): The measurement of resolution of a printer or video monitor based on dot density. For example, most laser printers have a resolution of 300 dpi, most monitors 72 dpi, most PostScript images 1200 to 2450 dpi. The measurement can also relate to pixels in an input file, or line screen dots (halftone screen) in a prepress output film. The more dots per inch, the higher the resolution, and therefore quality of the image. For example, 92 DPI means 92 dots horizontally and 92 dots vertically, which equals 8464 dots per square inch.

Download: The transfer of files or other information from one piece of computer equipment to another.

Drag and Drop: The process of moving text, graphics, or photos to different locations in a document.

Driver: A software utility designed to tell a computer how to operate an external device. For instance, to operate a printer or a scanner, a computer will need a specific driver.

Due Diligence: Such a measure of prudence, activity, or assiduity, as is properly to be expected from, and ordinarily exercised by, a reasonable and prudent person under the particular circumstances; not measured by any absolute standard, but depending on the relative facts of the special case.

Effective ISO: Analogous to film speed. A higher number means the camera sensor needs less light to make a good exposure. Higher numbers can help in situations of low light where flash may not be effective, e.g., large interiors in low light.

Encapsulated PostScript (EPS): A graphic file format developed by Aldus, Adobe, and Altsys to allow exchange of PostScript graphic files (image information) between professional graphics programs.

Encipher: To convert a plaintext into unintelligible language or signals by means of cipher system.

Encode: To write (or save) a file format.

Encrypt (Encode, Encipher): To convert plain text into unintelligible forms by means of a cipher system (crypto system). Encryption (and decryption) can be implemented in software on computers or in hardware–the set of mathematical logic that actually converts (encrypts/decrypts) data.

Encryption: A method of converting data into a secure format. You need a password or key to read an encrypted file. The act of converting electronic data into a code so that people will be unable to read it. A key or a password is used to decrypt (decode) the encrypted biometric data.

End User: A person who interacts with a biometric system to enroll or have his/her identity checked.

Enrollee (Biometric): A person who has a biometric reference template on file.

Enrolment (Biometric): The process of collecting biometric samples from a person and the subsequent preparation and storage of biometric reference templates representing that person's identity.

Entropy: A mathematical measurement of the amount of uncertainty or randomness.

Equal Error Rate: The error rate occurring when the decision threshold of a system is set so that the proportion of false rejections will be approximately equal to the proportion of false acceptances.

Exchangeable Image File (EXIF): A standard for storing information, primarily with images that use JPEG compression. Most digital cameras create EXIF information. EXIF information is embedded in the image file.

Export: The process of transporting data from one computer, program, type of file format, or device to another.

Extended Graphics Array (XGA): Is a high–resolution graphics standard introduced by IBM. It provides resolutions of 640 by 480 or 1024 by 768 pixels, and supports simultaneous colors (65 thousand colors). In addition, XGA allows monitors to be non–interlaced.

Extraction (Biometric): The process of converting a captured biometric sample into biometric data so that it can be compared to a reference template.

f-number (Photography): (focal ratio) Is the diameter of the camera lens diaphragm aperture in terms of the effective focal length of the lens. For example, f/11 represents a diaphragm aperture diameter that is one-eleventh of the focal length (or the focal length is 11 times the aperture). Some times called F-stop(see F-stop).

Failure to Acquire Rate: The frequency of a failure to acquire.

Failure to Acquire: Failure of a biometric system to capture and extract biometric data (comparison data).

Failure to Enrol Rate: The proportion of the population of end–users failing to complete enrolment.

Failure to Enrol: Failure of the biometric system to form a proper enrolment template for an end–user. The failure may be due to failure to capture the biometric sample or failure to extract template data (of sufficient quality).

False Acceptance Rate (FAR): The probability that a biometric system will incorrectly identify an individual or will fail to reject an impostor. The rate given normally assumes passive impostor attempts.

False Acceptance: When a biometric system incorrectly identifies an individual or incorrectly verifies an impostor against a claimed identity.

False Match Rate: Alternative to 'False Acceptance Rate'. Used to avoid confusion in applications that reject the claimant if their biometric data matches that of an enrollee. In such applications, the concepts of acceptance and rejection are reversed, thus reversing the meaning of 'False Acceptance' and 'False Rejection'. See also 'False Non–Match Rate'.

False Non–Match Rate: Alternative to 'False Rejection Rate'. Used to avoid confusion in applications that reject the claimant if their biometric data matches that of an enrollee. In such applications, the concepts of acceptance and rejection are reversed, thus reversing the meaning of 'False Acceptance' and 'False Rejection'. See also 'False Match Rate'.

False Rejection Rate (FRR): The FRR is the frequency that an authorized person is rejected access. FRR is generally thought of as a comfort criteria, because a false rejection is most of all annoying. FRR is a non–stationary statistical quantity which does not only show a strong personal correlation, it can even be determined for each individual feature (called personal FRR).

False Rejection: When a biometric system fails to identify an enrollee or fails to verify the legitimate claimed identity of an enrollee.

Federal Information Processing Standards (FIPS): A set of standards developed by the National Institute of Standards and Technology for use by the US government. FIPS use algorithms and cryptographic functions to ensure security. FIPS 140–1 is one of the more commonly known FIPS standards that specifies security requirements related to the design and implementation of cryptographic modules.

Field Of View (FOV): The horizontal or vertical scene size at a given length from the camera to the subject.

Field Test/Field Trial: A trial of a biometric application in 'real world' as opposed to laboratory conditions.

File Format: A method for encoding information in a file. Each type of file has a different file format that specifies how the information is organized. Some common image file formats include JPEG, TIFF, BMP, and GIF.

File Server: A computer that serves as the storage component of a local area network and permits users to share its hard disks, storage space, files, etc.

File Transfer: The electrical transfer of a file from one storage or processing unit to another.

File: In database terms, a collection of records stored and handled as a single unit. For example, an executive telephone book may be a file consisting of the names, titles and telephone numbers of the executives listed in the company's human resources database.

Filtering (Biometric): The process of classifying biometric data according to information that is unrelated to the biometric data itself. This may involve filtering by sex, age, hair color or other distinguishing factors, and including this information in an end user's database record. This term is particularly used in conjunction with Automated Fingerprint Identification Systems.

Filters/Optical: A glass or acetate sheet usually placed over a camera lens for changing characteristics of an image or to create a special effect.

Filters/Software: A program that accepts data as input, transforms it in some manner, and then outputs the transformed data. For example, a software program such as PhotoShop can take blurry pictures and filter them to produce a clearer picture.

Firewire: A very fast external bus that supports data transfer rates of up to 400 Mbps. Firewire was developed by Apple and falls under the IEEE 1394 standard. Other companies follow the IEEE 1394 but have names such as Lynx and I–link.

Fixed Focus Lens: Worry free camera operation. Fixed–focus lenses have their focus distance set to obtain good results within a wide range of distances without the need for a focus mechanism.

Flash Memory: A type of memory chip (Solid–State Removable Storage) that can retain data after the system has been turned off. Its advantage is that digital cameras with flash memory can have batteries go "dead" and yet retain image data. Abbreviated SSD, a solid state disk is a high–performance that contains no moving parts.

Focal Length: The distance from the center of the lens to a plane at which point a sharp image of an object viewed at an infinite position. The focal length determines the size of the image and angle of FOV seen by the camera through the lens. This is the center of the lens to the image pickup device.

Forgery: an unauthorized alteration made with the intent to deceive or defraud

F–Stop: A term used to indicate the speed of a lens. The smaller the F–number the greater amount of light passes through the lens.

Genetic Penetrance (Biometric) The degree to which characteristics are passed from generation to generation.

Gigabyte (GB): A measure of computer memory or disk space consisting of about one thousand million bytes (A thousand megabytes).

Goats (Biometric): Biometric system end users whose pattern of activity when interfacing with the system varies beyond the specified range allowed by the system, and who consequently may be falsely rejected by the system.

Graphic Converter: A digital imaging software application that enables you to convert images and photos from one file format to another.

Graphic Interchange Format (GIF): A raster graphic file format developed by CompuServe to exchange image files across multiple platforms. GIFs are also the preferred file format for web graphics because they have small file sizes.

Gray Level: The brightness of a pixel. The value associated with a pixel representing it's lightness from black to white. Usually defined as a value from 0 to 255, with 0 being black and 255 being white.

Gray Scale: A term used to describe an image containing shades of gray as well as black and white.

Hamming Distance: The number of disagreeing bits between two binary vectors. Used as measure of dissimilarity.

Hardware: The 'nuts and bolts' of the computer system, that includes the monitor, CPU, printers, disc drives, etc.

Hash Code: Also known as message digest. A unique fingerprint of data that can be used for image tamper identification or comparison.

Hash Function: One–way hash function–a function that produces a message digest that cannot be reversed to produce the original.

Header: A comment or description added to the top of an image. Also referred to as a caption.

Histogram: A bar graph analysis tool that can be used to identify contrast and dynamic range image problems. Histograms are found in most software programs that are used to manipulate digital images.

Hue: A term used to describe the entire range of colors of the spectrum; hue is the component that determines just what color you are using. In gradients, when you use a color model in which hue is a component, you can create rainbow effects.

Icon: A small graphic symbol or picture on a computer screen that represents a file, folder, disk, or command.

Identification/Identify (Biometric): The one–to–many process of comparing a submitted biometric sample against all of the biometric reference templates on file to determine whether it matches any of the templates and, if so, the identity of the enrollee whose template was matched. The biometric system using the one–to–many approach is seeking to find an identity amongst a database rather than verify a claimed identity. Contrast with 'Verification'.

Image Processing: Capturing and manipulating images in order to enhance or extract information.

Image Resolution: The number of pixels per unit length of image. For example, pixels per inch, pixels per millimeter, or pixels wide.

Import: The process of bringing data into a document from another computer, program, type of file format, or device.

Impostor (Biometric): A person who submits a biometric sample in either an intentional or inadvertent attempt to pass him/herself off as another person who is an enrollee.

Infinite/Finite Conjugate: A lens design in which light from a source (not at infinity) is focused down to a spot. Most video lenses, which take the image of an object at a finite distance away and focus it onto a CCD array, are designed for this scenario.

Infrared Data Association (IrDA): A method of transferring data that relies on an infrared connection rather than a cable connection. Requires IrDA receiving capability on your computer.

Infrared Radiation (IR): Is electromagnetic radiation of a wavelength longer than visible light, but shorter than microwave radiation. The name means "below red" (from the Latin infra, "below"), red being the color of visible light of longest wavelength. Infrared radiation spans three orders of magnitude and has wavelengths between 700nm and 1000nm.

Institute of Electrical and Electronics Engineers (IEEE): Abbreviation of Institute of Electrical and Electronics Engineers. IEEE is an organization composed of engineers, scientists, and students. The IEEE is best known for developing standards for the computer and electronics industry. In particular, the IEEE 802 standards for local–area networks are widely followed.

Integrated Services Digital Network (ISDN): A system of digital phone connections which has been available for over a decade.(post POTS) This system allows voice and data to be transmitted simultaneously across the world using end–to–end digital connectivity.

Integrity: Knowing or having assurance that data or information is transmitted from source to destination without undetected alteration.

International Color Consortium (ICC): Founded in 1993 by 8 industry vendors for creating, promoting and encouraging the standardization and evolution of an open and accessible color management system for hardware and software.

Interpolation: When resizing an image, a process that uses nearby pixels to estimate the color of new pixels added to the larger image.

ISO–International Organization for Standardization: Created the seven layer OSI structure for telecommunications

Joint Photographic Experts Group (JPEG): Is an acronym for Joint Photographic Experts Group, which is the organization that developed the format. for storing high–quality color and grayscale photographs in bitmap form. JPEG provides lossy compression by segmenting the picture into small blocks, which are divided to get the desired ratio; the process is reversed to decompress the image. JPEG uses the JPEG File Interchange Format, or JFIF.

JPEG Compression: A file compression standard established by the Joint Photographic Experts Group that uses a combination of DCT and Huffman encoding to compress images. JPEG is a "lossy" compression algorithm, meaning that it slightly degrades image quality.

JPEG File Interchange Format (JFIF): A minimal file format which enables JPEG bit streams to be exchanged between a wide variety of platforms and applications.

Junction Field Effect Transistors (JFET): in which semiconductor channels of low conductivity join the source and drain and in which these channels are reduced and cut off by the junction depletion regions, which reduce the conductivity and cause a voltage to be applied between the gate electrodes. Used for junction field effect transistors.

Key Exchange: The process for getting session keys into the hands of the conversants.

Key Length: The number of bits representing the key size. The longer the key, the stronger it is.

Key Recovery: A mechanism for determining the key used to encrypt some data.

Kilobyte (KB): An amount of computer memory, disk space, or document size consisting of approximately one thousand bytes.

Least Significant Bit (LSB): The LSB is the right most bit in a binary number. For Example 00000001, 1 is the LSB.

Light–Emitting Diode (LED): A semiconductor diode that converts electric energy into electromagnetic radiation at a visible and near infrared frequencies when its *pn* junction is forward biased.

Liquid Crystal Display (LCD): A flat panel of tiny cells used on most mobile computers in place of a monitor. Or a convenient, full–color display found on a digital camera that lets you view and review your digital pictures when they are taken.

Live Capture (Biometric): The process of capturing a biometric sample by an interaction between an end user and a biometric system.

Local Area Network (LAN): A communications network connected by cables and confined to a single office or building. It enables a group of computers to exchange files and share peripheral devices.

Lossy Compression: A method of reducing image file size by throwing away unneeded data, causing a slight degradation of image quality. Tiff is a lossless file format.

Luminance: The brightness, darkness, and contrast information of an image.

Man–in–the–Middle (MIM): An attack against a public key exchange in which the attacker substitutes his own public key for the requested public key; also called a *bucket brigade attack*.

Marquee: The outline of dots created by the selection tool on an image when an operator is performing a task such as cropping, cutting, drawing a mask, etc.

Mask: A defined area used to limit the effect of image–editing operations to certain regions of the image. In an electronic imaging system, masks are drawn manually (with a stylus or mouse) or created automatically–keyed to specific density levels or hue, saturation and luminance values in the image. It is similar to photographic lith masking in an enlarger.

Masking (Human Visual System): Generally defined as any interference between two or more visual signals or stimuli that results in an increase or, more often, a decrease of their visibility.

Match/Matching: The process of comparing a biometric sample against a previously stored template and scoring the level of similarity. An accept or reject decision is then based upon whether this score exceeds the given threshold.

MD2–**Message Digest 2: (**Message Digest Algorithm 2) A cryptographic hash function developed by Ronald Rivest in 1989. The algorithm is optimized for 8–bit computers. MD2 is specified in RFC 1319. Although other algorithms have been proposed since, such as MD4, and MD5. Even as of 2004 MD2 remains in use in public key infrastructures as part of certificates generated with MD2 and RSA.

MD4–Message Digest 4: (Message Digest Algorithm 4) A message digest algorithm (the fourth in a series) designed by Professor Ronald Rivest of MIT in 1990. It implements a cryptographic hash function for use in message integrity checks. The digest length is 128 bits. The algorithm has influenced later designs, such as the MD5 algorithm.

MD5–Message Digest 5: (Message Digest Algorithm 5) A standard algorithm that takes as input a message of arbitrary length and produces as output a 128–bit fingerprint or message digest of the input. Any modifications made to the message in transit can then be detected by recalculating the digest. (Similar in concept to a CRC).

Megabyte (MB): An amount of computer memory consisting of about one million bytes.

Megapixel (Mp): This is an approximate measure of an image's resolution. One Mega Pixel equals approximately one million pixels. It is only approximate because it is a term derived by the marketing departments of camera manufacturers, not engineers, and different formulas are used to determine what a Mega Pixel is, including varying the definition of one million pixels.

Message Authentication Code (MAC): Is a short piece of information used to authenticate a message. A MAC algorithm (sometimes termed a keyed hash function) accepts as input a secret key as well as the message, and produces a MAC (sometimes known as a tag). The MAC protects both a message's integrity–by ensuring that a different MAC will be produced if the message has changed–as well as its authenticity–because only someone who knows the secret key could have generated a valid MAC

Message Digest: A number derived from a message. A single change in a character in the message will change the message digest.

Metadata: Information about an image. For example, metadata with images from digital cameras can contain the date and time the picture was taken, the shutter speed, the exposure settings of the camera, and if a flash was used.

Monochrome: An image containing a single color.

Morphing: A special effect used in motion pictures and video to produce a smooth transformation from one object or shape to another.

Most Significant Bit (MSB): In computing, the most significant bit (MSB) is the bit position in a binary number having the greatest value. The MSB is sometimes referred to as the left–most bit.

Motion Picture Experts Group (MPEG): Motion Pictures Experts Group. A body within the International Organization for Standardization (ISO) that established the

MPEG–1, MPEG–2, and MPEG–4 digital audio and video compression standards. MPEG is also used to refer to video and audio clips compressed using the MPEG standards and the MPEG standards themselves.

Multimedia: The combination of two or more media into a single presentation. For example, combining video, audio, photos, graphics and/or animations into a presentation.

Multiple Biometric: A biometric system that includes more than one biometric system or biometric technology.

National Institute of Standards and Technology (NIST): An agency of the U.S. government that establishes national standards [http://csrc.nist.gov].

National Science Foundation (NSF): An independent U.S. government agency that sponsors, funds, and fosters research and development in science and engineering. The NSF became involved in wide area networking in the mid 1980s and founded NSFNET, which connected academic and research institutions. NSFNET was later connected to the Advanced Research Projects Agency Network (ARPANET), and eventually developed into the network that we now refer to as the Internet.

National Security Agency (NSA): An agency of the U.S. government responsible for intercepting foreign communications for intelligence reasons and for developing crypto systems to protect U.S. government communications.

Near Infrared (NIR): Near Infrared light is not visible to human eyes, but many celestial objects shine brightly with this light. Typically associated with heat, NIR images show the presence of molecules and complex compounds.

Neural Net/Neural Network: One particular type of algorithm. An artificial neural network uses artificial intelligence to learn by past experience and compute whether a biometric sample and template is a match.

Nickel Metal Hydride Battery: Recommended for digital cameras, these batteries have high energy density (50% more than Ni–Cd) and can be charged over 500 times in their life cycle. They charge very fast and hold their energy longer than other batteries. When they are disposed of they have a low environmental impact.

One–to–a–Few: A hybrid of one–to–many identification and one–to–one verification. Typically the one–to–a–few process involves comparing a submitted biometric sample against a small number of biometric reference templates on file.

One–to–Many: Synonym for ‘Identification’.

One–to–One: Synonym for ‘Verification’.

One–Way Hash: A hash function for which it is extremely difficult to construct two blocks of data that yields exactly the same hash result. Ideally, it should require a brute force search to find two data blocks that yield the same result.

Open–Set Identification (Biometric): Identification, when it is possible that the individual is not enrolled in the biometric system. Opposite of ‘Closed–Set Identification’.

Out of Set (Biometric): In open–set identification, when the individual is not enrolled in the biometric system.

Palette: A thumbnail of all available colors to a computer or devices. The palette allows the user to chose which colors are available for the computer to display. The more colors the larger the data and the more processing time required to display your images. If the system uses 24–bit color, then over 16.7 million colors are included in the palette.

Passive Impostor Acceptance: When an impostor submits his/her own biometric sample and claiming the identity of another person (either intentionally or inadvertently) he/she is incorrectly identified or verified by a biometric system. Compare with 'Active Impostor Acceptance'.

PCMCIA Card: A credit card size memory or PC card that meets the PC Card Standard developed jointly by the Personal Computer Memory Card International Association (PCMCIA) and the Japan Electronic Industry Development Association (JEIDA).

PCX: A popular bitmapped graphics file format, designed by Zsoft, that handles black and white, 2–bit, 4–bit, 8–bit and 24–bit color. A Windows Paintbrush bitmap image standard.

Performance Criteria (Biometric): Pre–determined criteria established to evaluate the performance of the biometric system under test.

Peripheral: A term used to collectively describe computer hardware accessories such as printers, modems, scanners, etc.

Personal Computer (PC): A small, single–user computer based on a microprocessor. In addition to the microprocessor, a personal computer has a keyboard for entering data, a monitor for displaying information, and a storage device for saving data. (Note: Another often used definition for (PC) is Printed Circuit; i.e. printed circuit board).

Personal Computer Memory Card International (PICT): A graphics file format used primarily on Macintosh computers. PICT files can contain both object–oriented and bit–mapped graphics. There are two types: PICT I and PICT II. PICT II is the current standard and supports color up to 24–bit.

Personal Computer Memory Card International Association (**PCMCIA):** A standard for a credit card–size memory or input/output device that fits into a notebook, laptop or personal computer. The PCMCIA card eliminates the need to have the camera connected to the PC to record pictures.

Photons: The force particles which carry electromagnetic interactions that behave like both a wave and a particle. They possess no mass or charge. Photons move at the speed of light, 300,000,000 meters per second.

Physical/Physiological Biometric: A biometric, which is characterized by a physical characteristic rather than a behavioral trait. Such as:' Ear Shape', 'Face Recognition', 'Finger Geometry', 'Finger Image', 'Hand Geometry', 'Iris Recognition', 'Palm', 'Retina', 'Speaker Verification' and 'Vein check'. Contrast with 'Behavioral Biometric'.

PIN (Personal Identification Number): A security method whereby a (usually) four–digit number is entered by an individual to gain access to a particular system or area.

Pixel (PICture ELement): The smallest element of a digitized image. Also, one of the tiny points of light that make up a picture on a computer screen. The number of pixels *n* for a given maximum resolution (*w* horizontal pixels by *h* vertical pixels) can be found using the formula: $n = wh$. This yields e. g. 1.92 megapixels (= 1,920,000 pixels) for an image of 1600 x 1200. The majority of digital cameras have a 3:2, or 4:3 aspect ratio, i.e. $w/h = 4/3$

Pixels per Inch (PPI): A measurement of how an image is displayed. The greater the number of pixels per inch, the higher the quality of the image.

Plain Old Telephone service (POTS): Refers to the standard telephone service that most homes use. In contrast, telephone services based on high–speed, digital communications lines, such as ISDN. ISDN is not POTS. The main distinctions between POTS and non–POTS services are speed and bandwidth. (POTS is generally restricted to about 52 Kbps) (52,000 bits per second). The POTS network is also called the public switched telephone network (PSTN).

Plain Text: (clear text) The readable data or message before it is encrypted.

Plug and Play: An automated installation process used to connect peripheral devices such as digital cameras to computers. When new devices are plugged into the computer the computer recognizes the device and prompts the user to choose setup options and finish installation. USB devices are plug and play.

Plug–In: A software module that adds functionality to a larger program.

Polychromatic Light: Light of more than one color or wavelength.

Population (Biometric): The set of end–users for the application.

Portable Network Graphics (PNG): Pronounced ping. A new standard that has been approved by the World Wide Web consortium to replace GIF because GIF uses a patented data compression algorithm. PNG is completely patent and license–free.

PostScript: A page description language developed by Adobe Systems, Inc. to control precisely how and where shapes and type will appear on a page. Software and hardware may be described as being PostScript compatible.

Primary Colors: Colors that can produce other colors by mixing them together. For example, in the RGB color model, red, green, and blue are primary colors.

Private Key: The privately held "secret" component of an integrated asymmetric key pair.

Pseudorandom Number Generator (PRNG): A procedure that generates a sequence of numerical value that appear random. Cryptographic PRNGs strive to generate sequences that are almost impossible to predict. Most PRNGs in commercial software are statistical PRNGs that strive to produce randomly distributed data with a sequence that may in fact be somewhat predictable.

Public Key Algorithm: A cipher that uses a pair of keys, a public key and private key, for encryption and decryption; also called an *asymmetric algorithm.*

Public Key: A key used in public key crypto that belongs to an individual entity and is distributed publicly. Others can use the public key to encrypt data that only the key's owner can decrypt.

Purkinje Images: A threefold image of a single object seen by one person reflected in the eye of another person. This effect is caused by the object being reflected by the surface of the cornea and by the anterior and posterior surfaces of the eye lens.

Random Access Memory (RAM): The most common form of computer memory in which the CPU stores data that is currently in use. RAM is usually volatile memory, meaning that when the computer is turned off, crashes, or loses power it is lost.

Random Number: A number with a value that cannot be predicted. Truly random numbers are often generated by physical events that are believed to occur randomly.

Raster: Raster images are made up of individual dots; each of which have a defined value that precisely identifies its specific color, size and place within the image. (Also known as bitmap images.) Therefore, resizing the image can affect its quality.

Read Only Memory (ROM): This form of memory can be read but not updated or changed by a computer. It refers to specific electronics in a computer; however non–alterable disks like CDs or CD ROMs are another type of read only memory. It is non–volatile because does not disappear when power is shut off.

Real Time Image Processing: A data processing system that responds immediately to the user. Image processing that executes each function immediately and displays it at a high enough resolution to be viewed.

Receiver Operating Curves (ROC): A graph showing how the false rejection rate and false acceptance rate vary according to the threshold.

Recognition (Biometric): The preferred term is 'Identification'.

Record (Biometric): The template and other information about the end–user (e.g. access permissions)

Resize: To alter the resolution or the horizontal or vertical size of an image.

Resolution: The number of pixels per unit length of image. For example, pixels per inch, pixels per millimeter, or pixels wide. The minimum feature size of the object under inspection. Resolution is also a measurement of the imaging system's ability to reproduce object detail.

Response Time (Biometric): The time period for a biometric system to return a decision on identification or verification of a biometric sample.

Reusable Password: A password that can be used over and over, as opposed to a one–time password. Most passwords used today are reusable passwords.

RGB: Short for Red, Green, and Blue; the primary colors used to simulate natural color on computer monitors and television sets.

RSA Data Security, Inc. (RSA): Refers to the principles: Ron Rivest, Adi Shamir, and Len Adleman; or to the algorithm they invented. The RSA algorithm is used in public–

key cryptography and is based on the fact that it is easy to multiply two large prime numbers together, but hard to factor them out of the product.

Saturation: The degree to which a color is undiluted by white light. If a color is 100 percent saturated, it contains no white light. If a color has no saturation, it is a shade of gray.

Score: The level of similarity from comparing a biometric sample against a previously stored template.

Secret Key Algorithm: A crypto algorithm that uses the same key to encrypt data and to decrypt data; also called a symmetric algorithm.

Secret Key: A (Crypto) key that is used in a secret key (symmetric) algorithm. The secrecy of encrypted data depends solely on the secrecy of the secret key.

Secure: Safe, protected, free from attack or damage.

Seed, Random: A random data value used when generating a random sequence of data values with a PRNG.

Sensor Size: The size of a camera sensor's active area, typically specified in the horizontal dimension. This parameter is important in determining the proper lens.

Sequence: An ordered arrangement of symbols (letter, digits, etc.) having continuity. The members of a component of a cipher alphabet; the symbols in a row, column, or diagonal of the cipher square in order; key letters or key figures in order.

Serial: A data transfer method used to connect a peripheral, such as a digital camera, to a computer. The serial connection will allow for the peripheral to transfer data to the computer and vise versa.

Session Key: The secret (symmetric) key used to encrypt each set of data on a transaction basis. A different session key or set of session keys is used for each communication session.

Smart Card: Tamper–resistant hardware devices that store private keys & other sensitive information.

Smoothing: Averaging pixels with their neighbors. It reduces contrast and simulates an out–of–focus image.

Square Pixels/Rectangular Pixels: Point and shoot digital cameras utilize camcorder technology. Camcorders use rectangular pixels because TV displays are rectangular. For computers square is better because computer monitors display square pixels. When you start with a rectangular pixel you have to "lob" off part of the pixel to display it. Essentially you lose image data and introduce artifacts with rectangular pixels.

Steganography: Is the art and science of writing hidden messages in such a way that no one apart from the intended recipient knows of the existence of the message; this is in contrast to cryptography, where the existence of the message is clear, but the meaning is obscured. The name comes from Johannes Trithemius's Steganographia: a treatise on cryptography and steganography disguised as a book on black magic, and is Greek for "hidden writing."

Strong Crypto: Crypto facilities that exceed the standards for lightweight or medium–strength crypto and therefore face significant restrictions under U.S. export rules.

Sub Pixel: On both full–color LCD flat panels and CRT monitors, each pixel is constructed from three sub–pixels for the three colors, spaced closely together. Each single–color sub–pixel is brightened according to the triplicate number reference, and due to their proximity, they create an illusion of being one specially–tinted pixel. A recent technique for increasing the apparent resolution of a color display, named sub–pixel rendering, uses knowledge of pixel geometry to manipulate the three colored sub–pixels separately, which seems to be most effective with LCD displays set at native resolution. This is a form of anti–aliasing, and is mostly used to improve the appearance of text. Microsoft's Clear Type™, which is available in Windows XP, is an example of this.

Subroutines: A set of instructions, appearing within a computer program, for performing a specific task.

Subtractive Colors: Transparent colors that can be combined to produce a full range of color. Subtractive colors subtract or absorb elements of light to produce other colors.

Symmetric Algorithm: A crypto algorithm that uses the same crypto key for encrypting and decrypting; also called a secret key algorithm.

Symmetric Key Encryption: Process using one and only one key to perform both the encryption and decryption processes.

Synchronous Transmission: The entire message is sent with control information surrounding the text portion of the transmission.

T1: A digital communications line which has a capacity of 1.544 megabits per second (Mbps)

T3: A digital communications line having a capacity of 44.736 Mbps.

Tagged Image File Format (TIFF): The standard file format for high–resolution bit–mapped graphics. TIFF files have cross–platform compatibility.

Tagged Image File Format for Electronic Photography(TIFF/EP): A version of TIFF file format used by Kodak digital cameras to store non–image data with many different types of image data. **Timestamp:** The dates and times associated with a file.

Template Ageing (Biometric): The degree to which biometric data evolves and changes over time, and the process by which templates account for this change.

Template Size: The amount of computer memory taken up by the biometric data.

Template/Reference Template: Data, which represents the biometric measurement of an enrolee, used by a biometric system for comparison against subsequently submitted biometric samples.

Text: Part of the message containing the basic information which the originator desires to be communicated.

Third Party Test: An objective test, independent of a biometric vendor, usually carried out entirely within a test laboratory in controlled environmental conditions.

Threshold/Decision Threshold: The acceptance or rejection of biometric data is dependent on the match score falling above or below the threshold. The threshold is adjustable so that the biometric system can be more or less strict, depending on the requirements of any given biometric application.

Throughput Rate: The number of end users that a biometric system can process within a stated time interval.

Thumbnail: A small, low–resolution version of a larger image file that is used for quick identification or speedy editing choices.

Timestamping: Recording the time of creation or existence of information.

Transparency: Allowing an application to perform on a circuit/connection without impacting on the usual operations or the operators of the circuit.

Triple DES (3DES): An encryption configuration in which the DES algorithm is used three times with three different keys.

Trojan Horse: A program with secret functions that are surreptitiously access information without the operator's knowledge, usually to circumvent security protections.

True Color Display: A device capable of displaying 16,777,216 colors. Truecolor formerly referred to any device capable of displaying 32,768 colors or more, but hicolor more accurately describes this color level as well as 65,536 colors.

True Color: Color that has a depth of 24–bits and 16.7 million colors.

Trust: A firm belief or confidence in the honesty, integrity, justice, reliability, etc., of a person, company, etc.

TTP (Trust Third Party): A responsible party which all participants involved agree upon in advance, to provide a service or function, such as certification by binding a public key to an entity, time–stamping, or key–escrow.

Type I Error: In statistics, the rejection of the null hypothesis (default assumption) when it is true. In a biometric system the usual default assumption is that the claimant is genuine, in which case this error corresponds to a 'False Rejection'.

Type II Error: In statistics, the acceptance of the null hypothesis (default assumption) when it is false. In a biometric system the usual default assumption is that the claimant is genuine, in which case this error corresponds to a 'False Acceptance'.

Universal Resource Locator (URL): The global address of documents and other resources of the World Wide Web (www) These are the internet's equivalent to addresses.

Universal Serial Bus (USB): The USB offers a simplified way to attach peripherals and have them be recognized by the computer. USB ports are about 10 times faster than a typical serial connection. These USB ports are usually located in easy to access locations on the computer.

Unsharp Masking: A process by which the apparent detail of an image is increased; generally accomplished by the input scanner or through computer manipulation.

User: The client to any biometric vendor. The user must be differentiated from the end user and is responsible for managing and implementing the biometric application rather than actually interacting with the biometric system.

Vector Image: An image made up of individual objects instead of pixels. The objects are defined by mathematical equations. You can adjust the size of a vector image and the image remains clear and of high quality. This type of file format is typically used in engineering and architecture.

Verification/Verify: The process of comparing a submitted biometric sample against the biometric reference template of a single enrolee whose identity is being claimed, to determine whether it matches the enrollee's template. Contrast with 'Identification'.

Video Graphics Array (VGA): a resolution type that uses analog signals and is only capable of 16 colors @ 640x480 and 256 colors @320x200 respectively. VGA is considered to be the lowest common denominator in graphics display.

Virtual Memory: Disk space on a hard drive that is identified as RAM through the operating system, or other software. Since hard drive memory is often less expensive than additional RAM, it is an inexpensive way to get more memory and increase the operating speed of applications.

Watermark (Digital): A code embedded into digital material that can be used to establish ownership, may be visible or invisible to the user. Font or graphics added to an image, usually to provide copyright protection. A fragile watermark is to detect every possible modification of the image. A semi–fragile watermark is should be insensitive to allowed manipulations, such as lossy compression, or image resizing.

What You See Is What You Get (WYSIWYG): Refers to the ability to output data from the computer exactly as it appears on the screen.

Whitepoint: The whitest area of an image. You can control the intensity of the white in an image by adjusting the whitepoint.

Working Distance: .The distance from the front of the lens to the object under inspection.

World Wide Web (www): Is a system of Internet servers that support specially formatted documents. The documents are formatted in a language called HTML (HyperText Markup Language) that supports links to other documents, as well as graphics, audio, and video files. This means you can jump from one document to another simply by clicking on hot spots. Not all Internet servers are part of the World Wide Web.

Write Once; Read Many (WORM): Most common to optical disks, WORM refers to data storage that cannot be changed once written. However, it may be read as many times as desired. (CD–R)

Zero Effort Forgery: Where an impostor uses his or her own biometric sample and claims the identity of a different enrollee.

Zoom Lens: A variable length lens that can be adjusted from wide angle to telephoto. The higher the number, the greater the range of the zoom.

Appendix A FEDERAL RULE 901 — Requirements

ARTICLE IX. AUTHENTICATION AND IDENTIFICATION

RULE 901.REQUIREMENT OF AUTHENTICATION OR IDENTIFICATION

(a) General Provision. The requirement of authentication or identification as a condition precedent to admissibility is satisfied by evidence sufficient to support a finding that the matter in question is what its proponent claims.

(b) Illustrations. By way of illustration only, and not by way of limitation, the following are examples of authentication or identification conforming with the requirements of this rule:

(1) Testimony of Witness With Knowledge. Testimony that a matter is what it is claimed to be.

(2) Nonexpert Opinion on Handwriting. Nonexpert opinion as to the genuineness of handwriting, based upon familiarity not acquired for purposes of the litigation.

(3) Comparison by Trier or Expert Witness. Comparison by the trier of fact or by expert witnesses with specimens which have been authenticated.

(4)Distinctive Characteristics and the Like. Appearance, contents, substance, internal patterns, or other distinctive characteristics, taken in conjunction with circumstances.

(5)Voice Identification. Identification of a voice, whether heard firsthand or through mechanical or electronic transmission or recording, by opinion based upon hearing the voice at any time under circumstances connecting it with the alleged speaker.

(6)Telephone Conversations. Telephone conversations, by evidence that a call was made to the number assigned at the time by the telephone company to a particular person or business, if

(A) in the case of a person, circumstances, including self–identification, show the person answering to be the one called, or

(B) in the case of a business, the call was made to a place of business and the conversation related to business reasonably transacted over the telephone.

(7)Public Records or Reports. Evidence that a writing authorized by law to be recorded or filed and in fact recorded or filed in a public office, or a purported public record, report, statement, or data compilation, in any form, is from the public office where items of this nature are kept.

(8)Ancient Documents or Data Compilation. Evidence that a document or data compilation, in any form,

(A) Is in such condition as to create no suspicion concerning its authenticity,

(B) Was in a place where it, if authentic, would likely be, and

(C) Has been in existence 20 years or more at the time it is offered.

(9)Process or System. Evidence describing a process or system used to produce a result and showing that the process or system produces an accurate result.

(10)Methods Provided by Statute or Rule. Any method of authentication or identification provided by Act of Congress or by other rules prescribed by the Supreme Court pursuant to statutory authority.

Rule 1001. Definitions

(1) Writings and Recordings. "Writings" and "recordings" consist of letters, words, or numbers, or their equivalent, set down by handwriting, typewriting, printing, photostatting, photographing, magnetic impulse, mechanical or electronic recording, or other form of data compilation.

(2) Photographs.“Photographs” include still photographs, X–ray films, video tapes, and motion pictures.

(3) Original. An “original” of a writing or recording is the writing or recording itself or any counterpart intended to have the same effect by a person executing or issuing it. An “original” of a photograph includes the negative or any print therefrom. If data are stored in a computer or similar device, any printout or other output readable by sight, shown to reflect the data accurately, is an “original”.

(4) Duplicate. A “duplicate” is a counterpart produced by the same impression as the original, or from the same matrix, or by means of photography, including enlargements and miniatures, or by mechanical or electronic re–recording, or by chemical reproduction, or by other equivalent techniques which accurately reproduces the original.

Nebraska Court Opinions

State of Nebraska, appellee, v. Romona Anglemyer, also known as Romona Werner, appellant.

State v. Anglemyer, 269 Neb. 237

Filed January 28, 2005. No. S–04–57

U.S. FEDERAL RULES OF EVIDENCE (For the Admissibility of Film)

The admissibility of film has been well established in American jurisprudence since 1859. These rules are codified in Article X of the Federal Rules of Evidence. The following excerpt summarizes the requirements for using photographs as evidence:

FEDERAL RULES OF EVIDENCE ARTICLE X. CONTENTS OF WRITINGS, RECORDINGS, AND PHOTOGRAPHS

Rule 1003. Admissibility of Duplicates

A duplicate is admissible to the same extent as an original unless (1) a genuine question is raised as to the authenticity of the original or (2) in the circumstances it would be unfair to admit the duplicate in lieu of the original.

Rule 1004. Admissibility of Other Evidence of Contents

The original is not required, and other evidence of the contents of a writing, recording, or photograph is admissible if–

(1) Originals lost or destroyed. All originals are lost or have been destroyed, unless the proponent lost or destroyed them in bad faith; or

(2) Original not obtainable. No original can be obtained by any available judicial process or procedure; or

(3) Original in possession of opponent. At a time when an original was under the control of the party against whom offered, that party was put on notice, by the pleadings or otherwise, that the contents would be a subject of proof at the hearing, and that party does not produce the original at the hearing; or

(4) Collateral matters. The writing, recording, or photograph is not closely related to a controlling issue.

Rule 1005. Public Records

The contents of an official record, or of a document authorized to be recorded or filed and actually recorded or filed, including data compilations in any form, if otherwise admissible, may be proved by copy, certified as correct in accordance with rule 902 or testified to be correct by a witness who has compared it with the original. If a copy which complies with the foregoing cannot be obtained by the exercise of reasonable diligence, then other evidence of the contents may be given.

Rule 1006. Summaries

The contents of voluminous writings, recordings, or photographs which cannot conveniently be examined in court may be presented in the form of a chart, summary, or calculation. The originals, or duplicates, shall be made available for examination or copying, or both, by other parties at reasonable time and place. The court may order that they be produced in court.

Rule 1007. Testimony or Written Admission of Party

Contents of writings, recordings, or photographs may be proved by the testimony or deposition of the party against whom offered or by that party's written admission, without accounting for the non–production of the original. (United States)

U.S. CHAIN OF CUSTODY

For evidence to be admissible in a court of law, certain conditions must be met. One of these is know as "chain of custody." This simply means that any material, e.g. film, must be handled in such a way as to ensure that it is not altered, substituted, or contaminated in any way. Requirement for chain of custody in photo enforcement is usually met with a log that tracks who have had possession of the recorded images and associated data since the occurrence of the violation, and securing original film in limited access areas to prevent tampering.

APPENDIX B. LIST OF ON–LINE REFERENCES

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http://www.seanet.com/~rod/digiphot.html#II3

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http://www.acdsystems.com/English/Community/Resources/Glossary/index

http://www.kodak.com/US/en/digital/dlc/book4/chapter2/glossaryA.shtml

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