Image acquisition and storage for medical imaging systems

Melerick H Mitchell

University of Nevada, Las Vegas
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
IMAGE ACQUISITION AND STORAGE FOR MEDICAL IMAGING SYSTEMS

By

Melerick H. Mitchell
Bachelor of Science
Louisiana Tech University, Ruston, LA
1992

Master of Science
University of Nevada, Las Vegas
1998

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Electrical Engineering

Department of Electrical Engineering
University of Nevada, Las Vegas
December 1998
The Thesis prepared by

______________________________
Melerick H. Mitchell

Entitled

IMAGE ACQUISITION AND STORAGE FOR MEDICAL IMAGING SYSTEMS

is approved in partial fulfillment of the requirements for the degree of

______________________________
Master of Science In Electrical Engineering

Examination Committee Chair

Dean of the Graduate College
ABSTRACT

Image Acquisition and Storage for Medical Imaging Systems

By

Melerick H. Mitchell

Dr. Shahram Latifi, Examination Committee Chair
Professor of Electrical Engineering
University of Nevada, Las Vegas

Image Acquisition and Storage for Medical Imaging Systems investigates the issues and requirements to develop a medical imaging system for the dental industry. Research was conducted through studying image acquisition and digitization systems, image file format standards, and data image distribution techniques in a medical facility. Furthermore, the future trends in medical imaging industry were identified.

From the studies gathered, a medical imaging system called Miniature Image and Data Acquisition System (MIDAS) was created. MIDAS is an intraoral camera imaging system, which has the capability to capture images of patient’s teeth and gums, track images with patient data, and distributes images and data over a Local Area Network (LAN). These capabilities match or exceed those found in most intraoral camera systems.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
ACKNOWLEDGEMENTS

I would like to thank my parents Melvin and Bobbie Mitchell, my brother Raamel, Dr. Michael Banks D.D.S. and my thesis committee Dr. Shahram Latifi, Ph.D., Dr. Eugene McGaugh, Ph.D., Dr. Yahia Baghzouz, Ph.D., and Dr. Walter Vodraska, Ph.D. for their support, encouragement, and advice in aiding me to complete my thesis. I would also like to thank the following companies for their contribution of equipment and/or supplies: Schott Fiber Optic Co, Bechtel Nevada Corporation, and Raytheon Systems Company. Special thanks to Shalan Small for the added support, and for the proofreading and editing my thesis.
TABLE OF CONTENTS

ABSTRACT .................................................................................................................................. iii
ACKNOWLEDGEMENTS ........................................................................................................ iv
TABLE OF CONTENTS .............................................................................................................. v
LIST OF FIGURES .................................................................................................................... vii
LIST OF TABLES ..................................................................................................................... viii
CHAPTER 1. INTRODUCTION ................................................................................................. I

CHAPTER 2. COMPONENTS OF AN IMAGE ACQUISITION SYSTEM ...................... 5
  2.1 Acquiring The Image ....................................................................................................... 5
    2.1.1 Lens ............................................................................................................................. 5
  2.2 Fiber Optics ....................................................................................................................... 8
    2.2.1 Image Fibers ............................................................................................................... 9
  2.3 Converting an Optical Image To a Digital Image ..................................................... 11
    2.3.1 CCD Operation ........................................................................................................12
      2.3.1.1 Calculating the Lens Size for a CCD Camera ..............................................12
  2.4 Storing The Image .......................................................................................................... 13
    2.4.1 Video Capture Cards ............................................................................................... 14
    2.4.2 Electronic Image Standards ................................................................................... 14
  2.5 Distributing The Image .................................................................................................. 17
    2.5.1 Picture Archiving and Communication System (PACS) ................................... 17
      2.5.1.1 The STATVIEW DX System ......................................................................... 20
      2.5.1.2 TelePACS .......................................................................................................... 21

CHAPTER 3. THE MIDAS PROTOTYPE ........................................................................... 24
  3.1 Purpose ............................................................................................................................ 24
  3.2 Design Objectives ........................................................................................................... 24
  3.3 Approach ......................................................................................................................... 25
  3.4 Database Design and Structure ..................................................................................... 26
    3.4.1 Database Tables ........................................................................................................ 26
    3.4.2 Patients, Employees, and Image Viewing Database Forms .............................. 29
    3.4.3 Real Time Image Viewer ........................................................................................30
  3.5 MIDAS Hardware ........................................................................................................... 35
    3.5.1 MIDAS Imaging Equipment .................................................................................. 35

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
LIST OF FIGURES

Figure 1.1. Primary Intraoral Components ................................................................. 2
Figure 1.2. MIDAS Flow Diagram ............................................................................. 4
Figure 2.1. Standard Lens Diagram ........................................................................... 6
Figure 2.2. Construction and operation of fiber optic cables ..................................... 8
Figure 2.3. Focusing an image onto a fiber bundle ................................................... 10
Figure 2.4. TelePACS 2.0 Systems and Clusters Diagram ....................................... 23
Figure 3.1. Patient Data Input Form ......................................................................... 31
Figure 3.2. Employee Data Input Form ..................................................................... 32
Figure 3.3. Individual Image Viewing Form ............................................................... 33
Figure 3.4. Four Image Viewing Form ....................................................................... 34
Figure 3.5. Image Fiber Alignment Apparatus ........................................................... 37
LIST OF TABLES

Table 2-1. Recommended Lens Sizes for CCDs ................................................................. 13
Table 2-2. Bitmap file formats .......................................................................................... 15
Table 2-3. Medical images generated by a 600-bed hospital .......................................... 19
Table 3-1. Patient Info Database Table Structure .......................................................... 27
Table 3-2. Patient Images Database Table Structure ...................................................... 28
Table 3-3. Employee Data Database Table Structure ...................................................... 28
Table 3-4. Video Capture Card Features Comparison ...................................................... 38
Table 3-5. CCD Camera Specifications ........................................................................... 39
Table 5-1. Comparison of intraoral camera systems to MIDAS ..................................... 48
Table 5-2. CCD Camera Prices ....................................................................................... 50
Table 5-3. Video Capture Card Prices ............................................................................ 50
Table 5-4. Intraoral Camera System Prices ..................................................................... 50
CHAPTER 1.

INTRODUCTION

Advances in imaging technology have improved medical imaging techniques in computed tomography (CT), magnetic resonance imaging (MRI) systems, and sonography. This thesis addresses the process of obtaining and distributing medical images; its emphasis has been directed towards images that are captured by optical devices and the process to distribute the images on a Local Area Network (LAN).

The dental industry has benefited from advances in imaging technology through the development of the intraoral camera. An intraoral camera allows a dentist to view patient's teeth and gums in greater detail by using a digital camera and a computer workstation.

There is a vast array of intraoral cameras currently available. Some of the more common brands are: VistaCam, TeliCam, DentaCAM, Dolphin Imaging Systems, Oral Scan, Insight, and InstaView. Most intraoral cameras consist mainly of the following: A CCD camera, a monitor, a PC, a video capture card, and a printer (Figure 1.1). Some of the more advanced intraoral cameras incorporate the usage of a fiber optic bundle to transfer the image and act as light guides. Some of the benefits of using an intraoral camera are:

♦ The camera can be used as an educational tool to train staff on new procedures
Improved communication between the physician and the patient

Ability to view fractured teeth, large amalgams that need crowns, or to support the need for treatment not evident by radiographs, in dental offices

Aid in locating canals in endo treatment

Verify dental impressions for accuracy

Check marginal fit of crowns, fit of partial dental framework

Verify if bridge abutments are parallel

Track the effectiveness of a particular treatment on a patient's teeth or gums

Figure 1.1. Primary Intraoral Components

A prototype intraoral camera system called Miniature Image and Data Acquisition System (MIDAS) was constructed. The MIDAS prototype was developed to find a more economical and feasible method of constructing an intraoral camera than the existing

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Some of the advantages that MIDAS has to offer over existing intraoral cameras are:

- An integrated hand-held camera and image capture device
- Ability to distribute images over a LAN or via the Internet
- The system's software has the capability to store images and retain vital patient data in one database
- Overall reduced cost for intraoral camera systems
- The database used in the system can export data tables in various standard database formats such as SQL server, Oracle, MS FoxPro, and Paradox.

The creation of an imaging system is a complex process. There are a number of issues and concerns that must be addressed to design the system. Some of those concerns are:

- Selecting the type of optical device to acquire the image
- Converting the optical image to a digital image
- Determining how to link the patient’s personal data and image data together
- Deciding which imaging format to implement when storing the images
- Selecting whom is going to view and use the images
- Determining how and where the images are going to be stored and distributed
- Designing the system to meet the current and future trends of medical imaging systems

To resolve these questions, background research was conducted on the following topics: the function and operation of Hospital Information Systems (HIS) and Picture Archiving Systems (PACS), the use of fiber optic cables in imaging systems, parts required for imaging systems, and the future trends of medical imaging systems.
The information presented in Chapter 2 provides the background information required for the design of MIDAS. From the findings of Chapter 2, the MIDAS Flow Diagram (see Figure 1.2) was created. Each step in the diagram is essential for the proper operation of the system.

![MIDAS Flow Diagram](image)

**Figure 1.2. MIDAS Flow Diagram**

The design and construction of MIDAS is discussed in Chapter 3. Some of the future trends of medical imaging systems are presented in Chapter 4. In addition to discussing how the system was designed and constructed, a cost and system capability comparison was performed in Chapter 5. The state of the art intraoral camera systems are used as a basis for evaluating the cost effectiveness of MIDAS.
CHAPTER 2.

COMPONENTS OF AN IMAGE ACQUISITION SYSTEM

2.1 Acquiring The Image

As introduced in Chapter One, the MIDAS prototype camera has the ability to capture, store and distribute images. Acquiring an image, which is the first step in the MIDAS Image Flow Diagram (see Figure 1.2) uses lenses and/or image fibers.

Two methods of capturing an image are: the use of one or more lenses to capture the image (this method is similar to the technique used in standard film cameras) and the use of an image fiber coupled with a series of lenses to capture the image.

2.1.1 Lens

Lenses are the principle building block for most optical systems. They allow light to be focused onto one point or dispersed to cover an entire area. A lens can also provide the mechanism for focusing an image onto an electronic sensing area. When a beam of light strikes a piece of glass, it will either be reflected away or experience refraction as it passes from one medium into the next. Reflection means that the light is returned to the first medium from which it originated\(^1\). Refraction on the other hand, is the change in the direction of light as it passes from the first medium into the next.
Fermat's principle for refraction states that if the refractive index \( n_g \) is the same for both media, then the light will not experience a change in direction. When the refractive index is different in both media, then a change in the direction of light will occur.

Lenses can be placed into two categories- those that force light to converge and those that cause it to diverge. Convergent lenses focus light onto one point, which is called the focal point \( (f) \) of a lens. Each side of the lens may have a different focal point (see Figure 2-1). Divergent lenses cause parallel light to spread out or diverge. The types of convergent lenses are biconvex, plano convex and positive meniscus. The types of divergent lenses are biconcave, plano-concave, and negative meniscus.

When selecting a lens for an optical system, the following must be considered: the distance between the lens to the object and the image plane, the required magnification or reduction for the image, and the focal length \( (F) \) of the lens. Of all things to be considered the focal length is the most important.

\[ \frac{1}{f} = \frac{1}{D} + \frac{1}{d} \]

Figure 2A. Standard Lens Diagram

The Lens Maker Equation (see Equation 2-1) provides the ability to calculate a
lens' focal length. The results are based on the lens refractive index \( n_e \), the radius of each side of the lens \( r_j \), and the thickness \( t \) of the lens.

\[
1/F = (n_e - 1)((1/r_1 - 1/r_2) + t (n_e - 1))/(n_e * r_1 * r_2)
\]

\[ t = 0 \text{ for thin lenses} \]

Equation 2-1. Lens Maker Equation

When more than one lens is used in the optical system, the total focal length can be calculated by using the following equation:

\[ F_{total} = (F_1 * F_2)/(F_1 + F_2 - d) \]

\[ d = \text{separation between lenses in combination} \]

Equation 2-2. Lenses in Combination Equation

The thickness of a lens can be neglected if a lens is considered to be thin. The equation for the focal length of a thin lens is:

\[ F = (1 * O)/(O + I) \text{ or } 1/F = (1/I) + (1/O) \]

Equation 2-3. Thin Lens Equation

In addition to specifying the focal length of a lens' system, the amount of magnification required of the optical system is needed. The magnification \( M \) can be calculated as the ratio between the image height \( y_i \), and the object height \( y_o \), or the ratio between the distance of the image from the lens \( I \) and the objects distance from the lens \( O \) (see equation 2-4).

\[ M = y_i/y_o = I/O \]

Equation 2-4. Magnification
2.2 Fiber Optics

There are times when it is impossible to capture an image using a standard optical device. The use of an image fiber is appropriate in circumstances regarding the position, location or size (10 cm³ or smaller) of an object. The image fiber captures the image and transfers it to a camera or monitor. Before discussing the operational procedures and benefits of using image fibers for medical imaging, an introduction about the principles of fiber optic cables is required.

A fiber optic cable is a circular dielectric waveguide that can transport optical energy (light) and information. Fiber optic cables are typically constructed of three parts: a fiber core, cladding, and outside jacket (see Figure 2.2). Good quality cores are made of extremely pure silica with index-modifying dopants such as GeO₂.

![Figure 2.2. Construction and operation of fiber optic cables.](image)

Fiber optic cables operate on the principle of internal reflection. The light that is projected into end of the cable travels down the cable by reflecting off the cladding of the cable (Figure 2.2). The core's higher index of refraction prevents the light from passing through the core and into the cladding of the cable.

Fiber optic cables offer many advantages over copper based wiring when used for transmission and communication purposes. Some of the advantages are:

- Immunity to electromagnetic interference
Increased level of security due to the extreme difficulty of line tapping

Capable of carrying information at high rates (9-100 MHz) over long distances

Ability to operate safely in environments with explosives, because fiber optic cables do not produce sparks

There are three types of fiber optic cables: single-mode step-index fibers, multimode step-index fibers, and multi-mode graded-index fibers.

Single-mode step-index fibers have a large change in refractive index between the inner core and the outer cladding. Single-mode fibers have a very small core diameter, which limits its operation to a single propagation mode meaning only one light source can enter the cable at a time. Only coherent light sources (i.e. lasers) may be used in single-mode step-index fibers.

Multimode step-index fibers work with incoherent light sources. The core size is much larger (550-1000 μm dia.) than single mode step-index fibers. This feature allows the cable to accept multiple light sources simultaneously. A downside to the larger core diameter is that it contributes to an increase in light losses in the cable.

Multimode graded-index fibers have a core size of 50-100 μm. Because of its smaller core size multimode graded-index fibers experience low light losses and better efficiency and bandwidth.

2.2.1 Image Fibers

Image fibers differ from a standard fiber optic cable in the sense that the fiber optic cables are in alignment at both ends of the cable, meaning an object projected onto one end of the cable is projected out at the other end in the same order.
The two types of image fibers are: bundle type and multicore fiber type image fibers. Bundle type image fibers are constructed by layering and fusing optical fibers together under heat and pressure. This process forms a rectangular structure of image sheets. During construction only the ends of the optical fibers are fused together and the middle fibers are left loose. This characteristic allows the cable to be flexible.

In multicore fiber type image fibers, the entire length of the fiber optic cables are fused. Because of the fusing process the cable is semi-flexible.

Transmitting an image through a fiber bundle is similar to the method used by cameras to project images on film. To view an object with a fiber bundle, the object must be illuminated by a light source, the light that is reflected from the object is transferred back through the bundle by the individual fiber optic cables to the camera. Since image fibers are often smaller than the objects they are trying to view, lenses are placed at each end of cable. The first lens focuses the object onto the cable and the second magnifies the image from the cable.

![Diagram of focusing an image onto a fiber bundle.](image)

**Figure 2.3.** Focusing an image onto a fiber bundle.

The resolution of the image projected from a fiber bundle is dependent upon two criteria: the core size of the optical fibers and the number of fiber optic cables in the bundle. The higher the number of fiber cables in the bundle, the greater the resolution. If

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
the fiber in the bundle is not totally covered by its portion of the image, its output may appear to be gray. Image fibers are often used in the construction of medical imaging devices such as endoscopes and fiberscopes. These devices allow doctors to transfer images of their patient's internal organs. Both endoscopes and fiberscopes use the outer ring of optical fibers to illuminate the object and center fibers to transfer the image to camera. The diameter of endoscopes and fiberscopes range from 2-18 mm and from 60-3,500 mm in length. The difference between the two devices is that fiberscopes have a larger range of flexibility.

2.3 Converting an Optical Image To a Digital Image

The previous section discussed how to acquire an optical image using lenses or image fibers. Before the optical image can be stored electronically, it should be converted to an electronic or digital format.

A device capable of converting the image from an optical source to a digital format is a Charged Coupled Device (CCD). A CCD is a semiconductor-based mechanism in which a finite isolated charged packet is transported from one position in the semiconductor to an adjacent position by sequentially clocking an array of gates.

In the early 1970's, Bell Laboratories began researching CCD technology. Initially the CCDs were designed to be simple analog shift registers. Currently CCDs are used in various machines such as scanners, fax machines, medical imaging devices, and digital cameras.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
2.3.1 CCD Operation

As mentioned earlier, CCDs were designed to operate as analog shift registers. Each pixel in the detector functions as a small capacitor that is able to store an electric charge in a potential well\(^5\). A potential well is a localized volume in the silicon that attracts electrons\(^4\). There are thousands of potential wells on each CCD chip, each storing a charge packet from the input light source.

The stored charge packet is read by using a series of clock pulses to shift the packets from one row to the next. After the field clock signals the end of a the light-integration period, the vertical readout clock sends out a pulse to shift the charge packets one row in the vertical direction. The top row of charge packets are placed in the vertical CCD (VCCD) register. The next clock pulse is from the horizontal readout clock, this shifts the charge packets in the VCCD register horizontally to the horizontal CCD (HCCD) register. The next pulse of the horizontal readout clock shifts the packets to the output sensor array.

The CCD device is often designed with the width of the detector to be 50 pixels longer than required. These extra pixels are constructed similarly to the regular photosites except that they are kept dark by a coating of opaque aluminum metallization therefore representing pixels without illumination\(^4\). The dark pixels are referred to as dark reference cells. These cells are used to calibrate the output video signal by acting as a buffer between valid video data pixels.

2.3.1.1 Calculating the Lens Size for a CCD Camera

CCD chips that are complying with the NTSC (National Television Standard
Committee) standard are constructed using a 4:3 ratio between the number of horizontal pixels and number of vertical pixels. When determining the minimum lens size required for focusing the image on the CCD, the hypotenuse distance of the chip must be calculated. The Pythagorean Theorem can be used to calculate the distance once the dimensions have been converted from pixels to millimeters. The hypotenuse distance of the CCD chip is the minimum diameter of the lens.

Lenses for CCDs are available in several different sizes. Table 2-1 contains some recommended lens sizes based on the CCD dimensions.

A primary component of the MIDAS is the digital camera, which is comprised of a CCD chip. A CCD chip coupled with a lens or a series of lenses completes the digitizing process.

<table>
<thead>
<tr>
<th>Lens Diameter</th>
<th>CCD Dimension (Hor. x Vert.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 mm</td>
<td>36 mm x 24 mm</td>
</tr>
<tr>
<td>1&quot;</td>
<td>12.70 mm x 9.525 mm</td>
</tr>
<tr>
<td>2/3&quot;</td>
<td>8.8 mm x 6.6 mm</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>6.4 mm x 4.8 mm</td>
</tr>
<tr>
<td>1/3&quot;</td>
<td>4.92 mm x 3.69 mm</td>
</tr>
</tbody>
</table>

Table 2-1. Recommended Lens Sizes for CCDs.

2.4 Storing The Image

Saving the image requires two primary steps. The first step is to capture the individual image frame, which can be achieved by using a video capture card. The
second step is to store the image to the hard-drive using one of the many available image file types.

2.4.1 Video Capture Cards

A video capture card is a device that can capture either individual frames of video or entire segments of video. Most capture cards have the ability to process video from several different type of sources such as: camcorders, VCR's, CCD cameras and from cable television. Two types of video input standards used in capture cards are the NTSC (National Television Standard Committee) and the PAL (Phase Alternative Line) standard. The NTSC standard was developed in the 1950's to establish a standard for television reception on Black and White televisions. The NTSC standard uses 525 lines per frame, a 60 frame per second (fps) update rate, and the YIQ color space. This standard is used both in the United States and in Japan for television broadcasting.

PAL video standard is used mostly in Europe. It uses 625 lines per frame, and a frame rate of 50 fps. The update rate is lower for PAL than for NTSC; this will result in an increase in flicker (meaning the picture may appear to be slightly jerky) from a PAL video source.

2.4.2 Electronic Image Standards

Images may be saved electronically in several different formats. Some of the imaging formats are PCX, BMP, JPEG, TIFF, and DICOM. Table 2-2 describes some of the key characteristics of each imaging standard.
<table>
<thead>
<tr>
<th>Format</th>
<th>Max bits/pixel</th>
<th>Max Num. of Colors</th>
<th>Max Image Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMP</td>
<td>24</td>
<td>16,777,216</td>
<td>65,535 x 65,535 pixels</td>
</tr>
<tr>
<td>GIF</td>
<td>8</td>
<td>256</td>
<td>65,535 x 65,535 pixels</td>
</tr>
<tr>
<td>JPEG</td>
<td>24</td>
<td>16,777,216</td>
<td>65,535 x 65,535 pixels</td>
</tr>
<tr>
<td>PCX</td>
<td>24</td>
<td>16,777,216</td>
<td>65,535 x 65,535 pixels</td>
</tr>
<tr>
<td>TIFF</td>
<td>24</td>
<td>16,777,216</td>
<td>4,294,967,295 pixels</td>
</tr>
</tbody>
</table>

Table 2-2. Bitmap file formats.

The PCX format was the first bitmap file storage standard for IBM PC's. It was created to be used in Microsoft Paintbrush software. Each PCX file is comprised of three sections: a PCX header, the bitmap data, and an optional color table.

One of the most used image file formats in the Microsoft Windows environment is BMP (BitMaP). A bitmap file consists of four main parts: a bitmap file header, a bitmap information header, a color table, and the bitmap bits. The bitmap file header contains information about the file, which also includes the location where in the file the bitmap data begins. Information about the bitmap images width and height is stored in the bitmap information header. The colors used in the bitmap are contained in the color table. Microsoft Windows 3.x bitmap files come in four-color formats: 2 color (1 bit per pixel), 16 color (4 bits per pixel), 256 color (8 bits per pixel), and 16.7 million color (24 bits per pixel). The bitmap bits contains the actual image data in the same order it was scanned on the screen.

To conserve space on the hard drive images are often compressed. The JPEG (Joint Photographic Experts Group) imaging standard incorporates a lossy image compression scheme in its design. A lossy compression scheme differs from a lossless...
scheme. When lossy compression is implemented some image data is lost, this is in order to achieve greater compression ratios\(^7\). However, when lossless compression is implemented none of the image data is lost during compression.

There are several stages required to compress JPEG images. First, the image is divided into 8 x 8 blocks, each of which is transformed into the frequency domain using the Discrete Cosine Transform\(^8\). Secondly, the values in the amplitude matrix are divided by the values in a quantization matrix. This is to filter out amplitudes that are less important to the overall appearance of the image\(^7\). During the last stage a lossy compression algorithm is used to compress the quantized amplitude matrix.

The TIFF (Tagged Image File Format) image format was designed to represent raster images i.e. images generated by scanners, frame grabbers, and paint/photo retouching applications\(^7\). It implements different data compression schemes depending on the image’s color model. A benefit of the TIFF standard is that it is compatible with both Macintosh and IBM PC based computers.

All TIFF files start with a header, which are 8 bytes long. The first two bytes contain byte order information which define the type of computer format used. The next two bytes identify the file format version. The last four bytes contain the image file directory.

The American College of Radiology (ACR) and the National Electrical Manufactures Association (NEMA) created DICOM (Digital Imaging and Communications in Medicine) standard in 1983. The purpose of DICOM was to create a standard medical imaging format, and to establish a standard for interconnection of medical imaging devices and on standard networks. DICOM 3.0, which is the current
version, provides a group of standard formats, which can be used to exchange images independent of vendor or modality.\textsuperscript{10}

The design of the DICOM communications protocol is modeled after the Transmission Control Protocol/Internet Protocol (TCP/IP) and the International Standards Organization - Open Systems Interconnection (ISO-OSI).

2.5 Distributing The Image

Once the image has been captured and saved on a disk drive or a file server, the question arises as to how and where the image will be distributed to the users. In many cases the images will only be distributed within a hospital complex, but due to the rapid growth in telecommunication systems, medical images are now being distributed on a regional or national level.

2.5.1 Picture Archiving and Communication System (PACS)

One of the means of viewing the medical images that are stored on the hospital's network has been through the use of PACS (Picture Archiving and Communication System) viewing stations. The PACS viewing stations are being used to replace the traditional light box used by physicians to view films.\textsuperscript{11} PACS provide a method of acquiring, storing, and distributing the medical image to the physician. A PACS viewing station users interface should ideally be user friendly the user should have the ability to go through an electronic work list at the same speed as a film-based system.

There are many factors that affect the functionality, usability, and cost of PACS. Some of those factors are:
The capability and reliability of the computers used on the system

The transmission speed of the communication media

Availability of storage space on the file servers

The data acquisition methods to be used to acquire the image

Resolution of the display equipment (i.e. monitors)

The level of artificial intelligence to be implemented

Quality and type of opto-electronic devices

The power, speed, and flexibility of the software being used

Standardization of image and hardware types

The ability to integrate the PAC with the hospital's HIS (Hospital Information System)/RIS (Radiology Information System)

When determining how PACS are to be integrated with the hospital's local area network (LAN), the following should be considered to increase the transmission speed and prevent overloading of the hospital existing LAN: first compress the image before distributing it and secondly, instead of distributing the image over the hospital's LAN media, install a dedicated transmission media for PACS transmissions. One of the best transmission media is fiber optic cable since it offers a higher transmission rate than twisted pair or co-axial cable.

File storage space can quickly become a concern on a PACS system because of the high number of medical images produced by many medical imaging systems. Computed Tomograph (CT) and Magnetic Resonance Imaging (MRI) exams generate on the average 20 to 100 images per exam. Currently x-ray exams only generate two to four images per exam but this could soon change due to advances in Computed Radiography.
CR offers direct digital acquisition of x-ray exam data through reusable photo-stimulatable phosphor plate, which is read by laser without the use of developing film. A hospital with approximately 600 beds will generate over 1,800 GBytes of images per year (see Table 2-3).

<table>
<thead>
<tr>
<th>Imaging Exam</th>
<th>Num. of Images</th>
<th>Num. of Bits/Image</th>
<th>Num. of GBytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray</td>
<td>250,000</td>
<td>2048 x 2048 x 12</td>
<td>1573</td>
</tr>
<tr>
<td>Computed Tomography</td>
<td>425,000</td>
<td>512 x 512 x 12</td>
<td>167</td>
</tr>
<tr>
<td>Magnetic Resonance</td>
<td>225,000</td>
<td>512 x 512 x 12</td>
<td>88</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>150,000</td>
<td>512 x 512 x 8</td>
<td>39</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>100,000</td>
<td>256 x 256 x 8</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>1,150,000</td>
<td>------------</td>
<td>1,874</td>
</tr>
</tbody>
</table>

Table 2-3. Medical images generated by a 600-bed hospital

During the design of the archival system the number of years required to store an image must be considered. Using the information presented in Table 2-3 if the images were saved for seven years approximately 12 TBytes of storage space would be required. For efficient storage and retrieval of images, a three-level archive structure is recommended: 1) image storage at the individual workstation 2) a central short term storage of current studies and associated comparison images, and 3) high-capacity slow access long term storage of past images.

PACS are being used throughout many parts of the world, since 1987. Japan's total number of PACS used has increased to over 300 units. Various organizations are developing PACS, two models are the STATVIEW DX System by EMED, and TelePACS 2.0 System by the Medical Information Systems Laboratory of the Institute of...
2.5.1.1 The STATVIEW DX System

In the early 1990's EMED released STATVIEW Classic which was an image network system. The STATVIEW DX System later replaced it. The STATVIEW DX System is a more robust system than its predecessor. It uses RS-6000 based file servers, one is active and the second acts as a hot standby. The DICOM 3.0 standard was incorporated in its image storage routine and has the ability to connect a hospital's RIS/HIS system.

The storage space on the STATVIEW DX System requires close monitoring due to the fact that each image requires 10 Mbytes of disk space, the previous version of STATVIEW storage was 400 Kbytes of disk space. In order to keep file space available images are stored for a limited time (normally a week). Once an image has been inactive for over a week, it is tagged and purged from the system.

One of the benefits of the STATVIEW DX System is that images can be copied to the Microsoft (MS) Windows clipboard and then inserted into other applications such as MS Word or MS PowerPoint. Another benefit is that its compatibility with many different brands of medical imaging equipment. Those brands include, the Siemens Vision MRI, the Siemens Somatome Plus 4 Power CT and various Kodak imaging products.

A downside to the STATVIEW System is its design, which is similar to a system that is based on a central database design. This design could cause a bottleneck effect on the system if there becomes an over abundance of request for images.
2.5.1.2 TelePACS

TelePACS 2.0 is another version of PACS. The first version TelePAC 1.0 was installed in the Radiology Clinic of the University of Athens, in various clinics of the University Hospital in Heraklion, Crete and in the Venizelion Regional Hospital. TelePACS 2.0 later replaced TelePAC 1.0.

TelePACS was designed based on the idea of developing an integrated hospital information system (HIS) that is capable of supporting all patient related clinical processes within a hospital. Another goal of the system was to enable the user to acquire and access information in a timely and efficient process. To improve the efficiency of the system a study was conducted to monitor the interaction between the doctor and the patient. A distributed database design was used to store the patient's personal information and images on the TelePACS. The principle of a distributed database design is to distribute the logical and physical components of a single database over a communication network while keeping the distribution hidden from the users.

The TelePACS image management system utilizes a series of servers to distribute the medical images to where they are needed. The required servers and their purposes are:

♦ Acquisition server- is responsible for the acquisition of multimedia medical data
♦ Archive server- manages the permanent storage of images in a transparent hierarchical storage structure
♦ Central Hospital Server- holds the meta-information on patient data and acts as a gateway among heterogeneous information systems. This is where the context
resolution takes place

♦ Departmental Server- the front end to the hospital network
♦ Display Server- connected to a set of display workstations with advanced graphical user interfaces (GUI). It caches patient related data and schedules examination requests on acquisition servers
♦ Key Server- responsible for encryption and authentication
♦ Name Server- holds the directory of both local TelePACS 2.0 clusters and all remote TelePACS 2.0 systems. It manages both incoming and outgoing communication

TelePACS 2.0 is divided into two levels of hierarchy, the clusters and the systems. A TelePACS 2.0 cluster covers a hospital department and normally consists of more than one server. This cluster forms the basic component in the intra-hospital environment. A TelePACS 2.0 system consists of all the clusters located in the hospital. Each TelePACS 2.0 system acts as a node when a series of hospitals are connected together to form a regional management system (see Figure 2-4).
To determine how to distribute images over a network, two imaging systems were researched. The MIDAS system implements some of the features that encompass both the TelePACS and STATVIEW systems, namely a user-friendly interface, data acquisition methods, and the ability to copy and paste images into other Microsoft Windows applications.
CHAPTER 3.

THE MIDAS PROTOTYPE

3.1 Purpose

Currently the average cost of an intraoral camera system, which includes software, ranges from $3,500 to $6,000. The MIDAS prototype was developed to create a more economical and feasible method of constructing an intraoral camera.

3.2 Design Objectives

The design objectives of the MIDAS were divided into primary, and secondary, objectives. Primary objectives were the essential items required for the system to operate. Secondary objectives are objectives that increase the performance of the system, and provide an increased flexibility in the operation of the system.

Primary objectives:

♦ Ability to view images in real time
♦ Ability to capture individual video frames
♦ Images to be stored in a database and referenced to a patient's ID number
♦ Creation of a simple hand-held camera device
Secondary objectives:
♦ Creation of a customized software program that displays live video
♦ Develop a database, which has the capability to distribute images over a LAN
♦ For the software to have the capability to allow the user to compare up to four images simultaneously

3.3 Approach

In addition to performing the research presented in Chapter 2, a survey of existing intraoral camera systems was conducted. This additional research provided the background information necessary to gain an understanding of the capabilities of complete imaging systems. In addition to researching existing medical imaging systems, specific research was directed towards finding information on intraoral camera systems currently on the market and those still in the research and development phase.

After the initial background research was conducted, a list of the major components for the MIDAS intraoral camera system was comprised. From this component list, a cost comparison was performed. For more information about the component cost see the Cost Comparison section of Chapter 5.

Next the primary components for MIDAS were purchased. They were the CCD camera and the video capture card. The components were purchased based on their price and capabilities. The components were then installed into an existing PC and tested.

After purchasing the electronic equipment the database and video capture software was created. This database is responsible for storing the patient's personnel data and image data. The database has the capability to distribute images and patient data...
over a LAN. The integration of the patient database with the video capture software allows image data to be inserted directly into the database.

To capture images an optical wand was built. This device allows a dentist to acquire intricate details of the patient's teeth and gums. The details of the operation and design of the optical wand is presented in section 3.5.1.

3.4 Database Design and Structure

The database used in MIDAS was designed using Microsoft Access 97 in a Windows 95 environment. MS Access was selected because of its compatibility to MS Excel, MS Word, and Visual Basic. In addition to its software compatibility, MS Access has the capability to export its database in the following database standards such as SQL Server Oracle, Paradox, dBase III, and FoxPro. This function allows a user to use the data with a wide range of database software programs and/or tools.

3.4.1 Database Tables

Three tables were created to store the patient's personal data, patient's image data, and employee information. The structure of each database table used is described in Tables 3-1, 3-2 and 3-3.
<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDNum</td>
<td>Text</td>
<td>11</td>
</tr>
<tr>
<td>LastName</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>FirstName</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>MiddleInt</td>
<td>Text</td>
<td>2</td>
</tr>
<tr>
<td>PreferredName</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>StreetAddress</td>
<td>Text</td>
<td>25</td>
</tr>
<tr>
<td>City</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>State</td>
<td>Text</td>
<td>2</td>
</tr>
<tr>
<td>Zip</td>
<td>Text</td>
<td>10</td>
</tr>
<tr>
<td>HomePhone</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>Sex</td>
<td>Text</td>
<td>1</td>
</tr>
<tr>
<td>BirthDate</td>
<td>Text</td>
<td>8</td>
</tr>
<tr>
<td>Marital Status</td>
<td>Text</td>
<td>1</td>
</tr>
<tr>
<td>EmployedBy</td>
<td>Text</td>
<td>20</td>
</tr>
<tr>
<td>Occupation</td>
<td>Text</td>
<td>20</td>
</tr>
<tr>
<td>BusinessAddress</td>
<td>Text</td>
<td>30</td>
</tr>
<tr>
<td>BusinessCity</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>BusinessState</td>
<td>Text</td>
<td>2</td>
</tr>
<tr>
<td>BusinessZip</td>
<td>Text</td>
<td>10</td>
</tr>
<tr>
<td>BusinessPhone</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>ResponsibleParty</td>
<td>Text</td>
<td>30</td>
</tr>
<tr>
<td>InsuranceCo</td>
<td>Text</td>
<td>30</td>
</tr>
<tr>
<td>InsurancePolicyNum</td>
<td>Text</td>
<td>50</td>
</tr>
<tr>
<td>InsurancePhone</td>
<td>Text</td>
<td>14</td>
</tr>
<tr>
<td>NotifyInEmergency</td>
<td>Text</td>
<td>30</td>
</tr>
<tr>
<td>NotifyInEmergencyPhone</td>
<td>Text</td>
<td>16</td>
</tr>
</tbody>
</table>

Table Indexes:

PrimaryKey Field: IDNum

Table 3-1. Patient Info Database Table Structure
<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDNum</td>
<td>Text</td>
<td>11</td>
</tr>
<tr>
<td>ImageCounter</td>
<td>Number(long)</td>
<td>4</td>
</tr>
<tr>
<td>ImageName</td>
<td>Text</td>
<td>20</td>
</tr>
<tr>
<td>Image Notes</td>
<td>Text</td>
<td>200</td>
</tr>
<tr>
<td>DateCreated</td>
<td>Date/Time</td>
<td>8</td>
</tr>
<tr>
<td>EmployeeIdNum</td>
<td>Text</td>
<td>11</td>
</tr>
</tbody>
</table>

**Table Indexes:**

Primary Key Field: IDNum, ImageName

Table 3-2. Patient Images Database Table Structure

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>EmployeeIdNum</td>
<td>Text</td>
<td>11</td>
</tr>
<tr>
<td>EmployeeTitle</td>
<td>Text</td>
<td>30</td>
</tr>
<tr>
<td>LastName</td>
<td>Text</td>
<td>20</td>
</tr>
<tr>
<td>FirstName</td>
<td>Text</td>
<td>20</td>
</tr>
<tr>
<td>MiddleInt</td>
<td>Text</td>
<td>1</td>
</tr>
<tr>
<td>StreetAddress</td>
<td>Text</td>
<td>25</td>
</tr>
<tr>
<td>City</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>State</td>
<td>Text</td>
<td>2</td>
</tr>
<tr>
<td>Zip</td>
<td>Text</td>
<td>10</td>
</tr>
<tr>
<td>HomePhone</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>Pager</td>
<td>Text</td>
<td>15</td>
</tr>
<tr>
<td>Sex</td>
<td>Text</td>
<td>1</td>
</tr>
<tr>
<td>BirthDate</td>
<td>Date/Time</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table Indexes:**

Primary Key Field: EmployeeIdNum

Table 3-3. Employee Data Database Table Structure

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
The database tables, Patient Info, and Patient Images contain all the information related to the patient. The two tables are linked together by the social security number field in each table. The relationship between the two tables is a one-to-many relationship, such that each patient possesses a unique ID number (IDNum) in the Patient Info table but the same IDNum may be stored multiple times in the Patient Images table. Records in the Patient Images table are identified by a combination of two primary keys, ImageNum and IDNum (note: A primary key is a field or group of fields in a table which have been selected to make each record stored in the database unique.).

Two databases were created. The first database contained the tables used to store the data and the second contained all the forms, macros, queries, and modules. The purpose of attaching the tables to the primary database was for two initial reasons; the first reason, the database that contains the forms, macros, queries, and modules can be updated without manipulating the data, and secondly, it reduces the dependency of one file.

3.4.2 Patients, Employees, and Image Viewing Database Forms

In MS Access and Visual Basic (VB), data is stored in tables that are best displayed in forms. Forms allow a user to edit, add and delete data. A series of forms were created based on the patient data, employee data and patient image tables. Two separate data entry forms were created to input patient and employee data (see Figure 3.1 and 3.2). In these forms, existing patient or employee data may be edited or added to its related table.
Two different forms were created to view stored patient images. The first form allows only one image at a time to be viewed (see Figure 3.3). In this form, the dentist has the ability to add comments about the image being stored.

The second image viewing form allows the dentist to view four separate images simultaneously (see Figure 3.4). This feature allows the dentist to visually compare different images in order to analyze the improvement or regression in the condition of a patient's teeth and gums.

3.4.3 Real Time Image Viewer

A separate program called the Real Time Image Viewer (RTIV) was created to capture images and display the real time video from the optical wand. VB 5.0 was selected as the programming language because, it utilizes the same database jet engine as MS Access 97. This feature of VB and Access allowed data to be easily exchanged between the two platforms.

Images are captured as JPEG files. When an image is captured the name of the image file, and the patient IDNum is inserted into the Patient Image Database. This storing of the image file name with the patient IDNum allows the user to add additional comments or notes about the image using either of the two viewing forms.
| Social Num: | 444-4444 | Birthdate: | 5/5/80 | Sex: | Male |
| Last Name: | Rock | First Name: | Jim | Middle Init: |
| Perferred Name: | Jim | Marital Status: | Single |
| Street Address: | 1313 Mockingbird Lane | City: | Las Vegas | State: | NV | Zip: | 85711 |
| Home Phone: | (702) 222-2222 | Responsible Party: | |
| Employed By: | Aircraft Inc. | Occupation: | Engineer |
| Business Address: | P.O. Box 1313 | City: | Las Vegas | State: | NV | Zip: | 85777-1111 |
| Business Phone: | (702) 999-9999 | |
| Insurance Co: | Allstate | |
| Policy Num: | ABC123456 | Insurance Phone: | (702) 555-5555 |
| Notify In Emergency: | Larry Allen | Emergency Phone: | (702) 333-7777 |

Figure 3.1. Patient Data Input Form

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Figure 3.2. Employee Data Input Form
Figure 3.3. Individual Image Viewing Form
Figure 3.4. Four Image Viewing Form
3.5 MIDAS Hardware

The hardware used in the construction of MIDAS consisted of four main parts— an optical wand, an image bundle, a CCD camera, and a video capture card. This section discusses the creation and selection process used in integrating the parts of MIDAS.

3.5.1 MIDAS Imaging Equipment

The device created to capture images was the optical wand. Two versions of the optical wand were created. The first optical wand consisted of the following parts; a lens mount, an image bundle, an image fiber alignment apparatus, and a CCD camera. The operation of the optical wand is as such, the light that is reflected from the object is focused through the lens and onto the image bundle, which is connected to the image bundle mount. This light is transferred through the image bundle focused directly onto the CCD array in the CCD camera. Once the image is contained in the CCD camera it is then transferred to the video capture card. After the image is in the video capture card the software described in the section 3.4 transfers the image from the video capture card to the Patient Image table in the database.

The second optical wand differed from the first wand by not incorporating the use of an image bundle, instead a hollow tube replaced the length of bundle and a lens with a different focal point was used. Although the second optical wand did not use an image bundle its method of operation was the same as the first.
Due to the uniqueness of MIDAS many of the parts used on the optical wand and the CCD image bundle mount and alignment device had to be custom built for the system.

The image bundle used in the construction of MIDAS was circular in shape. Because of its shape and size a standard CCD lens mount could not be used to attach the image bundle to the CCD camera. To solve the mounting problem a customized mounting device was created. This device placed the bundle directly on the optical window over the CCD sensor array.

Four parts were used to mount the image bundle to the CCD camera. The first part that was created is the image bundle mount it is used to hold the image bundle for the optical wand and CCD camera alignment. The exterior walls of this part are round to aid in alignment of the bundle with CCD sensor.

The next three parts created worked in conjunction to create the Image Fiber Alignment Apparatus (IFAA) (see Figure 3.5). The Image Bundle Mount is inserted through the circular hole in the top of the IFAA when the two parts are integrated the image bundle can be moved in both the X and Y-axis, and rotated over the CCD sensor array. This freedom of movement increased the accuracy of alignment between the CCD array and the image bundle. All parts were designed for 1/3” CCD camera.
The other end of the image bundle was combined with a lens to create the handheld camera. The image bundle was mounted in the camera using the same image bundle holder found on the CCD camera.

A Stereo-Lithography Apparatus (SLA) was used to create the parts required for mounting the image bundle onto the CCD camera, and the body-tube and lens holder used in the handheld camera. Stereo-Lithography is a three-dimensional printing process that produces a solid plastic model. The process involves automating a laser beam to draw or print cross sections of the model onto the surface of photo-curable liquid plastic.

Four steps are required to produce the model. The first step is to create a three-dimensional Computer Aided Drafting (CAD) drawing of the part. The next step is part preparation, this step uses the SLA's proprietary software to divide the three-dimensional drawing into various cross sections. After this step, the photopolymer resin is loaded into the SLA. Then the SLA begins to build the part. Once the part is finished it is cleaned and placed in an UV-curing container to cure the resin.
3.5.2 Selecting the Video Capture Card

Three different video capture cards were reviewed. The video capture cards reviewed were GrabIt by Aims, Video Packer Plus by AuraVision, and WinTV by Hauppauge. Each card had the ability to display and capture images on a workstation. The following table compares the features of each video capture card. After reviewing each card the Win TV card proved to be the best card for the following reasons:

- Video displayed on the viewing screen was clearest
- The card utilizes the current personnel computer technology (i.e. the use of the Windows 95 operating system and PCI slots on the motherboard)

<table>
<thead>
<tr>
<th>Features</th>
<th>Video Packer Plus</th>
<th>WinTv</th>
<th>GrabIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection Port or Slot</td>
<td>16-Bit ISA Slot</td>
<td>PCI Slot</td>
<td>Parallel Port</td>
</tr>
<tr>
<td>Ability to display full-motion video</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Minimum Operating System</td>
<td>Windows 3.1</td>
<td>Windows 95</td>
<td>Windows 3.1</td>
</tr>
<tr>
<td>Audio Inputs</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Number of Video Ports</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Video Standards Supported</td>
<td>NTSC &amp; PAL</td>
<td>NTSC &amp; PAL</td>
<td>NTSC</td>
</tr>
<tr>
<td>Image File Formats Supported</td>
<td>BMP, TIF, JPEG, MMP, TGA</td>
<td>BMP, TIF, JPEG, GIF</td>
<td>BMP, TIF, PCX JPEG, TGA</td>
</tr>
<tr>
<td>Minimum PC Processor</td>
<td>486</td>
<td>Pentium 90 MHz</td>
<td>486</td>
</tr>
</tbody>
</table>

Table 3-4. Video Capture Card Features Comparison

3.5.3 CCD Camera

Two CCD cameras were used during the design and testing stage of creating MIDAS. Both cameras possessed almost the same qualities except the numbers of lines
of resolution were different. The table below contains the specifications of the cameras tested. Both cameras performed adequately when combined with the optical wand.

<table>
<thead>
<tr>
<th>Model:</th>
<th>PC-18</th>
<th>BC-1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Sensor:</td>
<td>1/3&quot; B/W CCD</td>
<td>1/3&quot; B/W CCD</td>
</tr>
<tr>
<td>Picture Element:</td>
<td>512(H) x 492(V) pixels</td>
<td>512(H) x 492(V) pixels</td>
</tr>
<tr>
<td>Scanning System:</td>
<td>525 Lines Interlaced</td>
<td>Unknown</td>
</tr>
<tr>
<td>Scanning Freq.:</td>
<td>15.743 kHz (H) x 59.9</td>
<td>Unknown</td>
</tr>
<tr>
<td>Resolution:</td>
<td>380 Lines</td>
<td>420 Lines</td>
</tr>
<tr>
<td>Min Illumination:</td>
<td>0.5 Lux</td>
<td>0.03 Lux</td>
</tr>
<tr>
<td>Video Out:</td>
<td>Composite 1V P-P Ohm/NTSC</td>
<td>Composite 1V P-P Ohm/NTSC</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>DC 8-15V, 150mA</td>
<td>DC 9-12V, 100mA</td>
</tr>
<tr>
<td>Lens:</td>
<td>1/3&quot;</td>
<td>1/3&quot;</td>
</tr>
</tbody>
</table>

Table 3-5. CCD Camera Specifications

3.6 Implementing MIDAS in the Office

MIDAS can be used as a stand-alone system or over a Local Area Network (LAN). MIDAS was primarily tested as a stand-alone system but it has the capability to be utilized over a LAN. If the system were used as a stand-alone it would either have to be placed on a moveable cart or used exclusively in one location.

If MIDAS is utilized over a LAN it will operate as a combination of a Picture Archiving and Communication System (PACS) and a Hospital Information System (HIS). The setup for the system would be as follows:

- The central server will store all the database tables
♦ Each workstation on the LAN will contain a run time copy of the database forms and real-time image viewer
♦ The tables on the server will be attached to the forms database on each workstation
♦ Video capture cards installed on each workstation
♦ For the purpose security assignment of user accounts for all users
♦ Installation of optical wands for each workstation

The following benefits of placing MIDAS on the LAN are:
♦ A centralized storage location for patient images and data
♦ Other personnel can access data
♦ Various office equipment can be shared i.e. printers, scanners, etc.

3.6.1 Disease Control Measures

To prevent the spread of disease from patient to patient a disposable clear plastic sheath is used to cover MIDAS before placing the instrument into the patient’s mouth. This sheath is disposed of after every use. The sheath completely covers the instrument and is attached by a clip at the cable end of the instrument. Sheaths are commonly used to cover intraoral cameras since, intraoral cameras are electronic instruments and cannot withstand most medical sterilization processes.

3.7 Exchanging Images over the Internet or Intranet

Images can be exchanged over the Internet by two methods. Since the images are stored as JPEG files they can then be sent through the Internet via email as an attachment. The second method of distributing an image over the Internet is by creating a website and
attaching the database table to it. If this method is used the following security steps should be implemented.

♦ The gateway to the website will allow registered users to access the images

♦ The patient’s personnel data is not revealed (i.e. name, address, social security number). Instead the patient will be assigned a personnel identification number

♦ Create a duplicated database and separate it from the database used in the office
CHAPTER 4.

THE FUTURE OF MEDICAL IMAGING SYSTEMS

The next stage of medical imaging will allow communication to occur between hospitals in metropolitan areas and rural communities. Images and live video will be exchanged between hospitals through the use of existing communication systems and via the Internet.

4.1 Telemedicine

Telemedicine is the next step in medical imaging technology. It presents a wider range of capabilities than PACS. Telemedicine allows doctors to exchange live medical images from remote locations. This is achieved by combining high-speed data links, LANs and digital cameras. The primary goal of Telemedicine is to improve medical access and care to patients, to allow more doctors, students, and patients the access to medical education and lastly to enhance the overall quality of medical care at an affordable cost. Advances in the design of LANs, image compression software and hardware, and the creation and acceptance of medical imaging standards has lead to the growth of Telemedicine technology\(^{10}\).

Telemedicine systems are allowing doctors to treat patients from remote locations. The patient is examined through the use of digital cameras at the remote
hospital. Images are either transmitted in an asynchronous or synchronous mode. Asynchronous transmission uses a store and forward technique to send images (similar to sending an email with an attachment). When synchronous transmission is used the images are transmitted in real time (live video) to the remote station. Synchronous transmission requires a higher bandwidth than asynchronous transmission. After receiving and viewing the images, the doctor can diagnose the patient’s condition and prescribe a remedy.

Telemedicine is being used in many hospitals located in rural communities across the United States. This usage has resulted in not only quality improved care for their patients but also a reduction in medical expenses. In the small town of Giddings, Texas (population 4,000), the use of Telemedicine has reduced their health care cost by 22%. Some of the additional benefits of Telemedicine are that doctors can remotely consult with other specialist, and the reduction of travel time required for both the patient and the physician.

Rural hospitals are not the only users of Telemedicine systems. The U.S. Army and the Medical College of Georgia have planned to install 25 home Telemedicine machines in the Georgia. These machines will incorporate an electronic stethoscope, blood pressure machine and a digital thermometer.

There are two types of Telemedicine systems: remote and regional. Remote Telemedicine systems provide medical care to distant underserved locations. Regional Telemedicine systems provide medical treatment to facilities located in the same metropolitan area.

Telediagnosis is the sharing of images and medical information in which the
primary diagnosis is made by the doctor at a remote location. Some of the current telediagnosis being practiced are:

- Telepathology- used by a pathologist to examine tissues under a microscope
- Telecardiology- transmission of images of the heart using ultrasound images
- Tele-Endoscopy- cameras are used to transmit images of a patient's colon, stomach, or the inside of the ear or nose
- Telepsychiatry- supports the remote practice of psychiatry

4.2 Internet Image Distribution

Many hospitals are looking toward the Internet to provide additional means for exchanging images. Hospital personnel will be able to review various clients' data and related medical images through the use of some of the standard Internet browsers like MOSAIC, Netscape, MS Explorer and Hot Java.

The process to exchange images through the internet is as such, after an Internet connection has been made between the client and the host hospital, the client search routine could be executed. This routine would allow the client to search for a patient either by using a combination of their name and identification number or using a unique identification number generated for hospital use only. If a hospital patient's unique identification number is used, the flexibility of being able to access the patient's information from different hospitals may be limited.

After the connection has been made and the patient has been selected, the image needs to be downloaded. If the still image were stored in a common format, such as JPEG, it would be a simple process to download and view it. Downloading errors may
occur if the image is stored using a PACS image compression algorithm and the Internet browser being used does not support the algorithm. The Intelligent Medical Image Retrieval (IMIR) System developed by Loral Aero System avoided this problem by creating a program in JAVA to distribute the PACS compression/decompression software.

In order for a hospital to distribute its images over the Internet, an Internet server is required. The Internet server contains the patient's information and medical images. The server is comprised of two primary components- a mass storage unit, and a host computer/workstation. All the data, images and downloading software, is located on the storage units. The host computer is a high performance workstation. It hosts the database management software, the Internet server software, the mass storage interface software, and the intelligent retrieval engine software.

Internet security is an important item when transferring personal medical information. The data must be protected from access by unauthorized users and during the downloading process from the host server to the client's machine. Before a client can access any information, his account number and password must coincide with what is stored in the hospital's Internet server. For additional security, a firewall can be created between the browser and the server, and should provide both authentication of the user and encryption of the data transferred. The products Netscape Communications Secure Sockets Layer and the Enterprise Integration Technologies Secure- Hypertext Transfer Protocol provide the firewall protection required to implement a secure Internet connection between the browser and the server.
Future versions of MIDAS will allow doctors to view patients in a remote location. However, with the current version of MIDAS, the database engine used allows medical images and patients data to be connected with Internet websites.
CHAPTER 5.

CONCLUSION

In this chapter several analyses were performed on MIDAS. The following items were analyzed: total system cost, the performance of the system compared to existing intraoral cameras, and the future enhancements of MIDAS.

5.1 Performance Analysis

To determine how the capabilities of MIDAS compared to other intraoral camera systems, a survey of three intraoral cameras was conducted. The intraoral cameras surveyed were: VistaCam, DMD, and Dolphin Imaging Systems. Each intraoral camera system was similar in design but, with different pros and cons. Table 5-1 compares the capability of each camera system.

When compared to the other imaging systems in Table 5-1, MIDAS outperformed the other systems. One of the major benefits of MIDAS is the way images are processed and stored. Of the systems surveyed only the Dolphin Imaging System stored its images in a JPEG format, but that was done in a two-step process. First the image was stored on the PC Card in the digital camera, and then the camera is connected to a computer and then the images are downloaded onto the hard-drive. MIDAS avoided this process by storing the images on the hard-drive at the time of capture, thus making it one-step process.
<table>
<thead>
<tr>
<th>Comparison Criteria</th>
<th>VistaCam</th>
<th>DMD</th>
<th>Dolphin Imaging Systems</th>
<th>MIDAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image System Manufacture</td>
<td>Air Techniques</td>
<td>Dental/Medical Diagnostic Systems Inc.</td>
<td>Dolphin Imaging Systems</td>
<td>Melerick Mitchell UNLV</td>
</tr>
<tr>
<td>Camera System Used</td>
<td>VistaCam</td>
<td>TeliCam</td>
<td>Fuji Digital Card Camera</td>
<td>MIDAS Optical Wand</td>
</tr>
<tr>
<td>Image Storage Capability</td>
<td>Images may only be temporarily saved on the monitor.</td>
<td>Images may only be temporarily saved on the monitor.</td>
<td>Images are initially stored on an ATA Type I or II compliant PC Card in the camera and then transferred to the computer hard-drive.</td>
<td>All images are stored on the computer's hard-drive.</td>
</tr>
<tr>
<td>Image File Format</td>
<td>Images may only be saved as printouts</td>
<td>Images may be saved as printouts and video may be saved on a VCR.</td>
<td>JPEG</td>
<td>JPEG</td>
</tr>
<tr>
<td>Views Allowed</td>
<td>Single Tooth and Full Face Views</td>
<td>Single Tooth and Full Face Views</td>
<td>Full Face Views and the whole dental arc</td>
<td>Full Face Views and the whole dental arc</td>
</tr>
<tr>
<td>Video Format</td>
<td>NTSC</td>
<td>NTSC</td>
<td>NTSC</td>
<td>NTSC</td>
</tr>
<tr>
<td>System Hardware Requirements</td>
<td>Monitor, VistaCam Control Unit, and Image Printer</td>
<td>Monitor, TeliCam, Image Printer and a VCR</td>
<td>A PC with the following: 75 MHz Pentium, with 16 Mb RAM, 100 Mb Hard Drive, and an Internal or External PC Card Drive</td>
<td>A PC with the following: 166 MHz Pentium, with 32 Mb RAM (min), 100 Mb Hard Drive available,</td>
</tr>
<tr>
<td>System Software Requirements</td>
<td>N/A</td>
<td>N/A</td>
<td>Windows 95 and Dolphin Imaging Software</td>
<td>Windows 95 and Microsoft Access 97</td>
</tr>
<tr>
<td>Networkable</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 5-1. Comparison of intraoral camera systems to MIDAS.
None of the systems surveyed incorporated the use of a database to store patient information and link that data with the captured images. Another advantage that MIDAS demonstrated over the systems surveyed were the two image viewing forms. This capability increased the ease of viewing and comparing the details of the different images.

5.2 Cost Comparison

As mentioned in Section 3.3, a cost comparison was performed before the design of MIDAS. The cost analysis provided a means of selecting components for MIDAS based on cost and performance.

Pricing information was compiled on various CCD cameras, video capture cards, and different intraoral camera systems currently on the market (tables 5-2 through 5-4). Purchasing a CCD camera off the shelf proved to be more economical according to a study written by Mike Castro (UNLV graduate student) on the estimated cost of constructing a CCD camera. Constructing a camera from scratch would cost from approximately $160-$200; this is much higher than the lowest price CCD camera which range from $100-$120. Using off the shelf components would also reduce production cost, since the amount of labor, assembly time, and equipment cost is greatly reduced.

The overall cost to construct MIDAS was approximately $900.00. Two-thirds of the systems cost was directed towards the purchasing of the various pieces of hardware and rest towards purchasing software packages to aid in the creation of the database and a customized video capture program. The total cost of the system would have been much higher if each component for the system was built individually.
### Table 5-1. CCD Camera Prices

<table>
<thead>
<tr>
<th>Company/Brand</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATV Research Inc.</td>
<td>1/3&quot; B&amp;W Miniature CCD Tube Camera</td>
<td>$120.00</td>
</tr>
<tr>
<td>ATV Research Inc.</td>
<td>1/3&quot; B&amp;W Board CCD Camera</td>
<td>$100.00</td>
</tr>
<tr>
<td>Marshall Electronics</td>
<td>1/3&quot; B&amp;W CCD Camera</td>
<td>$120.00</td>
</tr>
<tr>
<td>Sanyo</td>
<td>1/3&quot; B&amp;W CCD Camera</td>
<td>$240.00</td>
</tr>
<tr>
<td>Sanyo</td>
<td>1/3&quot; Color CCD Camera</td>
<td>$530.00</td>
</tr>
<tr>
<td>Sony</td>
<td>DXC 107A Medical CCD Camera</td>
<td>$1,900.00</td>
</tr>
</tbody>
</table>

### Table 5-2. Video Capture Card Prices

<table>
<thead>
<tr>
<th>Company/Brand</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagenation</td>
<td>Color Precision Frame Grabber Card</td>
<td>$400.00</td>
</tr>
<tr>
<td>Marshall Electronics</td>
<td>PCI 2Mb Video Frame Grabber Card</td>
<td>$330.00</td>
</tr>
<tr>
<td>WinTV</td>
<td>PC Video Capture Card</td>
<td>$130.00</td>
</tr>
</tbody>
</table>

### Table 5-3. Intraoral Camera System Prices

<table>
<thead>
<tr>
<th>Company/Brand</th>
<th>Description</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolphin Imaging Systems</td>
<td>Intraoral Camera w/o Software</td>
<td>$2,600.00</td>
</tr>
<tr>
<td>Dolphin Imaging Systems</td>
<td>Intraoral Camera w/ Software</td>
<td>$5,600.00</td>
</tr>
<tr>
<td>VistaCam</td>
<td>Intraoral Camera System</td>
<td>$3,100.00</td>
</tr>
<tr>
<td>DMD</td>
<td>Intraoral Camera System</td>
<td>$4,000.00</td>
</tr>
</tbody>
</table>
5.3 Objectives Achieved

Creating and building a medical imaging system is a difficult process. This thesis explored many of the options and capabilities of intraoral camera systems.

When compared to the other intraoral camera systems MIDAS offers more options and capabilities (particularly software capabilities) than many of the systems currently on the market. Some of the major objectives were achieved are the following:

♦ Ability to view images in real time environment
♦ Patient data and images are tracked on a common database
♦ A cost reduction of approximately of $1,600
♦ The ability to capture individual video frames
♦ Creation of an optical wand
♦ Multiple images may be view and analyzed simultaneously

5.4 Future Versions of MIDAS

Although the MIDAS prototype achieved all of its primary and secondary goals and objectives, there are still several ways to improve the system. Some of the future enhancements to the system should include the following:

♦ Incorporate edge enhancement algorithms to improve the clarity of the images being stored
♦ Implement the usage of the DICOM imaging standard
♦ Enhance to the imaging quality of the optical wand
♦ Create a method to measure the object being viewed

♦ Create an interface to interact with digital x-ray systems
REFERENCES


5 Per Nelvig, DDS, Kenneth Wing, DDS, PhD and Ulf Welander, DDS, PhD, "Sens-A-Ray", *Oral Surgery Medical Oral Pathology*, vol 74, no 6, pp 818-823, 1992

6 Video Packer Plus Installation Handbook


53

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
13 Manolis Tsilknakis and Dimitrios G. Katehakis and Stelios C. Orphanoudakis, "Intelligent Image Management in a Distributed PACS and Telemedicine Environment", *IEEE Communication Magazine*, pp 36-45, July 1996


VITA

Graduate College
University of Nevada, Las Vegas

Melerick H. Mitchell

Home Address:
2641 W. Camino de la Joya
Tucson, AZ 85742

Degree:
Bachelor of Science, Electrical Engineering Technology, 1992
Louisiana Tech University, Ruston, LA

Thesis Title:
Image Acquisition and Storage for Medical Imaging Systems

Thesis Examining Committee:
Chairperson, Dr. Shahram Latifi, Ph.D.
Committee Member, Dr. Eugene McGaugh, Ph.D.
Committee Member, Dr. Yahia Baghzouz, Ph.D.
Graduate Faculty Representative, Dr. Walter Vodraska, Ph.D.