Computer Integrated Endoscopic Simulator for Training in Esophagogastroduodenoscopy

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UNIVERSITY OF MIAMI

COMPUTER INTEGRATED ENDOSCOPIC SIMULATOR
FOR TRAINING IN ESOPHAGOASTRODUODENOSCOPY

By

Decho Surangsrirat

A DISSERTATION

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Doctor of Philosophy

COMPUTER INTEGRATED ENDOSCOPIC SIMULATOR
FOR TRAINING IN ESOPHAGOGASTRODUODENOSCOPY

Decho Surangsrirat

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We propose a computer integrated endoscopic simulator for training in upper endoscopy as a low-cost alternative to the traditional training methods and virtual reality simulators. The use of a real endoscope in conjunction with our simulator and computer system in an actual operating room setup makes the training environment similar to a real procedure. Endoscopic surgery is the performance of surgery through a small incision with the aid of special medical equipment called a flexible endoscope. The advantage of this technique over open surgery is that there is significantly less operative trauma, resulting in less pain and a shorter recovery time. Side effects of the surgery, such as the risk of infection, are also reduced. While endoscopy procedure has tremendous benefits, surgeons require considerable practice and time to develop competency. Traditionally, the procedure has been taught at the expense of patient comfort and safety, in other words, gastroenterology training fellows have performed the surgery under the supervision of physicians. Patients who undergo the endoscopies
performed by fellows, particularly early in the training period, have been more likely to suffer more discomfort and prolonged procedures. In this study, we introduce a new type of simulator which combines the use of mechanical model and computer system as an additional or low-cost alternative for training in upper endoscopy.

Our approach is to integrate a computer system with a realistic mechanical model to create a computer-based simulator for upper endoscopy training. The simulator will cover the basics of flexible endoscopy and teach a trainee the skills required to perform upper endoscopy. The mechanical training model with a sensor system that simulates a human upper gastrointestinal tract, including pathologies such as ulcers and polyps, will be built and integrated with computer software. The software offers the following functions: provides help to the trainee, provides curriculum-required learning tasks, and assesses the performance and diagnostic skills. Due to the optical nature of an endoscopic lens, the obtained image suffers from a barrel-type spatial distortion, which results in an inconsistent measurement of object size and distance. Our distortion correction system with automatic calibration, based on least squares estimation, offers a better perception of size and distance from the endoscopic images. In order to examine the endoscopic maneuvering skills of the trainee, the automatic evaluation system is created. The
system uses images from the exam procedure to verify the trainee skills. We use Support Vector Machine to classify endoscopic images of different regions in upper gastrointestinal tract. The experimental results on the distortion correction and image classification are reported. Simulator validation survey result from gastroenterology surgeons and fellows is included in this dissertation. A recommendation for further study is also enclosed.
To my beloved parents
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Decho Surangsrirat

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CHAPTER 1

Introduction

When people have to go to a hospital for an operation, traditional or open surgery is the procedure that most people think of. It requires one large incision that will leave a significant scar forever. Strong anesthesia is used and patients will suffer for a considerably long recovery time. For example, open surgery gallbladder removal requires a hospital stay of around six days and more than two months for the patients to be able to return to their normal activity. Open spine surgery requires at least a few months for recovery and also has high complication rates. Finally, open knee surgery causes much pain and requires a long recovery period. Fortunately for patients, the trend for most surgeries has moved toward the minimally invasive procedures.
Minimally invasive surgery or endoscopic surgery is surgery performed through a small incision with the aid of special medical equipment called a flexible endoscope. Instead of cutting the skin open to get direct access to the structures or organs involved, the surgeon will look through the camera and use the endoscopic tools to perform the procedure. Endoscopic surgery is now applied to many surgical fields such as gastrointestinal (GI), respiratory, urinary, and plastic surgery. The advantage of this technique over open surgery is that there is significantly less operative trauma, resulting in less pain and shorter recovery time. Side effects of the surgery, such as the risk of infection, also reduce. Randomized controlled trials have proven that these procedures are safer and more cost effective. Therefore, most surgeries today are done using minimally invasive techniques unless open surgery is needed due to special circumstances. Despite the tremendous benefits, surgeons require considerable practice and time to become competent in endoscopy.

For the minimally invasive surgery of the GI tract, the American Society of Gastrointestinal Endoscopy (ASGE) recommends gastroenterology fellows to perform a minimum of 130 upper endoscopy procedures during their fellowship while the joint advisory group for endoscopy in Britain recommends the minimum of 300 procedures to become competent (Weaver et al. 2004). Traditionally, the procedure has been taught at the expense of patient comfort and safety as fellows
have performed the surgery under the supervision of physicians. Patients who undergo the endoscopies performed by fellows, particularly early in the training period, have been more likely to suffer more discomfort and prolonged procedures (Gerson et al. 2004). Moreover, the endoscopists have not had enough time to train and oversee the training procedures. The national endoscopy database of the Clinical Outcomes Research Initiative (CORI) concluded that fellow involvement prolonged procedure time by 10-37%, with an estimated loss of reimbursement to the academic institution of $500,000 to $1,000,000 per institute with average total endoscopy volume of 4,000 procedures per year (McCashland et al. 2000).

1.1 Motivation

The endoscopic training process is time-consuming and costly. Recently, the use of simulators becomes an alternative method for endoscopic training. The trainees can experience the manual manipulations of an endoscope without sacrificing patient comfort and safety. The supervising physicians also benefit by a reduction in the time spent overseeing the procedure while the trainees in turn are not subjected to the time limitations associated with real-life patients. Simulators accelerate the fellow training process as they are not subjected to the availability of endoscopic
cases. Thus the trainee has an unlimited number of practices through the simulators. The previous validation studies found that computer simulation training enhances patient comfort during real-life endoscopy (Sedlack et al. 2004). The group trained on virtual endoscopy simulators reached the level of experts after three weeks of simulator training (Ferlitsch et al. 2002). Giulio conducted a randomized controlled trial that compared training between two groups of fellows with no experience in endoscopy (Giulio et al. 2004). They concluded that the computer-based simulator is effective in providing novice trainees with the skills needed for identification of anatomical landmarks and basic endoscopic maneuvers, and in reducing the need for assistance by supervisors.

With the complications and risk of involving patients in the endoscopic training process, there is a growing need for artificial simulators to substitute the traditional mean of the training. Thus far, we do not have enough simulators available for medical education training.

1.2 Research Objective and Challenges

Among the different types of simulators currently available, our approach is to integrate computer software with a realistic mechanical model to create a new low-cost computer based simulator for upper endoscopy training. A trainee will pass an
endoscope through the model which represents an upper GI tract to perform a predefined set of practice tasks. Integrated computer software will provide help during practicing with a required knowledge on the operation. An automatic evaluation system will grade the performance and give feedbacks to the trainee. With such a system, GI fellows can practice and improve their skills without waiting for an availability of a supervising instructor and more importantly without risking patients' comfort and safety. Our computer integrated endoscopic simulator (CIES) will cover the basics of flexible endoscopy and prepare a fellow in terms of the skills required to perform an upper endoscopy. Figure 1.1 illustrates a design of our system.

The goal of our research is to build a low-cost endoscopic training simulator system which incorporates a mechanical model and computer software together. It can be used as an effective supplement to the educational process of the gastroenterologist, providing an additional training option. The mechanical training model has to represent a real human upper GI tract to make a training experience as close to an actual procedure trained on patient as possible. The sensor system is added to the mechanical model to detect unsafe maneuvers. In this dissertation, we present a protocol for low-cost fabrication of the model and sensor
Figure 1.1: Diagram of the Computer Integrated Endoscopic Simulator (CIES), which includes the mechanical training model and computer software.
Figure 1.2: Illustration of the CIES. Trainee will pass an endoscope through the enhanced mechanical model. A computer with the developed software is connected to an endoscope control tower to provide help for the trainee along with feedback and evaluation.

system including materials and methods. We also developed computer software to be used in conjunction with the mechanical model as shown in Figure 1.2.

The main goals of the software are: 1) enhancing a training experience by creating an interaction between trainee and the training system; and 2) providing helps, and evaluating user performance. Two main technical components of our
computer software are distortion correction and automatic evaluation system using endoscopic image classification. Due to the optical system of an endoscope, a barrel-type spatial distortion of the image is obtained which results in an inconsistent measurement of object size and distance (Smith et al. 1992). Specifically, the further an object is from the field of view’s center, the more distorted the image becomes. We implemented a simple yet reliable distortion correction method based on least squares estimation to offers a better perception of size and distance from the endoscopic images. Since a distortion correction usually involves complicated camera calibration step, we designed an automated calibration system to allow a user to easily calibrate the endoscope using our software. In order for the software to evaluate the performance of a trainee automatically, it must be capable of determining the correct categories of the endoscopic images taken during an exam procedure. Images of difference regions in the upper intestinal tract are separated into multiple classes. Since an endoscopic image poses rich information expressed by texture features and Support Vector Machine (SVM) has demonstrated superior performance in the texture classification tasks (Kim et al. 2002 and Li et al. 2003), we implemented the classification scheme for this multiple classes task using SVM. The experiment results are impressive for the endoscopic image dataset from our mechanical model.
Thus, we investigated further on this classification problem on endoscopic images from both the simulator systems and patients. It could potentially be used for an endoscopic image categorization task for medical picture archiving and searching system.

1.3 Dissertation Contributions

The key contributions of this dissertation are summarized as follows:

- The design and development of a new type of upper endoscopy training simulator. A low-cost mechanical model representing the upper GI tract, including pathologies such as ulcers and polyps is combined with computer software, which allows fellows to practice the maneuvering skills on their own without the need of a supervising instructor.

- The protocol for low-cost manufacture of the upper GI tract mechanical model and sensor system, including the ideal materials and methods. Model for other endoscopic procedures can also be built by similar protocols.

- The design and development of a computer software package for upper endoscopy training. Our software can enhance a training experience and
allows users to practice endoscope maneuvering skills anytime. Optionally, it can also be used with any commercial mechanical model.

- Presenting a new method for an automatic calibration of a nonlinear distortion correction system using a least squares estimation. The calibration template is designed to provide a fast and easy way to calibrate an endoscope for distortion correction. The edge detection and cross correlation are used to automatically detect the center of the dot from the calibration paper.

- The implementation of multi-class endoscopic image classification for upper GI tract using SVM. An algorithm with polynomial kernel performs effectively with image intensity values as input features.

### 1.4 Dissertation Outline

This dissertation is organized as follows. We begin in Chapter two with a brief overview of related medical background, including traditional and endoscopic surgery as well as the history of the endoscope. Chapter three discusses the currently available simulators for endoscopic surgery. We discuss the different types of simulators, including the animal model, mechanical simulator, biomaterial
simulator, and virtual reality computer simulator; the history of the simulators is also reported. The advantages and disadvantages of each type are reviewed and compared with our simulator.

In Chapter four, we present the method and implementation of our mechanical model, a protocol that can also be used to manufacture other models for training in endoscopic procedure. The design and implementation of our computer software, including the technical components, is described in Chapter five. The configuration for integration of the computer software and mechanical model is also introduced. We will then show how the proposed distortion correction and endoscopic image classification system are developed for the simulator.

Visual observation and experimental results, including the survey from experts and potential users on our simulator, are presented in Chapter six. A comparison of the average errors between distorted images and corrected images is reported. The results of endoscopic image classification from two datasets are also presented. Lastly, to conclude the dissertation, we summarize the works and discuss possible directions for future research in Chapter seven.
CHAPTER 2

Medical Background

2.1 Traditional Surgery

The term “open” or “traditional surgery” refers to the performance of surgery through one large incision made with a scalpel to provide a surgeon with direct access to the target organs. Most open surgery requires general anesthesia, a combination of medications received through an intravenous needle or inhaled through a mask to induce sleep. Blood transfusion might be necessary to replenish the excessive blood lost. After the procedure, the incision is closed using stitches, staples, or adhesive strips depending on the location and depth of the incision, which will usually cause a long lasting scar.
The obvious downside of an open surgery is that, due to the large incision, the patient has to suffer through a painful and considerably long recovery time, typically between three to seven weeks. Mild infections at the incision site are common, and the risk of more serious infection is somewhat elevated. There are also risks inherent to general anesthesia, such as aspiration, although the serious side effects are uncommon. Surgical scars left by an open surgery are also extensive, and some patients have trouble coping with these permanent reminders of their operations. With an endoscope, most procedures can be done using minimally invasive techniques. Figure 2.1 illustrates an open cholecystectomy to remove a gallbladder stone in comparison with a minimally invasive laparoscopic surgery. Instead of removing a gallbladder through a single large incision in the abdomen of around 12 to 20 centimeters, a surgery is performed through four small incisions of around one centimeter where the scope and tools are introduced. At the present, an open surgery for gallbladder removal will only be performed if certain conditions occur, e.g., severe inflammation of bile duct or gallbladder or high pressure in blood vessels in the liver.
Figure 2.1: Comparison between laparoscopic surgery (minimally invasive) and open surgery to remove a gallbladder stone. Open surgery requires one large incision, while a minimally invasive procedure requires several tiny incisions.

Figure 2.2: The performance of a minimally invasive surgical procedure at Minnesota Institute of Minimally Invasive Surgery.
2.2 Endoscopic Surgery

Endoscopic surgery, minimally invasive, is a technique that involves the use of an endoscope to allow the surgeon to diagnose and treat disease through small incisions or natural body openings. Consequently, the patient suffers less pain, has a shorter recovery time, and experiences fewer side effects. Usually, there is no need for anesthesia. Many of the procedures can be performed as an outpatient surgery. Randomized controlled trials have proven that these endoscopic procedures are safer and more cost effective compared to the traditional surgery (Perrault et. al 2004; De Angelis et. al 2003; Kang et. al 2003; Nilsson et. al 2000).

The first endoscopic surgery was done in 1987 for a gallbladder removal. The operation result was impressive. As a consequence, similar approach was applied in many different fields, including cardiology, urology, neurology, gastroenterology, and gynecology as summarized in Table 2.1. Currently, a gallbladder removal and upper endoscopy are some of the most common endoscopic surgeries in the United States.
## TABLE 2.1: Endoscopic Surgery Procedures.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Type of Endoscope</th>
<th>Organ parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGD or Upper endoscopy</td>
<td>Gastroscope</td>
<td>Upper GI tract up to duodenum</td>
</tr>
<tr>
<td>ERCP</td>
<td>Gastroscope</td>
<td>Biliary system</td>
</tr>
<tr>
<td>Sigmoidoscopy</td>
<td>Sigmoidoscope</td>
<td>Large intestine from the rectum through the sigmoid colon</td>
</tr>
<tr>
<td>Colonoscopy</td>
<td>Colonoscope</td>
<td>Large colon and distal part of small bowel</td>
</tr>
<tr>
<td>Laparoscopy</td>
<td>Laparoscope</td>
<td>Abdominal or pelvic cavity</td>
</tr>
<tr>
<td>Theracoscopy</td>
<td>Theracoscope</td>
<td>Lung or other structures in the chest cavity</td>
</tr>
<tr>
<td>Rhinoscopy</td>
<td>Rhinoscope</td>
<td>Nasal passages</td>
</tr>
<tr>
<td>Bronchoscopy</td>
<td>Bronchoscope</td>
<td>The lower respiratory tract</td>
</tr>
<tr>
<td>Arthroscopy</td>
<td>Arthroscope</td>
<td>The interior of the joints of the knee, shoulder, elbow, wrist, ankle, and hip.</td>
</tr>
<tr>
<td>Spinal Endoscopy</td>
<td>Endoscope</td>
<td>Spine</td>
</tr>
<tr>
<td>Colposcopy</td>
<td>Colposcope</td>
<td>Cervix and the tissues of the vagina and vulva</td>
</tr>
<tr>
<td>Hysteroscopy</td>
<td>Hysteroscope</td>
<td>Uterine cavity</td>
</tr>
<tr>
<td>Falloscopy</td>
<td>Falloscope</td>
<td>Fallopian tubes</td>
</tr>
<tr>
<td>Fetoscopy</td>
<td>Fetoscope</td>
<td>Fetus, amniotic cavity, umbilical cord, and fetal side of placenta</td>
</tr>
<tr>
<td>Cystoscopy</td>
<td>Cystoscope</td>
<td>Urinary bladder</td>
</tr>
</tbody>
</table>
2.2.1 Endoscope

The endoscope is an optical device consisting of a flexible tube with an optical lens at the tip. The first endoscope was developed by Philip Bozzini from Austria in 1805 for examination of the canals and cavities of the human body. He created an instrument with attached light source called Lichtleiter (means light guiding instrument), created by Philip Bozzini in 1805. He used it to examine the urinary tract, rectum, and pharynx.

Figure 2.3: The first endoscope, the Lichtleiter, created by Philip Bozzini in 1805. He used it to examine the urinary tract, rectum, and pharynx.
instrument) as seen in Figure 2.3. The instrument consisted of two main parts, the light source and the speculum. The light source used a combination of various mirrors and a lantern to reflect light towards inside of the cavity. Observer received images of the illuminated object through “Observer Viewfinder”. The second part of the instrument, the speculum, consisted of four thin metallic sheets that dilate the orifice to be examined. Philip Bozzini designed different types of specula for various body parts. However, Vienna Medical Society disapproved the use of his instruments during that time.

Antoine Jean Desormeaus of France designed an instrument to examine the urinary tract and bladder in 1853 and he named it endoscope, which became the term we use today. After a series of trials by many researchers and physicists, Dr. Rudolph Schindler finally invented a flexible gastroscope in 1932, as shown in Figure 2.4. The lens was attached to the tip and about one third of the length of the scope could bend to travel through the mouth for examination of the stomach.

Currently, different types of endoscopes are available for different procedures as shown in Table 2.1. The general design is similar, including the insertion tube, or the shaft, and the control body. The differences are mostly in the size of diameter and the length of an insertion tube which depend on the location of the incision.
Figure 2.4: The first flexible endoscope developed by Dr. Rudolph Schindler in 1932. One third of the tube toward the tip could bend to a certain degree.

Figure 2.5: A modern endoscope is a long flexible tube with a camera and light sources attached to the tip. The image on the right is a close-up of the distal end of an insertion tube. Number 1 indicates the two light sources, 2 is the camera lens, 3 is the air and water release channel, and 4 is the channel for the endoscopic tools.
In a modern endoscope, as shown in Figure 2.5, the manipulation of the insertion tube is done through the control body. Two angle manipulation wheels on the control body precisely maneuver the flexible neck on the end to left/right and up/down, respectively. The head also has a small channel for tools necessary to the procedure and an air and water release channel. The images are sent to a control tower of the endoscope and output on the screen that a surgeon watches during the procedure.

### 2.2.2 Esophagastroduodenoscopy (EGD)

Esophagastroduodenoscopy (EGD) or upper endoscopy is an examination of the esophagus, stomach, and upper duodenum with a flexible endoscope as illustrated in Figure 2.6. It is the most commonly performed type of endoscopy. The procedure can be performed as an outpatient. Treatment procedure can also be performed during the operation. Training in EGD is considered to be a fundamental for other gastrointestinal endoscopies, including endoscopic retrograde choledochopancreatography (ERCP), endoscopic ultrasonography (EUS), and flexible colonoscopy.
Figure 2.6: To perform an EGD procedure, an endoscope is introduced through the patient’s mouth to examine GI tract, including the esophagus, stomach, and upper duodenum. Inset shows patient lying on her side in bed having an EGD.
CHAPTER 3

Endoscopic Simulator Review

Endoscopic training is a very important step to minimize complications from minimally invasive surgery. A surgeon must be able to perform a procedure in three-dimensional space while viewing the operation on a video monitor. These manual skills can only be mastered through extensive training. The American Society of Gastrointestinal Endoscopy (ASGE) recommends that gastroenterology fellows perform a minimum of 130 upper endoscopy procedures to become competent (Weaver et al. 2004). The current training method for fellows is to perform an endoscopic surgery under the supervision of an experienced surgeon. Patients who undergo surgery performed by fellows are likely to suffer more discomfort, prolonged procedures, and even possible unnecessary complications.
(Gerson et al. 2004). Therefore, simulators are increasingly becoming an alternative for the endoscopic training process.

The simulator in endoscopy dated back in 1969, the early models mostly consisted of bent tubing systems and were created using plastic and rubber. Animal models, usually porcine, were also used in the training process. In early 1980s, the first computer simulator is developed. Unfortunately, due to the cost of a computer platform at that time, it is not widely appreciated. In this chapter, we divide the endoscopic simulators into four different types: animal model, mechanical simulator, animal-based simulator, and virtual reality computer simulator. We will summarize the history of works related to endoscopic simulators for each type with emphasis on the models currently available.

3.1 Animal Model

Similar to other medical training procedures, animals are also used in the endoscopy training. A porcine model is commonly used for upper gastrointestinal (GI) endoscopy. While a living animal provides natural look and characteristic similar to the organs found in humans, there are many disadvantages. Firstly, even though the look and feel of the organs is similar to human, the anatomical
structures of a porcine GI tract are different. For example, there is a separate drainage of the bile and pancreatic duct into duodenum (Hochberger et al. 2001). Secondly, in order to handle the animal experiment, the training procedure requires substantial additional expenses due to the need of special animal laboratories and veterinaries support. Lastly, a highly debatable issue of the ethical and animal welfare is also the problem hindering the use of animal as a training model. The animals are sacrificed after the training procedures. Although, for this issue, most people feel that it is in some degrees acceptable if it serves the basic interest and welfare of mankind.

Figure 3.1: The use of an animal as a training model for minimally invasive surgery. Box from University of California at Irvine successfully performed a robot assisted natural orifice transluminal endoscopic surgery on a porcine model. (Box et al. 2004)
3.2 Mechanical Simulator

The first experimental model for endoscopic training dated back in 1969. Markman designed a new model for teaching rigid procto-sigmoidoscopic morphology (Markman 1969). The model consisted of a mannequin with projected images of a lower GI tract. The sequential images were projected as the scope advancing through the model. Classen and Ruppin in Erlangen presented a plastic mannequin, which allowed upper endoscopic examination by using a flexible panendoscope (Classen and Ruppin 1974). The early version of mechanical simulators only aimed to teach the students how to control the deflection wheels of the endoscope, but they often lacked an ability to simulate the training environment for a realistic maneuver of an endoscope.

In 1980, St. Marks Hospital designed a tube colon model with elastic mesenteries and appropriate fixations to simulate a looping phenomenon of colon. The model allowed a trainee to do an advanced straightening procedure. Although the model could train maneuvering skills for colonoscopy, it lacked of characteristics of living tissue and still required constant supervision of an instructor. Additional mechanical simulators that were developed between 1970s and 1990s are summarized in Table 3.1.
<table>
<thead>
<tr>
<th>Year and Author</th>
<th>Procedure</th>
<th>Simulator Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969 Markman, H.D.</td>
<td>Rigid Sigmoidoscopy</td>
<td>Mannequin with projected images of lower GI tract</td>
</tr>
<tr>
<td>1971 Heinkel, V.K.</td>
<td>Colonoscopy</td>
<td>Rubber model simulating turns of sigmoid colon</td>
</tr>
<tr>
<td>1972 Heinkel, V.K.</td>
<td>Upper Endoscopy</td>
<td>Rubber model simulating upper GI tract</td>
</tr>
<tr>
<td>1972 Williams, C.B.</td>
<td>Colonoscopy</td>
<td>Flat-board demonstration model</td>
</tr>
<tr>
<td>1974 Classen and Ruppin</td>
<td>Upper Endoscopy</td>
<td>Anatomically shaped plastic mannequin of upper GI tract</td>
</tr>
<tr>
<td>1975 Williams, C.B.</td>
<td>Sigmoidoscopy</td>
<td>Tube model simulating contour of lower GI tract</td>
</tr>
<tr>
<td>1980 St. Marks Hospital</td>
<td>Colonoscopy</td>
<td>Tube model with elastic mesenteries and fixations to mimic looping</td>
</tr>
<tr>
<td>1987 Empkie, T.M.</td>
<td>Sigmoidoscopy</td>
<td>A series of hollowed cantaloupes to simulate turns of sigmoid colon</td>
</tr>
<tr>
<td>1992 Leung, J.W.</td>
<td>ERCP</td>
<td>Model created from plumbing supplies and elastic tubing</td>
</tr>
<tr>
<td>1995 Lucero, R.S.</td>
<td>Colonoscopy</td>
<td>Plastic model simulating upper GI tract</td>
</tr>
</tbody>
</table>
The more advanced mechanical simulators are interphant model by Grund et al. from Tuebingen, Germany, as shown in Figure 3.2, and ERCP training model type E with indication function from Koken Co., Ltd., Tokyo, Japan, as shown in Figure 3.3 – 3.4 (Grund et al. 1998; Koken Co., Ltd. 2005). The interphant model is a three-dimensional anatomically shaped latex model. It includes pathological components such as polyps, tumors and malignant or benign structures. The lesions are created using an electrically conductive material called Artitex which has a wax like consistency that can be shaped as needed. According to a review from Hochberger, various electrosurgical interventions can be simulated (Hochberger et al. 2001).

The latest endoscopic training model commercially available, at the time of writing, is the ERCP training model LM-022 from Koken Co., Ltd. The model offers a realistic and accurate orientation and anatomical structures of esophagus, stomach, duodenum, and papilla of vater. It adds the fiberscope sensors to the model to enable a detection system to evaluation the completeness of the training. The buzzer will sound if a scope travels through certain areas.

Although the Koken LM-022 and Tuebingen Interphant models are complex and sophisticated, they both lack the natural structure of GI wall with the mucosal and submucosal layers, which one could say to be expected from any training
Figure 3.2: Interphant model for interventional endoscopy by Grund et al. from Tuebingen, Germany. This anatomically shaped latex model of upper GI tract includes an electrically conductive material to simulate polyps and tumors.

Figure 3.3: ERCP training model LM-022 from Koken Co., Ltd. The portable training box includes an indicating function board to check whether or not each part is observed.
3.3 Biomaterial Simulator

In mid-1990s, the simulator with a combination of animal specimen and synthetic materials was introduced. Freys is the first to report the use of porcine organs to teach an upper endoscopy (Frey et al. 1995). They secured a cleaned pig stomach simulators. However, the major drawback of a mechanical simulator, compared with other simulators, is that there is no interaction between trainee and simulator.
with a cork-board with the needles to perform a diagnostic EGC training. Hochberger and Neumann developed a similar simulator for training and teaching interventional upper GI endoscopy using the prepared porcine organ packages (Hochberger et al. 2001). The initial experiment used the anatomically shaped dummy with the visceral pig organs. Its structure is displayed in Figure 3.5. This model is called Neumann Biosimulation model. The model was designed to train the laparoscopic and open surgical procedures and could not be used for the endoscopic surgery training.

The later model was designed based on the previous models for training in endoscopic surgery, as shown in Figure 3.6 - 3.7. The Erlangen Endo-Trainer simulator consists of a mannequin head and torso which are mounted on the base that can be rotated to allow changing the position of the patient. The cleaned and specially prepared porcine organs inside of the torso need to be replaced before the beginning of each training section. Perfusion system for simulation of a bleeding ulcer is integrated to the system to allow emergency situation training. The compact-EASIE (Active Simulator for Interventional Endoscopy), shown in Figure 3.8, which is a simplified version of Erlangen Endo-Training, is also commercially available.
Figure 3.5: Neumann Biosimulation model for laparoscopic and open surgical procedure training developed in 1996 by Hochberger and Neumann. The visceral pig organs were cleaned and put inside of a mannequin.

Figure 3.6: Erlangen Endo-Trainer simulator from Erlanger Active Simulator for Interventional Endoscopy, University of Erlangen-Nurnberg. To prepare trainee for emergencies, bleeding was integrated into the model.
Figure 3.7: Basket removal of a common bile duct stone as seen on the Erlangen Endo-Trainer from Erlanger Active Simulator for Interventional Endoscopy (Gerson et al. 2004).

Figure 3.8: CompactEASIE simulator with liver, biliary system, and upper GI tract as ERCP setup plus optional perfusion pump for hemostasis training from Erlangen Active Simulator for Interventional Endoscopy.
However, there are a few drawbacks of the animal-based biomaterial simulator. Similar to the animal model, porcine anatomical structure of an upper GI tract is different from that of human, making the scope position and approach difficult to manage in some situations. It also requires much more preparation time per training, comparing to mechanical and virtual reality computer simulators. The animal organs need to be removed and re-install for every training session. Moreover, it might require a veterinary support and housing.

3.4 Virtual Reality Computer Simulator

The use of a computer simulator for GI endoscopy was first reported in 1990 (Williams et al. 1990). The simulator was adapted from the electronic video games by replacing the gaming interface with a dummy endoscope for training in left-right hand coordination and targeting skills. The subsequent model was programmed in MS-DOS operating system with a dummy colonoscope connected to the computer. The friction brake system was implemented to provide a force-feedback along with the computer generated patient groans if undue force or insufflations was applied. In 1992, Noar developed a more realistic computer simulator called the Robotics Interactive Endoscopy Simulation System (RIES) for
upper endoscopy and ERCP. Unfortunately, due to the expensive computer platform at the time, it was not widely accepted (Noar 1992).

With rapid technological advancements in 20th century, the computer simulators have emerged as an alternative for endoscopic simulation training. Currently, there are two major computer-based virtual reality simulators available on the market: AccuTouch Endoscopy Simulator by Immersion Medical Corp., California, USA and GI Mentor by SimbionixUSA Corp., Ohio, USA.

GI Mentor became the first commercial virtual reality computer simulator for GI endoscopy in 1998. It offers a three-dimensional computer graphic environment simulating GI endoscopic procedures. The simulator, which allows the training for both upper endoscopy and lower endoscopy, consists of the mannequin with a force-feedback device, the modified Pentax colonoscope, and the computer system. The camera at the tip of the colonoscope is replaced with a sensor to synchronize the scope positioning inside of the mannequin. With the latest version GI Mentor II, as shown in Figure 3.9 – 3.10, the training modules include the upper endoscopy, ERCP, lower endoscopy, flexible sigmoidoscopy and Endoscopic Ultrasonography (EUS). Different patient cases are available for each module, including the emergency bleeding situations in the upper GI. There are also games
Figure 3.9: GI Mentor II computer simulator from Simbionix USA Corp. The complete training station includes the dummy endoscope, mannequin, and computer system.

Figure 3.10: The user interface of GI Mentor II during the freehand training mode. The representation of patient feedback such as pain and amount of air are simulated on screen.
for improving the hand-eye coordination such as endoscopic basketball and endoscopic dart.

In 2000, Immersion Medical Inc. released a virtual reality endoscopy simulator called the Endoscopy AccuTouch System, as shown in Figure 3.11 – 3.13. It is similar to the GI Mentor in the sense that the training is done in the three-dimensional computer graphic generated environment. The difference is the AccuTouch computer models are developed from the actual patient data. It also uses the universal training platform, which can be used to train upper endoscopy, lower endoscopy, and bronchoscopy in the same machine.

Figure 3.11: Endoscopy AccuTouch System from Immersion Medical Inc. The universal training platform can be used for upper endoscopy, lower endoscopy, and bronchoscopy.
Figure 3.12: The video options and didactics for providing knowledge and teaching the proper techniques from the Endoscopy Accutouch System. The image represents the important organs for the ERCP procedure.

Figure 3.13: The user interface of Endoscopy Accutouch System during EGD training. Any change in physiology is shown through changes in vital signs and patient responses.
3.5 Comparison of Current Simulators

Here we compare our proposed simulator, CIES, with four other endoscopic simulators on the market: GI Mentor II from Simbionix USA Corp., Endoscopy AccuTouch System from Immersion Medical Inc., CompactEASIE from Erlanger Active Simulator for Interventional Endoscopy, and ERCP training model LM-022 from Koken Co., Ltd. Table 3.2 shows the comparison between time and cost for each simulator. Feature comparison is summarized in Table 3.3. A computer-based simulator requires a substantial one-time minimum initial investment from $40,000 up to $100,000 depending on the number and type of modules purchased. The CompactEASIE simulator requires a startup cost of around $4,000 and an additional $200 for each training session to cover the cost of the specially prepared porcine organs. While computer-based simulators have a high initial investment, the CompactEASIE, LM-022, and our CIES require a substantially lower initial investment. However, unlike the other simulators, the CompactEASIE has a cost per training session. Moreover, its set up is slow and complicated.

The training image from the CompactEASIE, LM-022, and CIES are real endoscopic images, while the GI Mentor II and AccuTouch simulators provide computer generated virtual reality images. Powered by a computer system, the GI Mentor II, AccuTouch, and CIES can provide real-time assistance, information,
TABLE 3.2: Time and cost comparison of the endoscopy simulators.

<table>
<thead>
<tr>
<th>Simulator Type</th>
<th>Initial Investment</th>
<th>Cost per Training</th>
<th>Setup Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>AccuTouch</td>
<td>&gt; $40,000</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>GI Mentor II</td>
<td>&gt; $40,000</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>CompactEASIE</td>
<td>$4,000</td>
<td>$200</td>
<td>3</td>
</tr>
<tr>
<td>LM-022</td>
<td>$2,000</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>CIES</td>
<td>$200</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

*Setup Time is based on 3-point scale (1=Fastest, 2=Fast, 3=Average)*

TABLE 3.3: Feature comparison of the endoscopy simulators.

<table>
<thead>
<tr>
<th></th>
<th>Training Image</th>
<th>Real-time Knowledge</th>
<th>Real-time Assistance</th>
<th>Evaluation System</th>
</tr>
</thead>
<tbody>
<tr>
<td>AccuTouch</td>
<td>Virtual Reality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>GI Mentor II</td>
<td>Virtual Reality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CompactEASIE</td>
<td>Endoscopic Image</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>LM-022</td>
<td>Endoscopic Image</td>
<td>No</td>
<td>No</td>
<td>Partially</td>
</tr>
<tr>
<td>CIES</td>
<td>Endoscopic Image</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
and a performance evaluation upon the completion of the training session; in contrast, the CompactEASIE and LM-022 lack interaction with users, so instructors are required for the training session. The LM-022 provides an observation function to indicate the regions of the GI tract that the users examine, which can be partially used to evaluate the performance.

Our CIES system tries to fill in the gap among commercially available systems. It includes an online knowledge database and real-time assistance features. The performance evaluation is given after completion of the training. Practicing with a real endoscope in a real operating room environment gives trainees more comfort when approaching real cases. At the same time, the CIES is a low-cost simulator, which makes it an affordable option for any training institution.
CHAPTER 4

Method and Implementation:
Mechanical Model

This chapter describes the method used to develop a mechanical model for our computer integrated endoscopic simulator for training in the upper endoscopy. The design and implementation of the mechanical model, including design, materials, and sensor system will be discussed. The procedure in this chapter may serve as a production protocol to help interested institutions or training centers manufacture such mechanical models.

4.1 Model Design

Our mechanical training model represents a human anatomy of the upper gastrointestinal (GI) tract as well as pathological lesions in the esophagus and
stomach. After a trainee acquires enough basic knowledge on upper endoscopy, they will be able to practice the hands-on skills by training with our endoscopic training simulator.

A trainee will pass an endoscope through the mechanical model to practice basic maneuver skills. The sensor system is integrated into the model to detect one of the common problems early in the learning process, pushing the endoscope too hard causing discomfort and risking perforation. Upon traversing an esophagus, as in the actual procedure, the trainee will be able to practice a retroflex skill to identify the Esophagogastric (EG) Junction. Then, the trainee will practice the biopsy techniques by attempting to place snare or biopsy forceps onto a polyp. The trainee also needs to observe and identify the location of important organs and lesions inside of the model. With the computer software, the training performances can be recorded on the computer. Help and evaluation are provided so that the trainees can practice anytime without their supervising physician.

The design of the mechanical model is done under a close supervision of an experienced gastroenterologist to ensure that an anatomical structure, color, and size are similar to that of a human. Figure 4.1 illustrates the blueprint of our mechanical model, which represents an upper GI tract, including esophagus, stomach, duodenum, and pathologies such as ulcers and polyps. Geometrically, our
mechanical model is comparable with a human anatomy. Its esophagus diameter and length are 3.5 and 30 centimeters, respectively. The volume of the stomach is approximately 1,000 cubic centimeters with the length of about 18 centimeters. The dimensions of the training box are 52 centimeters in depth, 21.5 centimeters in width, and 15 centimeters in height with the weight of 7 lbs. The sensor system is operated on AA batteries. A lightweight and portability model makes the simulator easy to use and conveniently available for students.

Figure 4.1: The design of the GI model represents human anatomy from esophagus to duodenum.
4.2 Materials

Table 4.1 shows the list of materials and costs for the mechanical model, including parts for the sensor system. They are all the common modeling and electronic items and can be found in any related shop or online. The total cost for the required materials is approximately $160, $142 for the model and $18 for the sensor system. It would be considerably less expensive if manufacture multiple models at once. An inexpensive cost would make it a feasible option for any medical training centers.

The GI model is made of a natural rubber called Para rubber, hevea brasiliensis, in this first version. Para rubber, raw material for natural latex, is chosen because it has all the suitable properties for representing an upper GI tract. It can be made to appear as if it were part of the human body. Another major advantage of the Para rubber is an elastomeric chemical property, which make this material elastic and durable. It also poses the heat and cold resistant property, which will provide the same feel and texture characteristic regardless of the temperature. Moreover, because it is the abundant natural material from Para tree, Para rubber cost is the cheapest material comparing to silicone, plastic, or resin. Pre-processed liquid latex can also be used as a substitute. From the implementation point of view, rubber is easier to cast a mold than a plastic and
TABLE 4.1: Materials and cost for the mechanical training model.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air dry modeling clay</td>
<td>$17</td>
</tr>
<tr>
<td>Amaco casting compound</td>
<td>$15</td>
</tr>
<tr>
<td>Corrugated plastic box</td>
<td>$9</td>
</tr>
<tr>
<td>AeroMarine liquid latex rubber</td>
<td>$27</td>
</tr>
<tr>
<td>(5) Plastic boards (model housing)</td>
<td>$35</td>
</tr>
<tr>
<td>(3) Silicone based paints</td>
<td>$29</td>
</tr>
<tr>
<td>Silicone adhesive</td>
<td>$6</td>
</tr>
<tr>
<td>Black foam board</td>
<td>$6</td>
</tr>
<tr>
<td>Cushioning foams</td>
<td>$4</td>
</tr>
<tr>
<td>Solderless breadboard</td>
<td>$4</td>
</tr>
<tr>
<td>AA battery holder</td>
<td>$2</td>
</tr>
<tr>
<td>Red LED</td>
<td>$1</td>
</tr>
<tr>
<td>(3) Long lever snap switches</td>
<td>$5</td>
</tr>
<tr>
<td>Resistors and wires</td>
<td>$2</td>
</tr>
<tr>
<td>Velcro fasteners</td>
<td>$4</td>
</tr>
<tr>
<td>General tools</td>
<td>Workshop</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$166</strong></td>
</tr>
</tbody>
</table>

*Some of the original materials are bought in Thailand; this table shows comparable materials and cost in the U.S.*
resin. There is no need for any special equipment since it does not involve an extremely high heat as in the plastic and resin.

4.3 Methods

Figure 4.2 shows the procedures for creating the model. After the design and material selection processes, the first step is to build a prototype model by hand to create a mold for Para rubber. For simplicity, we will refer to Para rubber as latex from this point on. Each part of an upper GI tract is built separately. First, to make a plaster mold of a stomach, a clay prototype model in the shape of stomach is created by hand under a close supervision of a gastroenterologist, by using a three-dimensional digestive system model for human anatomy/physiology class and anatomy textbook as descriptive references. At this step, the surface of the clay prototype model does not have to be very smooth since it will become the outside of a GI tract. Corrugated plastic boards are assembled as a container for the plaster mold casting (Figure 4.2a). The next step is to build a plaster mold, i.e., the “negative” of the GI tract. In brief, a parting agent such as a thin layer of petroleum jelly is applied to the surface of the clay prototype model to prevent the plaster mold from sticking to it. Plaster slurry is prepared, according to instructions for the particular plaster compound, and poured into the corrugated
Figure 4.2: Procedure for creating a GI training model. (a) A prototype stomach model is made from modeling clay. A plastic container is prepared for mold casting. (b) Half of the clay model is submerged into a liquid plaster. (c) The plaster mold is created from the clay model and is ready for liquid Para rubber latex casting. (d) The surface of the prototype model is carved to simulate the appearance of the inner surface of the GI tract. (e) Both halves of the clay prototype are placed into their molds. (f) One half of the stomach model has polyps attached to the inner surface.
plastic board container with a depth of half height of the clay model. Immediately afterward, the clay model is slowly dipped into the muddy plaster covering half of the model (Figure 4.2b). After the plaster is firmly cured (about one hour at room temperature), half of the mold is completed. The parting agent is applied to the remaining visible surface of the model and the solidified plaster surface. Plaster slurry is again poured into the container covering the whole model to form a complete mold (two halves).

After two halves of the plaster mold are completed as shown in Figure 4.2c, the clay model can be taken out of the cured plaster. The clay model is then cut into two halves horizontally. We first paint each half-model (different color from the green clay in Figure 4.2), and use a peeling knife to carve off the surface until all painted color disappears. The carved new clay model is slightly smaller than the negative mold so that there will be a roughly uniform distance between the clay model and the negative mold for casting. The surface of the clay model can now be carved to simulate the “texture” appearance of the inner surface of the stomach (Figure 4.2d). The liquid latex is mixed with dye (base color, pink color in Figure 4.2e and 4.2f) and poured into the mold. It is not required to completely fill the “negative”. However, the entire surface of the molds must be covered by the rubber. Both halves of the clay prototype model with “carvings” are placed into
their corresponding molds to cast the inner surface texture onto the rubber model as seen in Figure 4.2e. Customized painting and adding pathologies such as a polyp or ulcer can be done after the rubber is completely dry (about one day in room temperature). Figure 4.2f shows half of a stomach rubber model with polyps. Similar processes are repeated for the creation of esophagus and duodenum. Finally, two halves of stomach and other parts are glued together to form the whole mechanical model of the upper GI tract (Figure 4.3).

To assemble a mechanical model, the whole rubber model is placed and secured into a training box, which is made from six pieces of a hard plastic board.

Figure 4.3: The training model represents an upper GI tract. Specific anatomical parts are fixed within a box to allow the maneuvering of the endoscope through the model.
Lower esophagus, second part of a duodenum, and the lower end of the model around jejunum are fastened to the training box to allow maneuvers of the endoscope through the model. The mouth part is connected and screwed to the outside of the training box and serves as the entrance to the model. The total time requires to build the model is approximately four to five hours, excluding the waiting time. Additional models can be built with considerably less time since the only changes will be adding various customized pathologies at different locations and there is no need to create a new mold or clay model. Training procedures can be performed by using this mechanical model in conjunction with a commercial endoscope tower in a real operating room setup and a computer with the software installed. Based on our testing, the in-house made mechanical model can last for hundreds training sessions before requiring a replacement.

4.4 Sensor System

In order to add an interaction with the trainee and detect a common problem in an early training process, we incorporated a sensor system with the mechanical model. One of the most common problems in an early stage of the training is pushing an endoscope too hard without proper manipulation of the tip, subsequently causing discomfort and risking perforation. A sensor can be used to alarm trainee when an
unusual high force, from an endoscope, against the surface wall is detected. Seeing the alarm signal, the trainee can adjust how he/she perform during the practice and learn to avoid the same mistake in the future.

We chose to attach three sensors in the model for this first version. More sensors can easily be added later. Based on a recommendation from experienced endoscopist, we installed the three sensors in the areas of EG junction in the lower esophagus, upper area of greater curvature, and antrum, as seen in Figure 4.4. The circuit for the sensor system is fairly simple as shown in Figure 4.5. An uncommonly high force against the surface wall will activate the switch and notify the trainee of an inappropriate maneuvering. Long lever snap switches are used as the sensors. LED is used as an indicator. The power source is four regular 1.5 volts AA batteries. Since the switches are connected in parallel, the circuit carries current if any switch is on, a logical OR. Thus, adding more switches to the circuit can be done with ease by connecting a new switch in parallel with other switches.

The sensors are secured to the model by a removal hook and loop Velcro to allow a modification of the positioning and activation pressure. An instructor can manually change the location or adjust the nearness of the sensor to the surface wall, resulting in more or less sensitivity. The cushioning foam is added to loosely
Figure 4.4: Sensors and the circuit inside of the mechanical training model. The three sensors are circled.

Figure 4.5: Schematic diagram of the sensor system circuit. Long lever snap switches are used as sensors to detect unusually high pressure against the GI wall.
Figure 4.6: Complete mechanical training model with the sensor system. The LED is visible to alarm a trainee of improper maneuvering of the endoscope.

support the GI model and further secure the sensors in place inside of the training box. The complete mechanical training model is shown in Figure 4.6.
CHAPTER 5

Method and Implementation: Computer Software

Using a simulator system in upper endoscopy training has two advantages: 1) it reduces the reliance on patient; and 2) it improves the maneuvering skills of entry-level gastrointestinal (GI) fellows during the early stage of training. The computer software of our Computer Integrated Endoscopic Simulator (CIES) creates an interaction between the user and the simulator. It provides knowledge-based information, practice tasks, and assessment of the trainee’s maneuvering performance and diagnostic skills to ensure competency. With the computer software, trainees can practice anytime and as much as they want without a supervising physician. In this chapter, we present a framework and software configuration for our training simulator. More details, including methods and
algorithms, are provided on the two main technical parts of the computer software: distortion correction and image classification systems.

5.1 Simulator Configuration

The University of Miami Leonard M. Miller School of Medicine has a virtual reality simulator, the GI Mentor II, in the Department of Surgery. With this in mind, we developed a training simulator, the CIES, which combines the use of a real endoscope with the benefit of computer software. CIES will serve as an additional training option for GI fellows. Figure 5.1 illustrates the design and configuration of our training simulator.

To practice, a trainee will pass a real endoscope through the mechanical model. A computer with installed training software will be connected to the video output of an endoscope control tower through a Universal Serial Bus (USB) port. Thus, the video from the control tower can be displayed, recorded, or taken as a snapshot by the software. CIES combines the advantages of both mechanical and computer simulators, as summarized in Figure 5.2. With the mechanical model, a trainee is trained in a real endoscopic image environment. Our computer software can provide the trainee with online help, feedback, and evaluation. This system is
Figure 5.1: Illustration of the CIES. Trainee will pass an endoscope through the mechanical training model. A laptop with the training software is connected to an endoscope control tower to provide assistance, information, feedback, and evaluation.

also portable; the mechanical model can easily be stored in the operating room and the computer software can be installed on a laptop or the computer in the control tower.

The computer software consists of three main components, distortion correction, video recording, and evaluation systems, as shown in Figure 5.3. The distortion correction system is implemented to help trainees better perceive the
Figure 5.2: Advantages and disadvantages of mechanical simulator, virtual reality computer simulator, biomaterial simulator, and animal model. The CIES combines the advantages of mechanical and computer simulator together.

Figure 5.3: Illustration of the three computer software components: distortion correction, video recording, and evaluation system.
endoscopic image’s size and distance. The evaluation system reports the training performance and gives feedback to trainees upon completion of the training. Lastly, the video recording system allows trainees to record their performance during the training. While practicing and improving their endoscopic skills on the mechanical model, trainees can also request help from the software, such as video clips that explain and demonstrate basic endoscope maneuvering skills and biopsy techniques as well as the knowledge-based information for EGD procedure. With the complete set of the computer software, trainees will be able to learn the skills in upper endoscopy independently on their own time.

5.2 Computer Software Implementation

The software is developed for a PC-based computer. The minimum system requirements are Windows XP operating system with an Intel Pentium family processor, 512 megabytes of RAM, and 500 megabytes of available hard disk space. Bigger disk space is preferred to allow future expansion such as the additional instructor training or trainee performance video clips. The software is developed under the Microsoft .NET Framework with C# language. A free downloadable SQL Server Express database is used to store user information. The database’s table-definitions are shown in Figure 5.4. The library of reference images used for
Figure 5.4: Table-definition from the SQL Server Express database showing the Users and Procedures tables.

Figure 5.5: Main menu of the CIES training software. Users can enter the Practice Mode or Exam Mode. The previous performance results are recorded and can be reviewed through the View Exam History menu option.
comparison with snapshots captured during the examination procedure is stored in
the hard drive.

To use the simulator, a trainee needs to login to the program first so that
the corresponding account information can be retrieved. First time user can
register for a new account through the login page. The main menu, as shown in
Figure 5.5, provides a trainee with “Practice Mode” and “Exam Mode”. The
trainee or instructor can also review previous performances, such as scores, video
clips, and snapshot images, via the “View Exam History” menu. The “Instructor
Setting” menu is used by an instructor to set up a new mechanical training model
and calibration a new endoscopic camera. Multiple training models and endoscopes
can be set up to associate with the computer software. These settings are saved
after the initial setup.

5.2.1 Practice Mode

This mode aims to improve skills and confidence of trainees by allowing no
restriction on maneuvers and providing help when needed. The interface of
Practice Mode is displayed in Figure 5.6. When this mode is selected, the video
displayed on the PC by the software is the same as that on the endoscope tower.
The video can be enhanced by selecting the “Camera Mode” to turn on the camera
Figure 5.6: The user interface of the Practice Mode. The real-time image duplicates the image displayed on the monitor of the endoscope control tower. Users can turn on and off the camera distortion correction and video recording functions.

distortion correction function. A distortion correction system will be discussed in details in section 5.3. Trainees can practice and perfect their skills with a help of didactics and demonstration video clips. Although elapsed time is displayed, there is no time limit on the practice. Therefore, training could continue even without an instructor. The training performance video can also be recorded when the “Record” function is selected. The recorded video is saved as a video clip file under the folder associated with the username in the SQL Server Express database.
5.2.2 Exam Mode

The exam mode, as shown in Figure 5.7, has a similar interface to the Practice Mode. The aim of the Exam Mode is to test a trainee’s ability to perform an EGD. Similar to an actual upper endoscopy procedure, the trainee has to thoroughly examine the mucosa and look for abnormalities. The trainee also needs to navigate to the given anatomic regions and take snapshots. These snapshot images will be used to evaluate the thoroughness of his/her examinations by calculating the percentage of expected regions visualized. Total time and snapshot images are saved under the trainee’s username. A typical EGD lasts about five to ten minutes, so the trainee will receive a lower exam score if the exam takes more time than required. After the exam, the computer software system will automatically score the trainee’s maneuvering skills. The maneuver score is based on the correct percentage of expected regions visualized and the total time taken. Benchmarks can be set by instructors based on the average time and expected thoroughness of a typical procedure. The exam procedure is automatically recorded for further review by the trainee or an instructor.

After the trainee finishes all tasks from the Exam Mode, multiple questions associated with the procedure, such as what he/she has found and how to treat the findings, are given. These questions are adaptively programmed questions, i.e., the
next question will depend on the answer from the previous question as shown in Figure 5.8. An instructor can add as many questions to the list as needed. They are designed to test the diagnostic skill of the trainee. The diagnostic score is calculated from the answers to these questions. However, a trainee needs to achieve a full diagnostic score in order to successfully pass an exam.

![Computer Integrated Endoscopic Simulator 1.5 - Exam Mode](image)

**Figure 5.7:** The user interface of the Exam Mode. Users must take snapshots of the regions in the GI model based on the given tasks.
Figure 5.8: A series of chart illustrating the design of diagnostic questions. Answers provided by users determine the subsequent questions.

5.2.3 Instructor Setting

The computer software can be set up to work with multiple mechanical models and multiple endoscopes. For any new model, both in-house made and commercially purchased, an instructor needs to prepare the software for the first time use through the “Instructor Setting” menu. The “Setup New Mechanical Model” wizard will provide a step by step guidance, including name the model, set up the image database, and create the diagnostic questions, as shown in Figure 5.9. To set
up the image database, the instructor navigates through the model and takes multiple snap-shot images from each location. These images and their corresponding classes are entered to the computer. Then, the software will build a classifier for the corresponding model. In order for the distortion correction system to work accurately, an endoscope used for the first time also requires a calibration. An automatic calibration template is provided to greatly simplify this process, which will be discussed in section 5.3.1. The mechanical model set up and endoscope calibration processes are only needed to be completed once for any new mechanical model or endoscope.

Figure 5.9: The user interface of the Instructor Setting Mode. The instructor can set up multiple mechanical models to be used in later training sessions. Calibration of an endoscope can also be done in this menu option.
5.3 Endoscopic Distortion Correction System

Wide-angle lenses suffer from barrel distortion while zoom lenses suffer from pincushion distortion. Figure 5.10 shows these different distortion types for a lens. The point of focus for the endoscopic lens must be a short distance from its optical center due to the limited strength of light available. Thus, an extremely wide angle of view is needed to cover as much of the area as possible, which causes a severe barrel distortion. Moreover, the lens needs to be small enough to fit in the tip of the tiny examination tube of the endoscope. Therefore, regardless of type or manufacturer, barrel distortion will always present in an endoscopic image.

The spatial distortion results in a nonlinear change in the size and relative position of the image away from the center field of view, which can be clearly visualized in Figure 5.11. Therefore, objects in an image farther from the center of the field of view look significantly smaller than their actual size. Without necessary correction, subsequent analysis might suffer tremendous errors due to the false perception of size in the outer areas of the image.

Distortion correction in image processing is to find the transformation function to map from the distorted image to the corrected image as shown in equation 5.1.

\[ g(x, y) = T(f(x, y)) \]  

\( (5.1) \)
Figure 5.10: Illustration comparing the different types of distortion. Left: the undistorted grid image. Middle: the image representing barrel distortion. Right: the image representing pincushion distortion.

Figure 5.11: Endoscopic snapshot of a sheet of graph paper from an Olympus XQ 140 video gastroscope. The image clearly shows the result of a nonlinear distortion.
There are different types of transformation such as affine transformation for linear transform and polynomial function for nonlinear transform. Their purposes are to convert an image into other different perspective as illustrated in Figure 5.12.

Several methods are available for the distortion correction for the camera with normal viewing objective lens, but these approaches are not effective for the wide-angle lens of the endoscopes. Smith is the first to present the method for distortion correction in endoscope images (Smith et al. 1992). He gave a

![Figure 5.12: Example of various image mapping functions: (a) similarity transform; (b) affine transform; (c) perspective projection; and (d) elastic Transform.](image-url)
formulation using orthogonal Chebyshev polynomials to determine the model parameters by manually choosing the dots off the screen. These Chebyshev polynomials take the form of

$$ P_{j:N}^{(i)} = \sum_{k=0}^{j} (-1)^{k} \binom{j}{k} \binom{j+k}{k} \frac{i^{(k)}}{N^{(k)}} $$  \hspace{1cm} (5.2) 

where the $P_{j:N}^{(i)}$ are a set of polynomials that are orthogonal when evaluated at the $N+1$ integers $i = 0, 1, 2, \ldots, N$. $i^{(k)}$ is the factorial $i(i-1)(i-2) \ldots (i-k+1)$.

Asari proposed a new methodology for video endoscopic distortion correction based on the least squares estimation to create the mathematical model to map the images from distorted space onto the corrected space (Asari et al. 1999). The graph paper with the dots is used for calibration. Let $P_{ij}$ denote the center of a test dot in $i^{th}$ row and $j^{th}$ column. A set $S_j$ consisting of test dot center of the $j^{th}$ column is defined as

$$ S_j = \{ P_{1j}, P_{2j}, \ldots, P_{kj} \} $$  \hspace{1cm} (5.3) 

where $k_j$ is the number of dots in column $j$. The polynomial of degree $M$ is defined as

$$ S_j(x) = \sum_{a=0}^{M} b_{aj} x^a. $$  \hspace{1cm} (5.4) 

The least squares estimation is then used to estimate the coefficients $b_{aj}$. Helferty later applied similar method to the application of endoscopic virtual guidance
Miranda-Luna proposed a different method for endoscopic distortion correction based on grey level registration (Miranda-Luna et al. 2004). Let an original non-distorted image be represented by $U$, distorted acquired image be represented by $V$, and corrected image be represented by $W$. Mutual information of grey level distributions is used to measure a similarity between superimposed parts of two images.

\[ I(U, W) = H(U) + H(W) - H(U, W) \]  \hspace{1cm} (5.5)

$I(U, W)$ is the mutual information where $W = TV$ corresponds to a corrected image. To determine the parameters values of optimized transformation ($\sim T$), the mutual information function is used as

\[ \sim T = \text{average}_{\sim T} \max(I(U, TV)) \]  \hspace{1cm} (5.6)

Because only a radial distortion is expected for an endoscope, the goal is to calculate the expansion polynomial coefficients to alter the distance in the radial direction for the real-time correction. We simplify the distortion correction method based on least squares estimation previously proposed by Asari. Instead of using all the dots in the graph paper, only the reference points on the diagonal line are used to calculate the polynomial coefficients. Thus, a calibration process is greatly simplified.
5.3.1 Automatic Calibration Method

In order to automatically calculate the expansion polynomial coefficients, we designed the special graph paper for the calibration as shown in Figure 5.13. The dots are placed at the corner of the grid boxes on the diagonal line. They will be used as reference points in the automatic calibration process. Each dot is four millimeters in diameter. The grid box is seven by seven millimeters square.

The automatic reference points finding system is implemented to automatically perform a calibration process from a single endoscopic image. The
expansion polynomial coefficients can also be calculated using the specially designed graph paper in this one step process. Therefore, to calibrate an endoscope in our software, the user simply uses the template in our software to take a snapshot of the calibration graph paper. The distance of the endoscope can be varied depending on the size of the graph paper and the resolution of the endoscope. An overview of the automatic calibration process and the snapshot of the template with the calibration graph paper are shown in Figure 5.14.

Figure 5.14: Illustration of the automatic procedure for expansion polynomial coefficients calculation of a distorted endoscopic image. On the right is an endoscopic image of the calibration graph paper in the camera calibration template.
5.3.2 Reference Points Finding

The next step of the calibration process is to locate the center of the candidate dots to be used as the reference points and then estimate the grid size to calculate the theoretical points. The reference points are the center of the candidate dots in the distortion image. The theoretical points are the expected center of the candidate dots in the corrected image. To locate the center of the candidate dots in the distorted image, we use the edge detection technique to locate the approximate area of the dot to set the searching windows for the cross correlation technique to find the exact location of the dot. Figure 5.15 – 5.17 illustrates the automatic dot extraction procedure.

- Edge Detection

First, the edge detection technique is applied to find the rough center of the object in order to define the searching windows. The edges in an image are the areas with the strong intensity contrasts. Let the difference in intensity from two side of the coordinate \((x,y)\) is represented by \(D(x,y)\) and the total number of pixels on each side to be considered is represented by \(n\). The edge is detected by calculating the difference in the average of the intensity of the pixel on the two different sides of the candidate pixel by the following equation
The sharply increases in the $D(x,y)$ will represent the edge areas. After the edge
detection has found the area where the dot is located, the cross correlation
technique is applied to find the exact center of the dot.

- Cross Correlation

The cross correlation is then use to find the exact center of the dot. This technique
is to measure the similarity between two images in terms of their spatial
distributions of the image intensities. With this method, one image is held fixed
while the second is translated to overlay the first in every possible position. We use
the iteration approach to run through the searching window. Let the correlation
coefficient of the coordinate $(k,l)$ be represented by $R(k,l)$, the intensity of the
coordinate $(i,j)$ in the pattern image be represented by $A(i,j)$, and the intensity of
the coordinate $(i+k,j+l)$ in the searching window be represented by $B(i+k,j+l)$. Coordinate $(k,l)$ run through the size of the searching window and coordinate $(i,j)$
run through the size of the pattern image. The correlation coefficients are returned
for all pixel locations by the following equation

$$R(k, l) = \frac{\sum_i \sum_j A(i,j) \times B(i+k,j+l)}{\sqrt{(\sum_i \sum_j A(i,j)^2) \times (\sum_i \sum_j B(i+k,j+l)^2)}} \quad (5.8)$$
Figure 5.15: Illustration of the dot extraction procedure for the center point. The location of the dot is extracted using cross correlation from the searching region defined using edge detection.

Figure 5.16: Illustration of the dot extraction procedure for the second point from the center on the diagonal line.
This operation is equivalent to moving along the searching window in every possible location. The center of the location that holds the maximum correlation coefficient in the searching window represents the center of the dot. The center of the dot is recorded as a reference point. We repeat the process of the edge detection to find the searching window and cross correlation to find the dot center along the diagonal line to record all the reference points. With the assumption that the distortion in the center area of an image is negligibly small, the size of the grid box can be calculated from the coordinate between the reference point closest to the center and the reference point in the center. Hence, the theoretical points in
the corrected image can be calculated from the distance in the number of grid boxes from the center reference point.

5.3.3 Expansion Coefficients Calculation

After locating all the reference points and theoretical points, the expansion polynomial coefficients can be calculated. Because the distortion of the endoscope is radial about the distortion center, the nonlinear magnification of the polar coordinate is needed. Since the expansion polynomial coefficients are equivalent to the magnification of the distance in radial direction, the relationship between the distorted image space and corrected image space is defined as

\[
\rho = \sum_{n=1}^{N} a_n \rho^m, \quad \theta = \theta'
\]  

(5.9)

Let the distorted image center and corrected image center be represented by \((u', v')\) and \((u, v)\). The position in pixel of distorted image space and corrected image space be represented by \((x', y')\) and \((x, y)\). The magnitude of the vector from any pixel to the distorted image center and corrected image center is represented by \(\rho'\) and \(\rho\). The angle between this vector and the horizontal axis of the distorted image space and corrected image space is represented by \(\theta'\) and \(\theta\). The representation in polar coordinate of the distorted image space defined as

\[
\rho' = \sqrt{(x' - u')^2 + (y' - v')^2}, \quad \theta' = \arctan\left(\frac{y' - v'}{x' - u'}\right)
\]  

(5.10)
The representation in polar coordinate of the corrected image space is defined as
\[ \rho = \sqrt{(x-u)^2 + (y-v)^2}, \quad \theta = \arctan\left(\frac{y-v}{x-u}\right) \]  
(5.11)

- **Least Mean Square Estimation**

The reference points we calculated earlier represent the sample pixels from the distorted image space, similarly the theoretical points represent the corresponding pixels from the corrected image space. Least square estimation is the method to find the best fitting curve from the given sample points. The Least squares Kth degree polynomials method which \( a_0, a_1, \ldots, a_k \) are unknown polynomial coefficients is defined as
\[ y = a_0 + a_1 x + a_2 x^2 + \ldots + a_k x^k \]  
(5.12)

After the partial derivatives, given n points and fitting with polynomial coefficients \( a_0, a_1, \ldots, a_k \) yield the simple form of
\[
\begin{bmatrix}
 y_1 \\
 y_2 \\
 \vdots \\
 y_n 
\end{bmatrix} =
\begin{bmatrix}
 1 & x_1 & x_1^2 & \ldots & x_1^k \\
 1 & x_2 & x_2^2 & \ldots & x_2^k \\
 \vdots & \vdots & \vdots & \ddots & \vdots \\
 1 & x_n & x_n^2 & \ldots & x_n^k 
\end{bmatrix}
\begin{bmatrix}
 a_0 \\
 a_1 \\
 \vdots \\
 a_n 
\end{bmatrix}
\]  
(5.13)

This matrix equation can be solved by
\[ A = (X^T X)^{-1} X^T Y \]  
(5.14)
• Back-Mapping

Once we have computed the expansion polynomial coefficients, all the pixels in the distorted image space can be mapped onto the corrected image space. Since the corrected image is the nonlinear magnification of the distorted image, there will be vacant pixels left in the corrected image as shown in Figure 5.18. The back-mapping method is then used to obtain the corresponding image intensity information of these pixels.

The expansion back-mapping polynomial coefficients are derived to map every pixel from the corrected image space onto the distorted image space. According to the least square matrix equation above, the expansion back mapping polynomial coefficients can be calculated by using

\[ Y = \rho', \quad \rho' = \sqrt{(x' - u')^2 + (y' - v')^2} \]  \hspace{1cm} (5.15)
\[ X = \rho, \quad \rho = \sqrt{(x - u)^2 + (y - v)^2} \]  \hspace{1cm} (5.16)

After the expansion back-mapping polynomial coefficients are calculated, the corresponding \( \rho' \) of the distorted image space can be calculated from \( \rho \) of any pixel in the corrected image space and the image intensity information contained in that pixel in distorted image space is assigned to the pixel in corrected image space.

Finally, the size of the corrected image will be bigger than the distorted image as a result of the stretching. Because of the severe distortion in the corner
Figure 5.18: Result of the nonlinear distortion correction without back-mapping. Vacant pixels can be seen throughout the image.

Figure 5.19: Corrected image after back-mapping without image size limitation. Because of the difference in distortion severity across the image, there is no pixel value in some of the border areas.
areas compared to the center areas, the limitation in size of the corrected image is
set to prevent the empty pixels in the image. The corrected image without the
limitation in size is shown in Figure 5.19.

5.4 Endoscopic Image Classification System

To evaluate the maneuvering skills automatically, the software must be able to
determine the correct categories of the endoscopic images taken by the trainee for
the given tasks during the exam procedure. The software checks whether the
images taken fall into the correct class for the given task. In our case, the
endoscopic images are categorized into four classes: esophagus area (E),
gastroesophageal junction (G), corpus area (C), and polyp (P).

Previous works on endoscopic images classification mainly focused on binary
classification to identify cancer regions (Wang et al. 2001, Majewski et al. 2005,
Iakovidis et al. 2006). In this work, however, we implement the multiple classes
endoscopic image classification to identify the different regions and pathologies in
upper GI tract. We experimented with two datasets of endoscopic images from
EGD procedures; the dataset of images performed on our CIES, as shown in Figure
5.20, and the dataset which combines the images from both simulator systems and
actual patients. Since an endoscopic image poses rich information expressed by
Figure 5.20: A dataset of endoscopic images taken from our CIES (application dataset).

texture features and Support Vector Machine (SVM) has demonstrated superior performance in the texture classification tasks (Kim et al. 2002, Li et al. 2003), we implement the classification scheme for this task using SVM. Generally, image classification consists of two important steps, feature selection and classification. For our approach, instead of using feature extraction methods such as Gabor filter, wavelet filter, or Markov models (Jain et al. 1991, Lu et al. 1997, Nefian et al.
1998), we directly used intensity values of the raw pixels as input features for the Support Vector Machine (SVM).

SVM is based on the principle of structural risk minimization and was first proposed by Vapnik in 1995. SVM technique integrates dimension reduction and classification with its special capability to learn independently of the number of features. The key idea is to compute the maximum margin hyperplane. The hyperplane is the decision surface that separates the positives from the negatives. The margin is the distance from the hyperplane to the closest training points. Among the possible hyperplanes, the SVM method selects the optimal one where the margin is the largest. The examples nearest to the hyperplane are deemed the support vectors.

Figure 5.21: Illustration of the Support Vector Machine algorithm. The algorithm determines the maximum margin hyperplane that separates the two classes.
Initially, let us consider the case for which the data are linearly separable between the two classes. Linear SVM constructs a separating hyperplane represented by \( w \cdot x + b = 0 \), where weight vector \( w \) is normal to the hyperplane, and a bias \( b \) is proportional to the distance to the origin. Let \( x \) be an example, a binary decision is thus made according to an indicator function

\[
\text{sign}(w \cdot x + b) = \begin{cases} 
+1, & \text{if } w \cdot x + b > 0 \\
-1, & \text{otherwise}
\end{cases}
\]  

(5.17)

The margin can be obtained in terms of \( w \) and is given as \( 1/||w|| \), where \( ||w|| \) denotes the Euclidean norm of \( w \). SVM thus finds a \( w \) that maximizes the margin by

\[
\text{minimize: } \frac{1}{2} w \cdot w \\
\text{subject to: } c_i(w \cdot x_i + b) \geq 1
\]  

(5.18)

where \( c_i \) is the corresponding class label of each training instance \( x_i \).

However, it is unlikely that data are completely separable without error. In such cases, all data points cannot be correctly classified by a single linear separating hyperplane. Some data must be left out on the wrong side of a decision boundary. Linear SVM therefore seeks to simultaneously minimize the misclassifications while also maximizing the margin, called soft-margin SVM. This can be done by introducing a penalty for misclassification and the formula thus becomes
In the above formula, the nonnegative variables \( \xi_i \) is the overall penalty for individual misclassification. If \( x_i \) is misclassified, then \( \xi_i > 1 \). Hence, \( \sum_{i=1}^{n} \xi_i \) gives the total errors on the training set, which is traded off against the margin controlled by the parameter \( C \). A larger \( C \) leads to small number of misclassifications and smaller margin and vice versa. It can be difficult for SVM to find the weight \( w \) to construct the maximum margin hyperplane. Practically, rather than solving formula directly, the task is instead transformed into a quadratic optimization problem having the same solution as the original question but in a less complicated way of solving.

One of the main advantages of SVM is that it can be transformed into non-linear classifiers. SVM has an ability to generalize in order to accommodate a decision surface that is a non-linear function of the training data. This is achieved through mapping the training data points in the original input space \((x_i \cdot x_j)\) to a higher dimensional feature space \((\Phi(x_i) \cdot \Phi(x_j))\). However, through the use of kernel function, the actual mapping of the input data into the feature space is avoided. SVM can find a hyperplane in a feature space which is equivalent to finding a non-linear separating surface in the input space, this is known as kernel trick.
By applying the kernel trick, SVM learns polynomial classifier, radial basis function classifier, or any other appropriate classifier depending on the chosen kernel. A commonly used polynomial function kernel of order $p$ can be expressed as

\[ K(x_i, x) = \phi(x_i) \cdot \phi(x) \]  

(5.20)

As stated earlier that SVMs are invented for two-class problem. We implemented a strategy for multiple classes by using multiple SVMs classifiers based on the approach of one-against-all (OAA) and one-against-one (OAO). For the $p$-th class, the former approach creates a training set where those examples whose label is the $p$-th class are deemed positive and all others negative. From each of these training sets, the machine-learning system induces a separate binary classifier. The latter approach induces a separate binary classifier for every pair $(p, q)$ of class labels. Let $T$ be total number of classes. OAA made up of $T$ SVMs binary classifiers, one for each class. OAO made up of $T(T - 1)/2$ SVMs binary classifiers, one for each pair of classes. In our method, we induce all of these binary learners, this means we have a total of $T + T(T - 1)/2$ SVMs classifiers. For each OAA classifier, one point is given to the corresponding class for each positive assignment made, no score is given otherwise. On the other hand, all class
assignments made by OAO classifier are given a smaller score of $1/(T - 1)$. The final decision is made based on the combined score of all classifiers.

Using a trained SVM classifiers, an evaluation system can determine whether or not the images taken by trainee during the exam procedure is the expected images for the given tasks, i.e., the images taken fall into the expected classes after the classification process.

### 5.5 Video Recording System

The last piece of the computer software is the video recording system. It allows training performances to be recorded and then review at later time. It also provides trainee with the help during practicing through the online knowledge database and training video clips.

![Figure 5.22: A screenshot of the training helper in the Practice Mode. The video recording system allows side by side viewing of the training video clips.](image)
CHAPTER 6

Empirical Results

In this chapter, the results of the visual observation, numerical analysis of distortion correction and image classification, and the survey result from experts and prospective users on our endoscopic simulator are described. We start with the visual observation of the anatomy of gastrointestinal (GI) tract and pathologies inside of our mechanical model. Next, the results of the distortion correction are presented. As for the endoscopic image classification, we performed an experimental comparison between different input features and different Support Vector Machine (SVM) kernels. Last section reports the survey result on our Computer Integrated Endoscopic Simulator (CIES) from GI surgeons and fellows.
6.1 Visual Observation

The images of the areas and pathologies inside of our mechanical model are taken to show the visual appearance of the training scene. Figure 6.1 illustrates the location of the polyp and gastric ulcers. We separate the model into three areas:
based on the location, esophagus to the entrance of stomach (a), greater curvature (b), and antrum to duodenum (c). Figure 6.2 shows the images of esophagus and Esophagogastric (EG) junction taken from area (a). Figure 6.3 and 6.4 shows the images of the pathologies and the training operation taken from area (b) and (c). Several GI doctors confirmed that the visual appearance of our model is closely resemblance to the actual upper GI tract.

Figure 6.2: Endoscopic images of the esophagus and EG junction inside of the training model from area (a) in Figure 6.1.
Figure 6.3: Endoscopic images of the gastric polyp and the polyp snaring procedure inside of the training model from area (b) in Figure 6.1.

Figure 6.4: Endoscopic images of the gastric cardia and gastric ulcers inside of the training model from area (c) in Figure 6.1.
6.2 Endoscopic Distortion Correction

The computer software for automatic calibration and nonlinear distortion correction has been tested with the designed graph paper and the mechanical training model using the Olympus XQ140 video gastroscope. Figure 6.5 (a) is the original input video image from the endoscope of the calibration graph paper and Figure 6.5 (b) is the same image after the automatic calibration and nonlinear distortion correction. The curved grids outside the center area from the original image clearly shows the effect of lens distortion. The size of the dots in the corner areas also appears smaller than the dots in the center area. After the nonlinear distortion correction, the square grids in the outer areas suffer less effect from the distortion and the dot sizes look virtually equal throughout the image.

Similar to the graph paper, the result of the nonlinear distortion correction of the image of the polyp inside the mechanical training model is shown in Figure 6.6. The polyp on the top right of the image in the distorted image and corrected image clearly shows the different in size while the details of the area around the center of both images remain the same. Result from the distortion correction system reflexes more accurate measurement of the lesion size.
Figure 6.5: Comparison of the nonlinear distortion correction for an image of the calibration graph paper: (a) the original input image from an endoscope; (b) the image after the automatic calibration and nonlinear distortion correction.

Figure 6.6: Comparison of the nonlinear distortion correction for an image of the polyp inside of the mechanical training model: (a) the original input image from an endoscope; (b) the image after a nonlinear distortion correction. The object at the corner of the image was so distorted that the actual size was visually reduced by almost 100%.
To evaluate the result of the nonlinear distortion correction quantitatively, we compared the average distance error and the average object size error between the distorted image and corrected image. The average distance error is the average number of pixels difference from the actual location for each selected pixel in the image. Likewise, the average object size error here is based on the average area difference in square-pixel from the actual size for each selected dot in the calibration image.

6.2.1 Average Distance Error

Figure 6.7 illustrates the result of the nonlinear distortion correction system. The actual expected grid lines are overlaid on both original image and corrected image to demonstrate the effect of the distortion. The calculation is based on the difference in the distance to the theoretical points. The numerical result of the average distance error is presented in Table 6.1 as well as the comparison of an average distance error between distorted image and corrected image in Figure 6.8. The graph shows that the further away from the center, the more average distance error, which corresponds to the expected effect of the wide-angle lens. But the average distance error in the distorted image increases exponentially while increases linearly in the corrected image.
Figure 6.7: Comparison of the nonlinear distortion correction for an image of the calibration graph paper with the correct grid lines: (a) the original input image from an endoscope; (b) the image after the automatic calibration and nonlinear distortion correction.

<table>
<thead>
<tr>
<th>Distance from the Center (in number of grid)</th>
<th>Distorted Image Error (in pixels)</th>
<th>Corrected Image Error (in pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>$1.5 \pm 0.5$</td>
<td>$0.5 \pm 0.5$</td>
</tr>
<tr>
<td>3</td>
<td>$5.5 \pm 0.5$</td>
<td>$1.5 \pm 0.5$</td>
</tr>
<tr>
<td>4</td>
<td>$14 \pm 0$</td>
<td>$4 \pm 1$</td>
</tr>
<tr>
<td>5</td>
<td>$26 \pm 0$</td>
<td>$6.5 \pm 2.5$</td>
</tr>
<tr>
<td>6</td>
<td>$42 \pm 1$</td>
<td>$7.5 \pm 2.5$</td>
</tr>
</tbody>
</table>
Figure 6.8: Relationship between average distance error and distance from the center of the distorted image and corrected image.

6.2.2 Average Object Size Error

Similar to the average distance error, Figure 6.9 illustrates the result of the nonlinear distortion correction system. The actual expected dot size marks are overlaid on both original image and corrected image to demonstrate the effect of the distortion in size. The object size error is calculated based on the object size in the center of the image, with the assumption that there is no or minimal distortion effect around the center field of view. The numerical result of the average object size error is presented in Table 6.2 as well as the comparison of the distorted image
Figure 6.9: Comparison of the nonlinear distortion correction for an image of the calibration graph paper with the correct dot size: (a) the original input image from an endoscope; (b) the image after the automatic calibration and nonlinear distortion correction.

<table>
<thead>
<tr>
<th>Distance from the Center (in number of grids)</th>
<th>Distorted Image Error (in pixels²)</th>
<th>Corrected Image Error (in pixels²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>38.4</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>74.4</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
<td>2.4</td>
</tr>
<tr>
<td>6</td>
<td>124.8</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Figure 6.10: Relationship between average object size error and the distance from the center of the distorted image and corrected image.

and corrected image in Figure 6.10. The corrected image shows significantly low average size error, and it remains steadily low regardless of the distance to the center. In contrast, the average size error of the distorted image increases as the distance to the center increases.

### 6.3 Endoscopic Image Classification

For an endoscopic image classification, which is used in the automatic evaluation system, the experiments were performed on two datasets. First, a
dataset of 44 digital endoscopic images from the EGD procedures performed on our simulator system (Figure 5.20). This dataset is similar to the actual dataset that will be used in our actual simulator application. For the second dataset, we also experimented on the digital endoscopic images from EGD procedures performed on both patients and simulator systems to confirm the validity of the classification scheme on endoscopic images. A combined total of 100 digital endoscopic images are used in this dataset. The images for both datasets fell into four classes: esophagus area (E), gastroesophageal junction (G), corpus area (C), or polyp (P).

Three types of feature, normalized gray scale, down-sample RGB (Red-Green-Blue), and dimension reduction using Principle Component Analysis (PCA), are used as an input for the SVM classifier. The input images are resized to 96 × 96 pixels. Normalized gray scale uses normalized intensity values of the image as input features. Similar to normalized gray scale, down-sample RGB directly uses red, green, and blue intensity values as input features. However, we down-sample the RGB to reduce the size of input features by a factor of k, we used three in our experiments. That is, we divide an image into k-by-k blocks and keep only the intensity value at the center of a block. Lastly, we performed a dimension reduction using PCA on gray scale image to use as input features. PCA transforms a number of possibly correlated variables into a smaller number of uncorrelated
variables called principal components. The first principal component accounts for
as much of the variability in the data as possible, and each succeeding component
accounts for as much of the remaining variability as possible. In our experiments,
the first 50 principal components are retained as input features for the SVM
classifier.

SVM classifier with different kernel functions was tested in our experiments.
Three kernels, linear, third degree polynomial, and radial basis function (RBF) are
compared. To evaluate the classification performance, three widely used statistical
measurements; precision, recall, and F-measure are employed. Precision is a
measure of fidelity, i.e., the number of samples correctly classified divided by the
total number of samples classified. Recall is a measure of completeness, i.e., the
number of sample correctly classified divided by the total number of positive
samples. In a classification task, a precision score of 1.0 for a class C means every
item labeled as belonging to class C does indeed belong to class C. However, it does
not consider the number of items from class C that were not labeled correctly.
Recall of 1.0 means every item from class C was labeled as belonging to class C.
Similarly, it does not take into account about how many other items were
incorrectly also labeled as belonging to class C. Equation 6.1 and 6.2 represent
precision and recall, respectively.
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The F-measure combines the precision and recall equally into a single measure using the following equation:

\[
\text{Precision} = \frac{\text{TruePositive}}{\text{TruePositive} + \text{FalsePositive}} \tag{6.1}
\]

\[
\text{Recall} = \frac{\text{TruePositive}}{\text{TruePositive} + \text{FalseNegative}} \tag{6.2}
\]

\[
F\text{-measure} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}} \tag{6.3}
\]

Performance of SVM classifier using three difference kernels with various input features on dataset 1, referred as “application dataset”, and dataset 2, referred as “full dataset”, are shown in Table 6.3 and 6.4, respectively. As expected, the application dataset performs better than the full dataset with the best F-measure of 0.977 comparing to 0.870. Nevertheless, the characteristic is similar for both datasets. SVM with linear and polynomial kernels performances are relatively equal and they perform better than RBF for all cases. As for the input features, both normalized gray scale and down-sample RGB performances are better than pre-processing image using PCA. This shows that SVM can perform quite well even in our image classification tasks without any external feature extraction method. Overall, the best average result was achieved when using normalized gray scale and polynomial kernel. Using down-sample RGB or linear kernel provides comparable results, less than 0.060 lower in all performance measures.
TABLE 6.3: Performance comparison between different input features and different SVM kernels on dataset 1 (application dataset).

<table>
<thead>
<tr>
<th></th>
<th>Precision</th>
<th>Recall</th>
<th>F-measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB Features + RBF Kernel</td>
<td>0.590 (0.111)</td>
<td>0.563 (0.082)</td>
<td>0.568 (0.155)</td>
</tr>
<tr>
<td>RGB Features + Poly Kernel</td>
<td><strong>0.979 (0.042)</strong></td>
<td><strong>0.977 (0.046)</strong></td>
<td><strong>0.977 (0.026)</strong></td>
</tr>
<tr>
<td>RGB Features + Linear Kernel</td>
<td><strong>0.979 (0.042)</strong></td>
<td><strong>0.977 (0.046)</strong></td>
<td><strong>0.977 (0.026)</strong></td>
</tr>
<tr>
<td>Grayscale Features + RBF Kernel</td>
<td>0.520 (0.159)</td>
<td>0.445 (0.205)</td>
<td>0.477 (0.271)</td>
</tr>
<tr>
<td>Grayscale Features + Poly Kernel</td>
<td><strong>0.979 (0.042)</strong></td>
<td><strong>0.977 (0.046)</strong></td>
<td><strong>0.977 (0.026)</strong></td>
</tr>
<tr>
<td>Grayscale Features + Linear Kernel</td>
<td>0.957 (0.050)</td>
<td>0.955 (0.053)</td>
<td>0.955 (0.037)</td>
</tr>
<tr>
<td>PCA Features + RBF Kernel</td>
<td>0.674 (0.147)</td>
<td>0.657 (0.115)</td>
<td>0.659 (0.155)</td>
</tr>
<tr>
<td>PCA Features + Poly Kernel</td>
<td>0.674 (0.147)</td>
<td>0.657 (0.115)</td>
<td>0.659 (0.155)</td>
</tr>
<tr>
<td>PCA Features + Linear Kernel</td>
<td>0.808 (0.180)</td>
<td>0.795 (0.155)</td>
<td>0.797 (0.153)</td>
</tr>
</tbody>
</table>

TABLE 6.4: Performance comparison between different input features and different SVM kernels on dataset 2 (full dataset).

<table>
<thead>
<tr>
<th></th>
<th>Precision</th>
<th>Recall</th>
<th>F-measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB Features + RBF Kernel</td>
<td>0.243 (0.025)</td>
<td>0.240 (0.033)</td>
<td>0.240 (0.018)</td>
</tr>
<tr>
<td>RGB Features + Poly Kernel</td>
<td>0.826 (0.146)</td>
<td>0.810 (0.089)</td>
<td>0.813 (0.101)</td>
</tr>
<tr>
<td>RGB Features + Linear Kernel</td>
<td>0.863 (0.085)</td>
<td>0.860 (0.101)</td>
<td>0.860 (0.081)</td>
</tr>
<tr>
<td>Grayscale Features + RBF Kernel</td>
<td>0.192 (0.134)</td>
<td>0.240 (0.173)</td>
<td>0.206 (0.138)</td>
</tr>
<tr>
<td>Grayscale Features + Poly Kernel</td>
<td><strong>0.872 (0.094)</strong></td>
<td><strong>0.870 (0.089)</strong></td>
<td><strong>0.870 (0.088)</strong></td>
</tr>
<tr>
<td>Grayscale Features + Linear Kernel</td>
<td>0.862 (0.091)</td>
<td>0.860 (0.095)</td>
<td>0.860 (0.088)</td>
</tr>
<tr>
<td>PCA Features + RBF Kernel</td>
<td>0.344 (0.119)</td>
<td>0.320 (0.033)</td>
<td>0.327 (0.070)</td>
</tr>
<tr>
<td>PCA Features + Poly Kernel</td>
<td>0.331 (0.104)</td>
<td>0.310 (0.038)</td>
<td>0.315 (0.060)</td>
</tr>
<tr>
<td>PCA Features + Linear Kernel</td>
<td>0.648 (0.246)</td>
<td>0.630 (0.186)</td>
<td>0.637 (0.214)</td>
</tr>
</tbody>
</table>
6.4 Simulator Evaluation

A content validity survey was given to GI surgeons and fellows from the Division of Gastroenterology, University of Miami Leonard Miller School of Medicine, Miami, Florida and Department of Medicine, Phramongkutklao College of Medicine, Bangkok, Thailand. The mean scores of the responses are shown in Table 6.5.

Using the questionnaire survey, these experts and potential users were asked to give their opinions on the following statements: “This simulator training could potentially decrease the risk to patients undergoing endoscopy by fellows”, “It would be an advantage to train at an institution that has such a simulator available”, and “I would use this simulator in my training program”. A total of sixteen participants reviewed the simulator and evaluated its applicability using a questionnaire with a 5-point scale ranging from 1 = “strongly disagree” to 5 = “strongly agree”. Fourteen of them either strongly agreed or agreed that they would use this simulator in their training program. This initial feedback indicates a promising future for the developed model.
TABLE 6.5: The mean scores of responses to the CIES survey from GI surgeons and fellows (n=16).

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>• This simulator training could potentially decrease the risk to patients undergoing endoscopy by fellows.</td>
<td>4.13 ± 0.81</td>
</tr>
<tr>
<td>• It would be an advantage to train at an institution that has such a simulator available.</td>
<td>4.06 ± 0.85</td>
</tr>
<tr>
<td>• I would use this simulator in my training program.</td>
<td>4.38 ± 0.72</td>
</tr>
</tbody>
</table>

*The responses were given on a 5-point scale ranging from 1 = “strongly disagree” to 5 = “strongly agree”*
CHAPTER 7

Conclusion and Future Research Direction

7.1 Summary and Contributions

Endoscopic simulators can potentially reduce the reliance on patients, the number of required supervised procedures, and the time and cost of training. They are an effective supplement to the educational process of the gastroenterologist, providing an additional training option. Previous research suggests that computer simulators can aid in the training process (Sedlack et al. 2004; Giulio et al. 2004; Ferlitsch et al. 2002). This dissertation presented the newest addition to the currently available simulators. With the CIES, the trainee gains basic maneuvering skills of the endoscope by practicing with a real endoscope in a real operating room, resulting in more comfort when approaching real cases. With the software help available
during training, they could practice the maneuvering skills independently. Thus, trainees can practice on their own time without any limitation. The low investment cost makes it an economic addition to the endoscopic training program for any institution. It can also serve as an additional training tool to the currently used commercial simulators. Training with various types of simulators helps trainees maximize the experience with the endoscope before practicing on patients.

The designed distortion correction system offers a better perception of range and size from an endoscope. This method also works with any endoscopic system, not just the training simulator. Failing to correctly measure the size of any pathology could result in misdiagnosing its significance. These complications could be avoided by employing our distortion correction system to offset the incorrect measurement. With an automatic calibration and real-time distortion correction, the system can be employed easily. The endoscopic image classification allows our software to automatically evaluate the performance based on the images taken by trainees during the exam procedure. This classification scheme for endoscopic images from the upper GI tract can also be potentially useful as a categorization tool for medical picture archiving and searching systems. The major contributions of this research are summarized as follows:
• We have designed and developed a new type of upper endoscopy training simulator. We combined a low-cost mechanical model representing the upper GI tract including pathologies with computer software which allows fellows to practice the maneuver skills on their own time without the need of a supervising instructor.

• We have presented a protocol for manufacture of the upper GI tract mechanical model with the sensor system including the ideal materials and methods. Model for other endoscopic procedures can also be built by similar protocol.

• We have designed and developed a computer software package for upper endoscopy training. Our software can enhance a training experience and allows users to practice endoscope maneuver skills on their own time. It can be used with any commercial mechanical model and endoscope tower setup.

• We have presented a simplify method for an automatic calibration of a nonlinear distortion correction system using a least squares estimation. We have designed the calibration template and automation system to provide a fast and easy way to calibrate an endoscope for distortion correction. The edge detection and cross correlation are used to automatically detect the
center of the dot from the calibration paper. By using only dots on the
diagonal lines of the grid, the processing time is decreased.

- We have implemented a multi-class endoscopic image classification for
upper GI tract. An impressive performance is achieved by simply using
image intensity values as input features with a polynomial kernel SVM.

7.2 Future Research Direction

This study could make an important addition to the training process in endoscopic
surgery. Moreover, the simulators can potentially be used as a quality control to
evaluate the technical competency or used as a part of board examination for
gastroenterologists in the future. With the low investment cost of our simulator,
apart from training the surgeons, this simulator can also be used in the nurse
training program. Additional mechanical training models simulating different
endoscopic procedures such as endoscopic retrograde cholangiopancreatography
(ERCP) or bronchoscopy can be built. Our software can easily be reconfigured and
set up for training in other endoscopic procedures.

In the next version, the sensor system can be modified to send an indication
signal directly to the computer software instead of using LED. The software can
then generate more sophisticate outputs on the computer to create more
interaction, e.g., an uncomfortable sound from patient. The results of endoscopic image classification of the upper GI tract are encouraging. This enables the possibility of using similar method to analyze and induce information from the pictures or videos of actual endoscopic procedures. Those data might be able to use to provide support for physicians in various ways or in the digital image categorization task. Possible future applications such as real-time physician suggestion system based on the classification results can be investigated.

Further investigations could be performed to validate and evaluate effectiveness as a training tool and the benefit to the fellow training program. For example, an experimental comparison of supervising physician evaluation between a group of fellows who completed the CIES training and a group of fellows without the CIES training could be performed.
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