SYSC 4907
Final Report

Laparoscopic Surgery Simulator

Augmented Reality Surgery Trainer for Pediatric Surgeons

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Abstract

The field of laparoscopy is relatively new in the surgery world and it has distinct benefits over traditional “open” surgery techniques. However, these benefits come at the cost of a more complex procedure and a need for advanced training with the required equipment. In order to fulfill this need, various training aparati have been developed and tested, the most beneficial of which is Augmented Reality training modules as they combine the benefits of both physical simulators. Over the course of this project, we have developed a low-cost, stand-alone, training module instrumented with motion tracking sensors, Augmented Reality guidance and feedback, and a simple analysis system. This project can be easily carried into future years as the module built can easily continue to be improved through various methods and the research complete can be used to further branch this project into further territories. For the most part, this project has run smoothly over the two semesters, though this required some modifications and adjustments to the communication and team protocols as the project continued. We hope that the complete motion tracking and Augmented Reality training module will continue to be used in future projects for years to come and eventually be able to actively contribute to this vital field of advanced laparoscopic surgery training.

Acknowledgments

We would like to thank firstly our supervisors, Professor James Green and Professor Carlos Rossa for their continued support and guidance throughout the project. Their consistent meetings and engaged interest in the project helped us stay on track and on target over both semesters. We would also like to thank Conor McDermott for his assistance in 3D modeling and printing various components of the project. A big thanks to CUESEF and The Department of Computer Systems Engineering for funding the project and allowing us to purchase all the equipment we required to build our stand-alone training apparatus. We would also like to thank Dr. Nsar et. al. for the research provided that we were able to build off of. Lastly, thanks to Pat Fairs for giving us special access to the Computer Systems Maker Space and for being continually supportive and interested in our progress throughout the project.

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Chapter 1: Introduction Stuff / Background

1.1 Motivation

Professor Green and Professor Rossa were approached by surgeons from the Childrens Hospital of Eastern Ontario (CHEO) and SickKids, namely Dr. Ahmed Nasr who has been doing research into motion analysis Pediatric laparoscopic surgery (PLS) trainers. Dr. Ahmed Nasr expressed a need for additional research into training for Laparoscopic Surgery, especially expanding into the area of using Augmented Reality along with motion analysis in PLS training. By using the pre-existing PLS simulator as a reference we aim to enhance the motion analysis system by adding additional instrumentation and developing a program that integrated real time augmented reality and provide accurate results in order to enhance the user experience and training of future surgeons.

1.2 Purpose

A novel approach for abdominal surgery has arisen in recent decades, replacing old "open" surgery procedures. "Laparoscopic surgery means performing diagnostic and therapeutic procedures after gaining access to the abdominal cavity [1]." Patients suffer less discomfort and recover faster than with previous procedures because big "open" abdominal wounds are replaced with a few significantly tiny incisions through which a Laparoscope (Camera) and equipment may be introduced. Laparoscopic surgery also has the benefit of reduced bleeding, shorter hospital stays, and a quicker recovery period. However, the benefits of using this method come at the cost of a more difficult and complex operation. However, the advantages of using this minimally invasive surgery approach come at the expense of a more difficult and complex process. A need for enhanced training processes has evolved as a result of the numerous added problems, complexity, and the fact that there are many relatively new methods involved in laparoscopic surgery. This project aims to provide a solution to this problem. We will begin by reviewing some background information on laparoscopic surgery, as well as current advancements and research in the field, before discussing our suggested solution to this problem.

1.3 Context

Laparoscopic surgery has become widely used in clinical practice, with surgical trainees being required to learn laparoscopic techniques. The technical abilities required are, however, unique from those necessary for open surgery; depth perception is impaired due to visualization on a two-dimensional screen, tactile feedback is restricted, and long laparoscopic tools generate a fulcrum effect and amplify tremor. There is a significant learning curve associated with laparoscopic surgery, and these skills cannot be easily learned using the traditional apprentice model of surgical training [2]. Simulation is widely regarded as the way forward, and its use has been shown to improve trainees' laparoscopic surgery skills [2, 3]. Simulation provides an opportunity to improve technical skills in a structured low-pressure environment outside the operating room without compromising patient safety [4]. Various simulation methods have been described, from the devotion to virtual reality systems and animal models to box trainers. The interface of the Box trainer is usually not realistic and is designed to practice general skills required for laparoscopic surgery, such as instrument manipulation, cutting, and internal suturing. Virtual reality simulation uses computer-generated graphics and tactile feedback to recreate the operating environment and promote the practice of specific procedural skills and general laparoscopic skills [5, 6]. Virtual reality systems are, however, very cost-prohibitive and may be inaccessible to many trainees for regular personal use [7]. Virtual reality simulators are useful educational tools but do not show proven significant advantages over traditional models. The lack of standardization and a scarcity of articles makes a comparative analysis between simulators difficult, requiring more research in the area, according to the model suggested in this review 8].

The top mobile physical laparoscopic simulators which are currently being used are - The surgery simulator ecoSim SurgTrac Elite by Twin medical (Figure 1), Laparoscopic simulator Pyxus HD by Innovus medical (Figure 2), and Mini-invasive surgery simulator 815.021 by Zhejiang Geyi Medical Instruments (Figure 3).

Figure 1: Surgery simulator ecoSim SurgTrac Elite

Source: [9]

Figure 2: Laparoscopic simulator Pyxus HD

Source: [10]

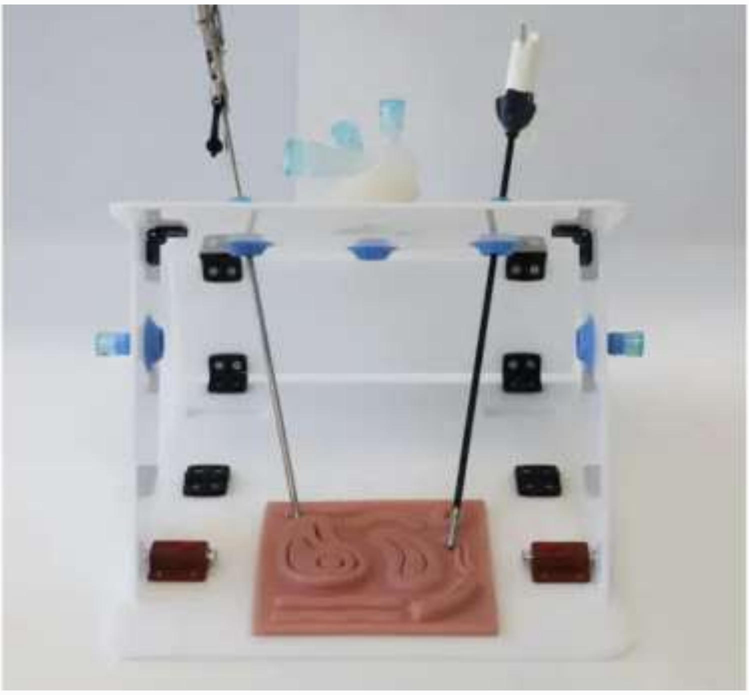

Figure 3: Mini-invasive surgery simulator 815.021

Source: [11]

The above available simulators provide users easy accessibility as none of them require a constant power source, they are compact and mobile and their prices range between 500$ - 700$. The simulators do not include virtual reality software or any form of computer-assisted guidance. The ecoSim SurgTrac Elite (Figure 1) does come with FLS software which helps users track their skill progression by measuring the time taken for task completion. The time is then converted into a score which is then compared to all online profiles that use the same interface. All the mentioned simulators do come with basic task tutorials which show the users how to perform the task in the most effective method but do not have any tool tracking system or real-time feedback, which helps users observe their speed and position during the task.

Beyond these basic physical simulators, there is development being done to use more advanced technology to assist with laparoscopic training. One study by the Universidad Politécnica de Madrid discusses how a group of researchers created a tracking system to assist with laparoscopic surgery [12]. The goal of this study was to undertake a more objective assessment of procedures of surgeons in simulation settings by focusing on this specific surgery. These researchers' EVA tracking system provides a surgical instrument monitoring system that allows for the evaluation of surgical tools by tracking their motions, location, speed, volume, and average acceleration within a simulator (Figure 4).

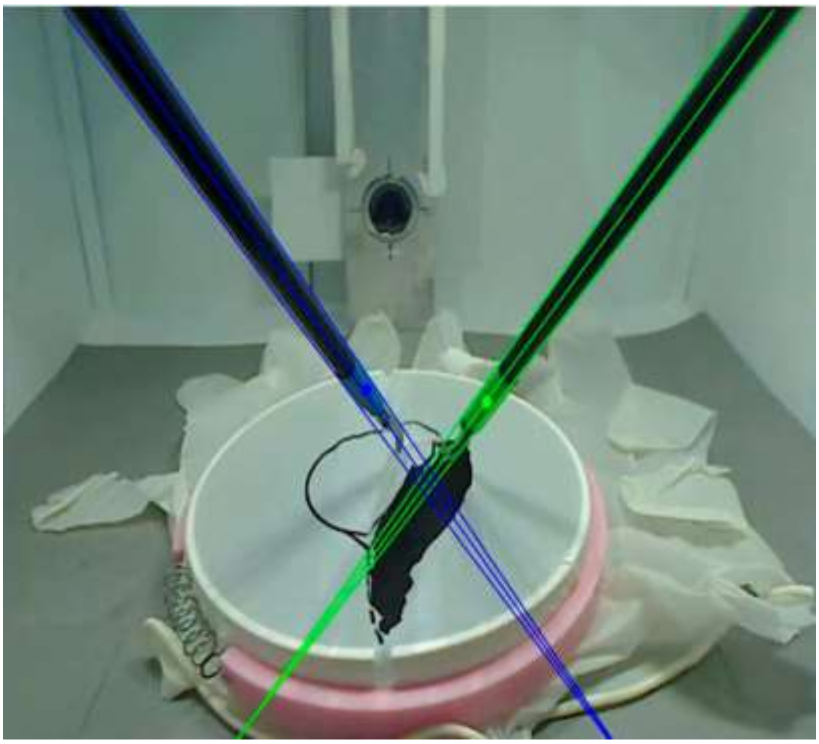

Figure 4: EVA Tracking system for laparoscopic surgery

Source: [12]

Furthermore, the EVA tracking system employs computer vision to determine the three-dimensional position of the instruments through an endoscopic camera and can properly estimate a surgeon's skill in a simulator. As a result of these features, a low-cost portable tracking system without the need for instrument modification is created. In addition, researchers demonstrated that the estimated metrics may be used to distinguish between beginner and experienced surgeons, as well as to establish a link between the stated metrics and those acquired by other optical tracking systems. Second, the metrics data were utilized to train a classifier that accurately predicts a surgeon's skills in a simulator resulting in an 83.3 percent success rate. Therefore, this result demonstrates a clear correlation between the surgeon's experience and the simulation task performance. Finally, the EVA system is now integrated into an application that will allow us to save and manage surgeon data while tracking their progress.

Along with these other technological advancements, there have been important advances in the area of Simulation trainers for Laparoscopy. In a paper published in 2016, Lahanas et al. [14] compare the advantages and disadvantages between physical reality (PR), augmented reality (AR), and virtual reality (VR) simulators. Traditionally only PR box trainers have been used in the simulated training of laparoscopic surgery but technological advancements have brought forth the creation of fully virtual simulators. The LAP Mentor VR system by 3D Systems shown in the figure below demonstrates an example of a completely virtual training system.

Figure 5: LAP Mentor VR

Source: [16]

There are many companies that have developed VR trainers with extensive virtual tasks for trainees to complete. These virtual simulators allow trainees to complete more complex tasks compared to those in physical trainers and get guidance and feedback from the virtual reality environment as they perform the surgery unlike normal tasks in physical simulators. However, these systems are extremely costly to develop, require advanced hardware to run, and lack the real-world haptic feedback of a physical system. This is where the benefits of

Augmented Reality simulators shine. Figure 6 below, taken from the paper, shows what they were able to classify as some advantages and disadvantages of the various systems.

Table 1: Advantages and disadvantages of PR, VR and AR in MIS simulation training

	PR	VR	AR
Advantages	- Realistic haptic feedback- - Cost-effective setup	- Objective assessment -Interactivity	-Realistic haptic feedback-Objective - assessment -Interactivity
Disadvantages	- Subjective assessment -Lack of interactivity	- Unrealistic haptic feedback -Lack of assessment protocol	-Lack of assessment protocol

Figure 6: Advantages and Disadvantages of PR, VR, and AR systems

Source: [14]

From the advantages we can see that Augmented Reality provides the haptic feedback that VR simulators cannot while also providing the interactivity that physical simulators lack. However, in the field of Laparoscopic Surgery Trainers very little research or work has been done on using augmented reality. In the paper, they acknowledge that there is a "clear gap in the current literature for AR laparoscopic simulation platforms. [13]"

One example of an augmented reality platform is the ProMIS augmented reality. In the paper "ProMIS Augmented Reality Training of Laparoscopic Procedures Face Validity" by Botden et al. [15] they discuss the validity of the ProMIS AR simulator. The simulator shown in figure 7 below utilizes a physical space with physical tasks and tracks the movement of the instruments with three cameras inside the mannequin in order to provide results to the user. The AR augmentations are shown on the monitor and include demonstrations, explanations, and feedback, which are often lacking in physical simulators.

Figure 7: ProMIS AR Trainer

Source: [16]

In another paper by Botden et al. comparing the VR simulator LapSim and the AR simulator ProMIS they conclude that “In comparison with the VR simulator, the AR laparoscopic simulator was regarded by all participants as a better simulator for laparoscopic skills training on all tested features[15].” This conclusion was a result of the fact that the augmented reality simulator was able to provide real tasks with haptic feedback as well as demonstration, guidance, and feedback to the trainee, all of which are critical to the training process.

From the context of the current state of the field, we can conclude that there is a need for more research and development in the area of Augmented Reality in laparoscopic surgery trainers. While maintaining the benefits of current low-cost physical simulators we will provide access to the advanced features that come from more complex systems.

1.4 Scope

The main scope of the project is to enhance the Children's Hospital of Eastern Ontario (CHEO) by integrating a motion analysis system that is capable of extracting various movements of the laparoscopic tool as the trainee performs the task. Providing augmented reality through various real-time feedback allowing trainees to conceptualize and perform better. And finally providing accurate evaluation based on task performance by analyzing motion accelerations and velocities. The constructed laparoscopic simulator aims to help surgical residents improve basic laparoscopic tasks & psychomotor skills, by providing feedback based on tasks. By creating a standalone, accessible, and portable simulator, surgical trainees are able to formally train outside the healthcare environment.

1.5 Solution

Based on the objective and purpose our solution is to develop a functional simulator capable of providing formal training for surgical residents for laparoscopic surgery at a minimal cost that can be also by beginners wanting to gain experience in laparoscopic surgery without having access to expensive equipment and constant observation of a senior surgeon. Building off of a previous design for a laparoscopic surgery training box, we intend to re-create the training apparatus and add additional instrumentation and augmented reality to the module in order to provide feedback and guidance to the trainee.

Our main functional goal is to produce a stand-alone laparoscopic surgery module that can provide guidance and feedback to the trainee in real-time as well as evaluate their performance. In order to achieve this goal, we will be assembling a simple pediatric laparoscopic surgery trainer design that can be built at low cost and used for basic training. The design will include a simple plastic box with laparoscopic surgery tools for grabbing and manipulating objects inside the simulator. The tools will be instrumented with sensors to track the forces of acceleration applied to the tools and gather information about their position inside the simulator. The box will include a webcam and monitor to display the view inside the box as it would inside the abdomen of a patient. Feedback will be displayed to the user in real-time to warn them if they are using excessive acceleration and rotational velocity at any point while completing the task. The monitor video feed will also be adapted with augmented reality to display simple guides to the user to demonstrate the tasks and aid in independent training. Finally, the box will evaluate a user based on their movements in the box during task completion and assign them a score to track their training progress.

1.6 Report Overview

The report continues with Chapter 2: The Engineering Project, which is the second section. From an engineering standpoint, this chapter discusses the project's health and safety, professionalism, project management, and the individual contributors' contributions to the project. The third chapter provides a general description of the project and the finished training apparatus. Following this basic outline, Chapters 4, 5, and 6 divide the project into three sections: Instrumentation, Augmented Reality, and Evaluation. Each team member has provided a thorough overview of their unique key project component. Chapter 7 brings the project to a close and offers some suggestions for future work that could be done on it, as well as for alternative directions that the project could take. Finally, Chapter 8 contains our thoughts on the project itself, as well as the project management and teamwork skills that we have gained as a result of our participation in it.

Chapter 2: The Engineering Project

2.1 Health and Safety

Although this project is not specifically related to any subject that involves large health and safety concerns, there were a few concerns that were appropriately addressed over the course of the project. The main concern was that the project was taking place during an ongoing pandemic. In response to this, the majority of meetings were conducted online and when in-person meetings were required masks were worn in situations as required by the university to prevent the spread of Covid-19. Aside from the general concern of the pandemic this project presented other health concerns in soldering the electronics together as well as milling and melt welding the plastic box together. In these situations, proper PPE was used including eye protection as well as proper ventilation for soldering and working with the plastics.

2.2 Engineering Professionalism

Over the course of the project each student has the opportunity to demonstrate their professionalism in the manner in which they conducted themselves within the team and in the team meetings. Each team member was continually responsive and involved in the project and never avoided or shirked their responsibilities when called upon. In addition to this reliability, the team endeavored throughout the project to seek copyright-free images and videos for our reports and project videos and provided all citations for others' work in accordance with proper professional practice as discussed in ECOR 4995.

2.3 Project Management

This project has been the longest that any of the students have been a part of a project consecutively. In order to ensure the project was managed and structured correctly weekly meetings with the professors were set up to ensure consistency of progress among the group. A logbook of work in progress, accomplishments, ideas, results of meetings, and planned work was established early in the term to help the students stay on track and keep the supervisors informed of each student's progress. Initially, the team was communicating solely through a discord server, however, after difficulties in communication early in the fall term the team switched to using Whatsapp for the majority of communication which greatly improved the response times and fluidity of communication throughout the team. For both the project proposal and Progress report, Gantt charts were established for each student to outline the work that would be completed each week. Lots of time went into creating these Gantt charts (Which can be seen in the Project Proposal in Appendix A) with realistic timelines and expectations so that each student could stay on track over the long duration of the project and the other students and professors could be aware of what work each student was planning to complete in a given week.

2.4 Justification of Suitability for Degree Program

Each group member has individually outlined how the project and the work they completed relate to their program.

2.4.1 Michael Marsland - Computer Systems Engineering

Michael is a student of Computer Systems Engineering. In the project, he mainly focused on researching and implementing Augmented Reality as well as creating the Apparatuses main program. He also worked with Raqib on creating the system through which the data from the sensors could be passed into the microcontrollers and to the main program in the Jetson Nano microprocessor. The combination of software development and hardware communication encompasses the main areas of study for Computer Systems Engineering. Beyond that, Michael took on the main management role on the team employing his leadership and project management skills which are a large component of the Engineering program as a whole.

2.4.2 Raqib Khan - Biomedical Electrical Engineering

Raqib Khan is studying Biomedical and electrical engineering which comprises courses such as digital electronics, bioelectrical systems, and physical electronics. These courses have instilled the required knowledge and skill to conduct research, assemble hardware, develop circuits and components, and program the most appropriate sensors to create the motion analysis system used in the project in order to extract accurate data from trainees. He has collaborated with Michael in transferring motion data to the main program through the Jetson Nano and programming the 3D visualization through Blender.

2.4.3 Ahmad Rahme - Biomedical Electrical Engineering

Ahmad is a Biomedical and Electrical Engineering student. He spent the majority of his time on the project researching and developing a task evaluation process, as well as creating 3D models for the primary program's activities. He also collaborated with Michael on the development of a software application for apparatus applications. The use of engineering principles to build and manufacture equipment and software is the fundamental area of study for Biomedical and Electrical Engineering.

2.5 Individual Contributions

2.5.1 Project Contributions

Table 1: General Individual Project Contribuations

Team Member	Contributions			
Michael Marsland	3D modelling and printing of the Trocars	Construction of the Apparatus components into a complete system	Software implementation of the Apparatus Application	Addition of Augmented Reality to the Application
Raqib Khan	Sensor selection for motion analysis system	Calibration code and accuracy testing	Hardware integration and 3D printing sensor housing and target disk	Synchronous sensor extraction code
Ahmad Rahme	Selection and 3D modelling of the training tasks	Derivation of a basis of evaluation from the data of Dr. Nsar	Software implementation of the analysis program	Addition of evaluation based of the sensor data of the trainee

2.5.2 Report Contributions

Table 2: Individual Final Report Contributions

Section	Team Member
Chapter 1	
1.1 Motivation	Raqib Khan
1.2 Purpose	Ahmad Rahme
1.3 Context	Ahmad Rahme
1.4 Scope (Problem Statement)	Raqib khan

1.5 Solution (Accomplishments)	Raqib Khan
1.6 Report Overview	Ahmad Rahme
Chapter 2	
2.1 Health and Safety	Michael Marsland
2.2 Engineering Professionalism	Michael Marsland
2.3 Project Management	Michael Marsland
2.4.1 Michael Marsland - Computer Systems Engineering	Michael Marsland
2.4.2 Raqib Khan - Biomedical Electrical Engineering	Raqib Khan
2.4.3 Ahmad Rahme - Biomedical Electrical Engineering	Ahmad Rahme
2.5 Individual Contributions	Michael Marsland, Raqib Khan, Ahmad Rahme
Chapter 3	Raqib Khan
Chapter 4	Raqib Khan
Chapter 5	Micahel Marsland
Chapter 6	Ahmad Rahme
Chapter 7	Michael Marsland
Chapter 8	Ahmad Rahme

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Chapter 3: Project Overview

The overall goal of this project is to simply combine the benefits of top of the market simulators by building our own standalone, portable, AR simulator that collects user data, displays real-time feedback and evaluates users based on the performance of the task. In terms of design, we wanted to construct a simulator from materials and components that are low in cost and easy to assemble and integrate. This allows for easy replication and adequate training to enhance the basic psychomotor skills of future surgeons. The simulator consists of various components that are easily available and are mentioned in the table below.

Table 3: List of Components for the System

Item	**Quantity**
Plastic sheets	4
USB camera	1
Laparoscopic Instrument	2
3D printed custom trocars	2
3D Sensor housing	2
MPU6050	2
VL530X	2
Arduino Uno microcontroller	2
Jetson Nano processor	1
Breadboard	1
3D printed target disk	2
Display monitor/ mouse/ keyboard	1
3D printed Pegboard task	1
3D printed wire the loop task	1

The simulator is constructed using four 12 x12 inch plastic sheets which are melt welded together using a soldering iron. the shape and size of the box was optimized for the augmented reality camera feed, as well as taking into consideration length of the tools, and the sizes of other similar models on the market.

Figure 8: Simulator box construction

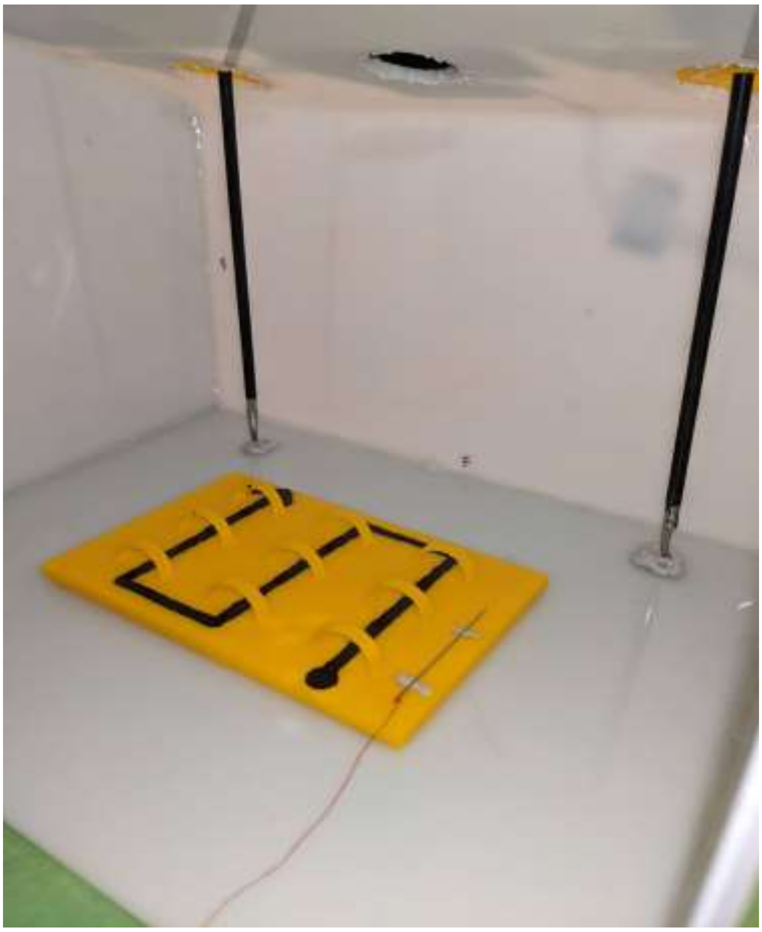

Figure 9: Interior of constructed simulator box

The trocars, sensor housing and tasks were 3D printed based on the specified requirements of the simulator. The trocars use two revolving circles in a similar manner to a mechanical gyroscope to hold a point on the tool at a fixed location in space. The sensor housing is attached to the trocar and allows easy access and placement for the sensors.

Figure 10: Custom 3D printed Trocar

Each tool is integrated with its own sensor circuit and is controlled by the Arduino Uno which later passes the data to the Jeston Nano where the data is used for augmented reality development and task evaluation. The flow diagram below shows you the data flow within the simulator.

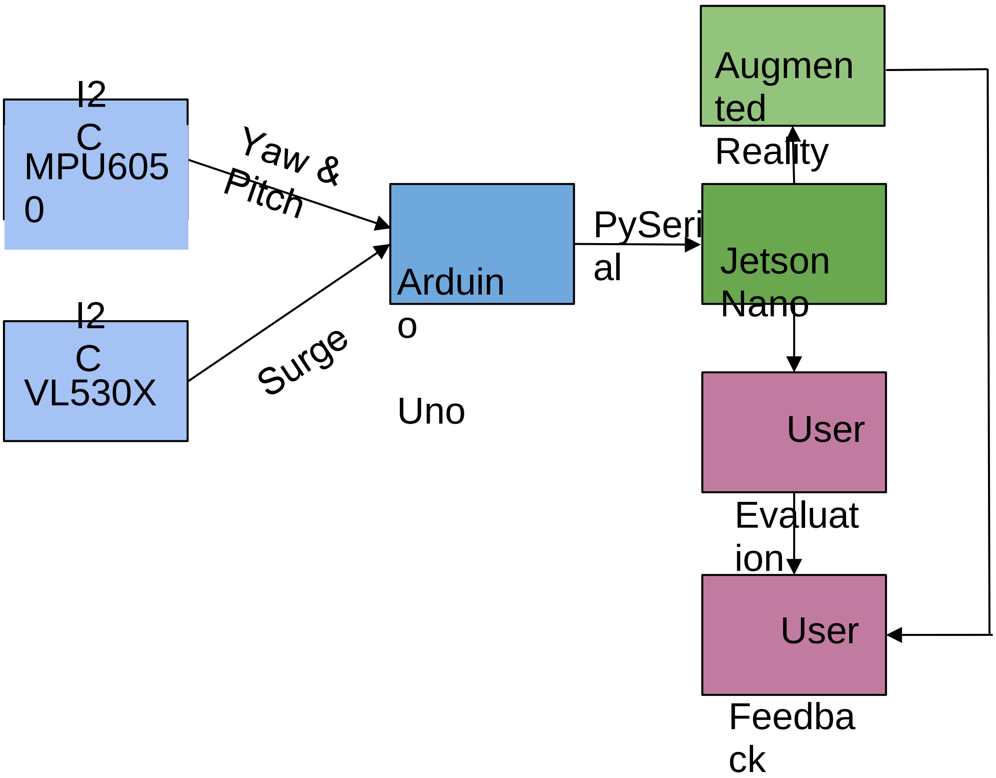

Figure 11: Data Flow Diagram of the System

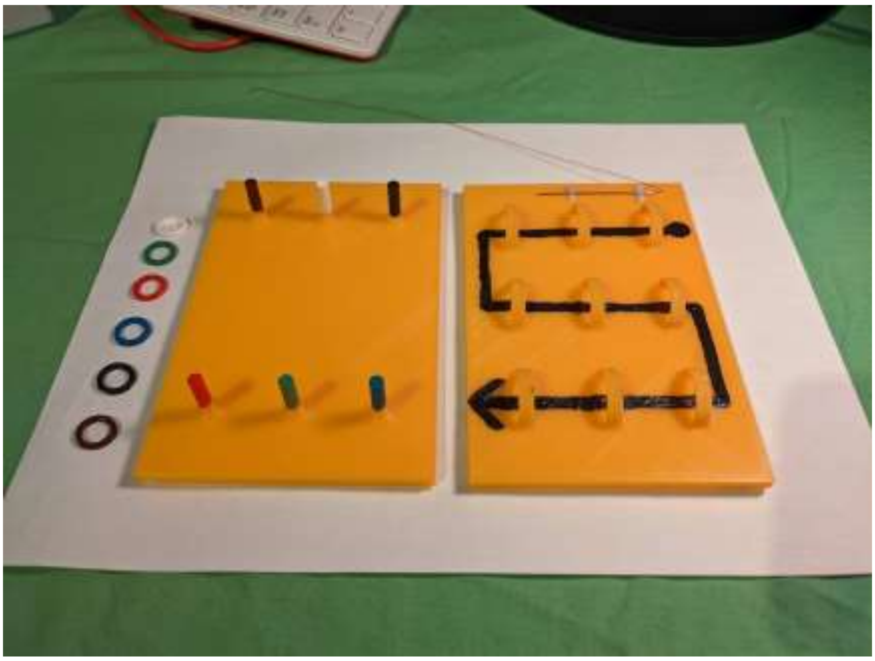

Figure 12: 3D printed pegboard and wire loop task

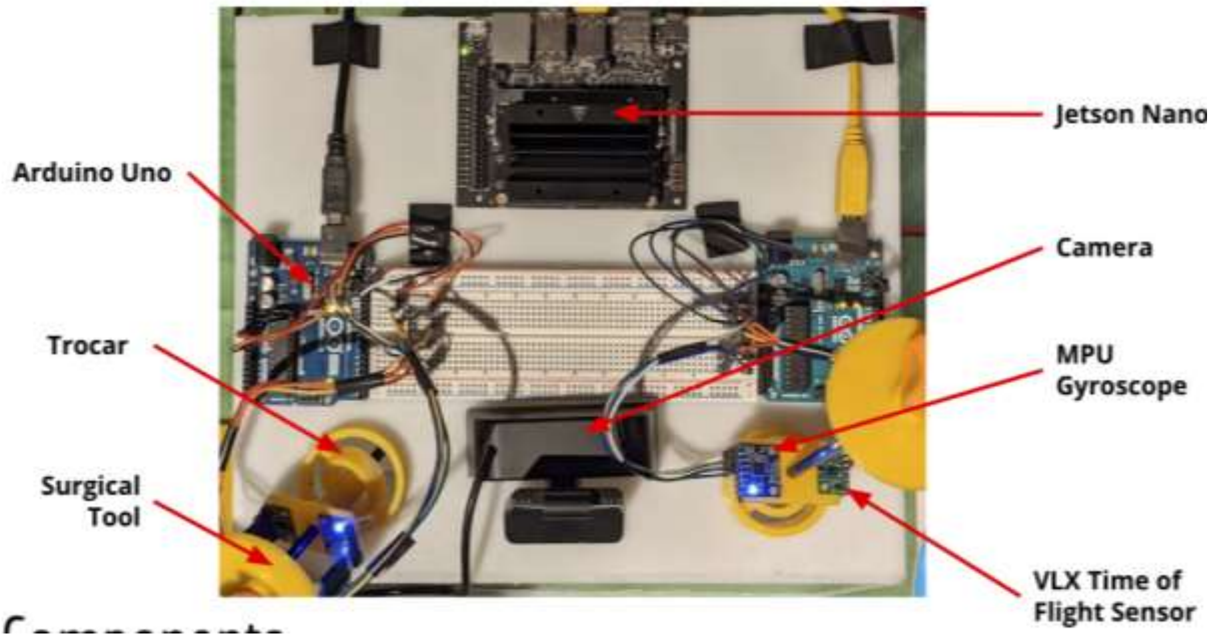

Figure 13: Components of the simulator

The simulator is further broken down into the instrumentation chapter that describes the different components of the motion analysis system and how these components integrate with each other. The Augmented reality chapter describes the main training program used and the integration of various guidance feedback provided to the user. The last chapter covers the custom printed tasks used and how evaulation of the trainees based of task performance is conducted. The categories mentioned are explained in much more detail in the subsequent chapters below.

Chapter 4: Instrumentation

In order to achieve the stated goals of the simulator, integration of a motion analysis system is crucial in constructing a successful simulator. The motion analysis system consists of a 2 sensors circuits (breadboard and jumper wires), microcontrolllers, custom 3D printed sensor housing and target disk integrated to each of the two tools of the simulator. The components used and their description will be provided in the subsequent sections. These sensors are programed to extract the yaw, pitch and surge motion of the trainees during simple task execution. This data is collected and compiled using the microcontroller which then passes the data for further augmented reality display and task evaluation of the trainees.

4.1 MPU6050 sensor

MPU6050 is a Micro Electro-mechanical system (MEMS), it consists of three-axis accelerometer and three-axis gyroscope Figure (14). It is used to measure to measure angles of motion (degrees) , rotational velocities (250°/s) and acceleration (g) . The MPU6050 also consists of Digital Motion Processor (DMP), which has property to solve complex calculations of quaterions.

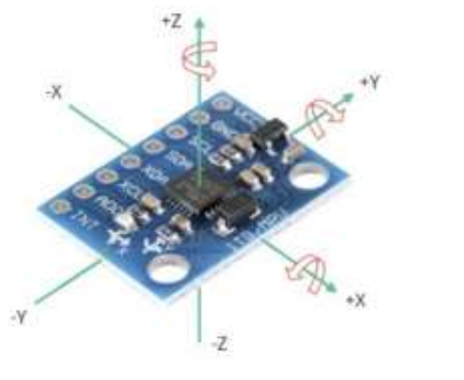

Figure 14: MPU6050 sensor

4.1.2 MPU6050 Gyroscope

The gyroscope works based on the corolis effect which gives us the rate of change of the angular position over time, called angular velocity. Therefore, it has to be programmed to integrated over a time to get the angle position. By setting the Angular velocity limit to (250°/s) and its corresponding sensitivity to 131, the raw sensor readings can be converted into degrees prior to applying the integration**.** This is done by dividing the readings by the sensitivity measurement unit**.** We are then able to measure rotation in Euler angles in yaw and pitch mode. Pitch mode measures rotation along the y axis, representing the surgical tool moving up and down. Yaw mode measures rotation along the z axis, representing the surgical tool moving from side to side shown in figure (15).

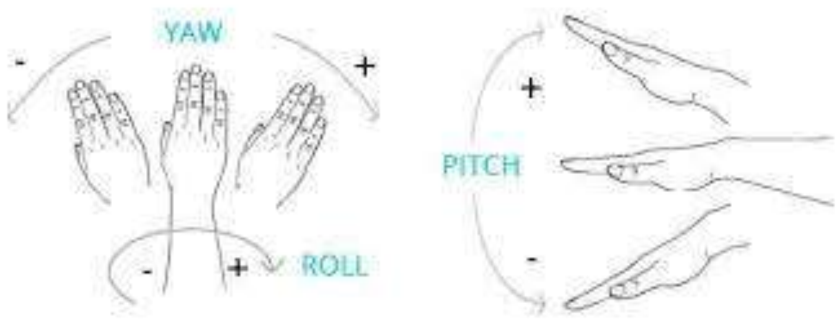

Figure 15: Yaw and pitch mode representation

4.1.2 MPU6050 Accelerometer

Acceleration values of the yaw and pitch motion are calculated using the DMP of the MPU6050. By programming the sensor to negate gravitational acceleration we are able to analyse the rate of change of speed (m/s^2) during yaw and pitch mode (figure 16).

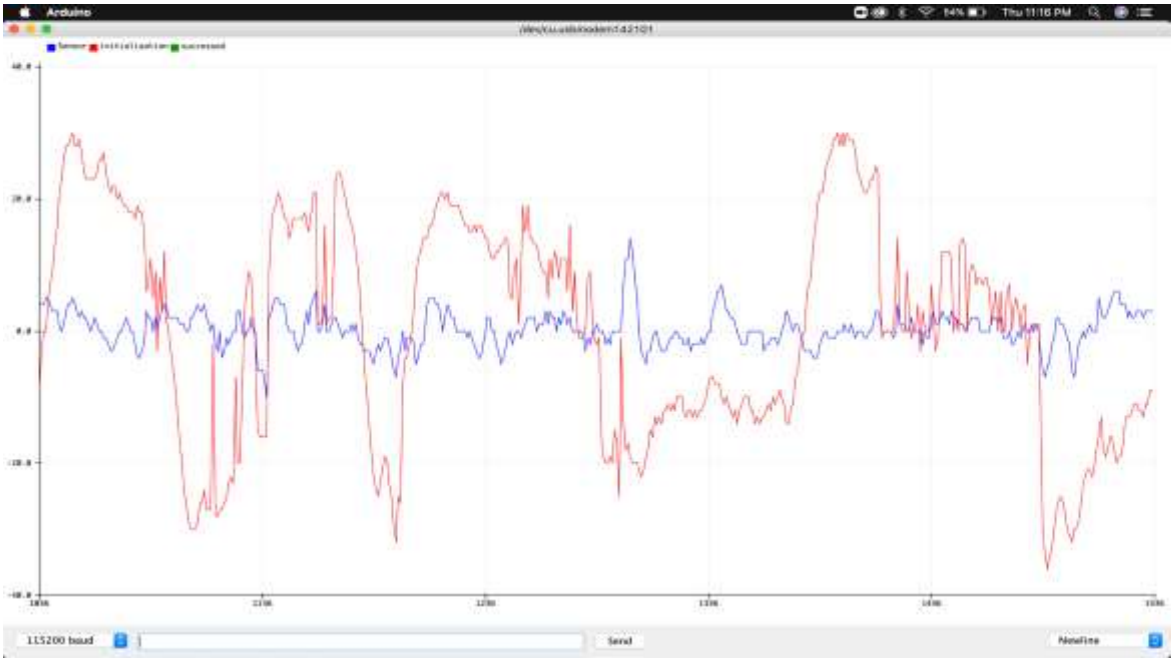

Figure 16: Acceleration Data from IMU

4.1.3 MPU6050 Calibration

At the beginning of the process all of the accelerometer and gyro offsets are set to zero. We then take 1000 readings from the IMU and calculate the mean value for each offset. These values are then entered into the IMU to become the new offsets. The calibrate routine will continue to take the mean IMU readings until the calibration is within a certain tolerance.

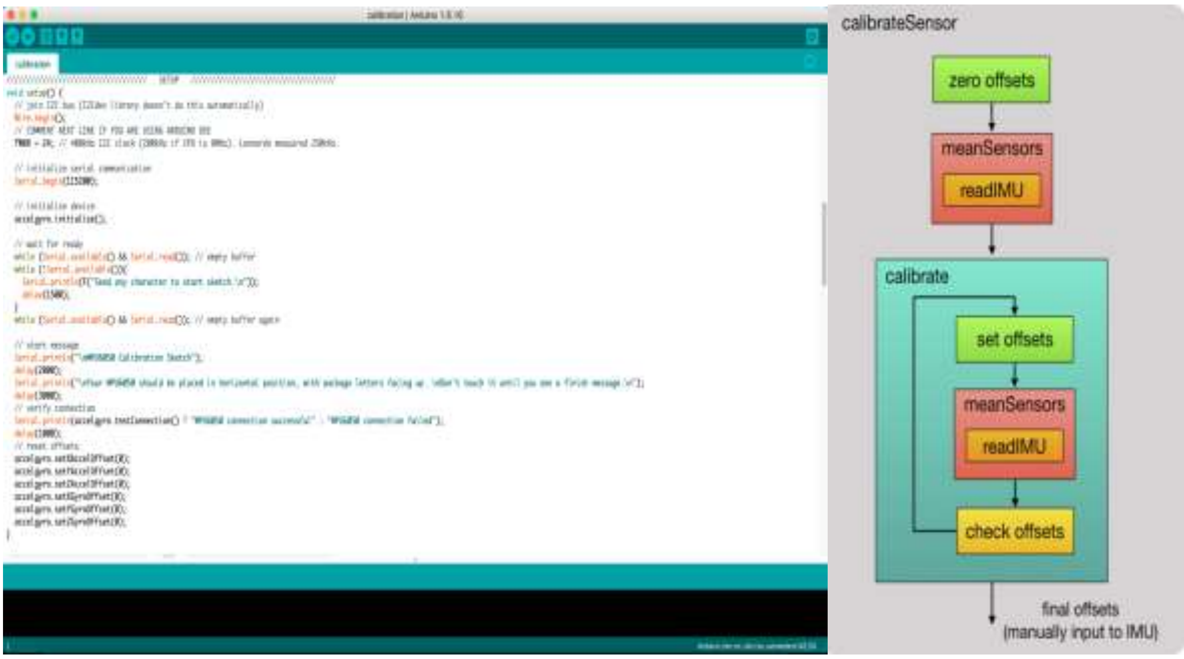

Figure 17: Arduino IDE calibration code for MPU6050

Source: [17]

4.2 VL530X Sensor

The VL53L0X is a light detection and ranging sensor that contains a very tiny invisible laser source, and a matching sensor. The VL53L0X can detect the "time of flight", or how long the light from the laser takes to reflect off the target disk and is picked up by the receiver sensor . Since it uses a very narrow light source, it is good for determining distance of only the surface directly in front of it. Unlike sonars that bounce ultrasonic waves, the 'cone' of sensing is very narrow. Unlike IR distance sensors that try to measure the amount of light bounced, the VL53L0X is much more precise and doesn't have linearity problems or 'double imaging' where you can't tell if an object is very far or very close. The sensor has a measuring range upto 2m and is independent of the target reflectance.

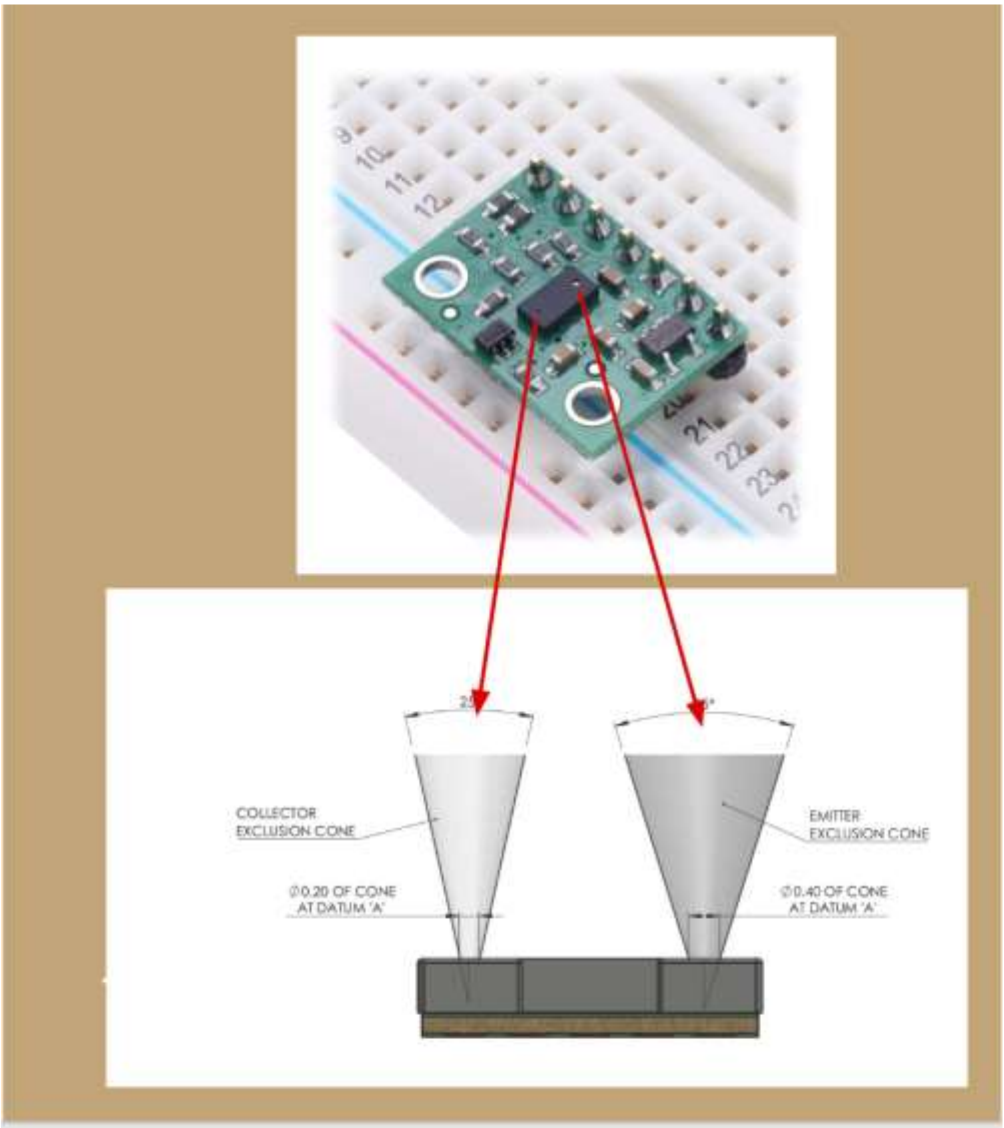

Figure 18: VL530X Sensor

By calculating the offset distance between the placed sensor and the tool, the sensor is programmed to calculate the surge in (mm) of the medical instrument. By analysing the surge of trainees we are able to improve their overall depth perception.

4.3 Arduino Uno

The Arduino Uno is a microcontroller that uses a ATmega328P chip. The MPU6050 and VL530X communicate with the Arduino Uno through I2C serial communication. By using the open-source Arduino Software (IDE) we are able to develop code responsible for data extraction. The data is then passed to the Jetson Nano through PySerial communication which is used for augmented reality and data evaluation.

Figure 19: Arduino Uno Microcontroller

4.4 3D printed Components

The Motion analysis system also consists of a sensor housing that is mounted on the trocar and allows easy access to the sensors, in the case of any defaults or malfunctions.

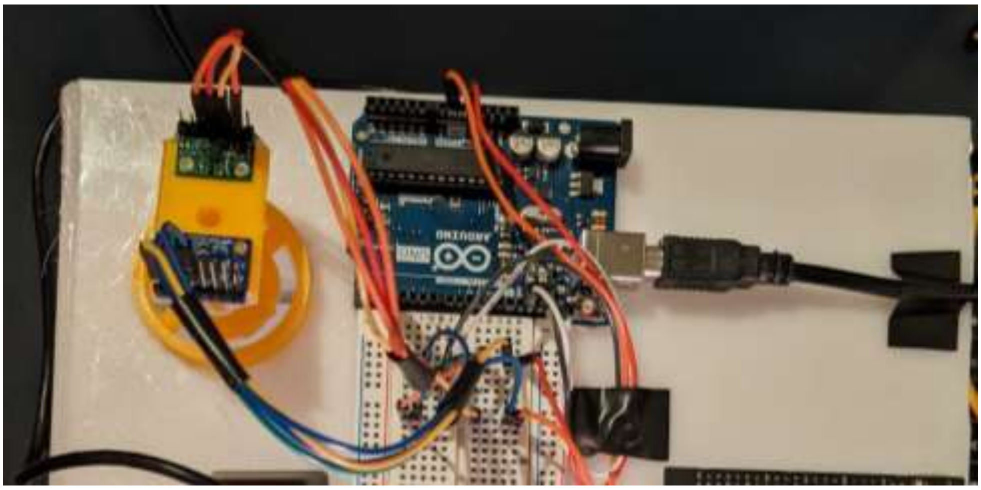

Figure 20: Sensor position and housing

The motion analysis system also consists of a target disk that acts as the reflector for the VL530X sensor. The target disk is positioned at the base end of the instrument allowing us to measure surge as the tool is inserted and extracted.

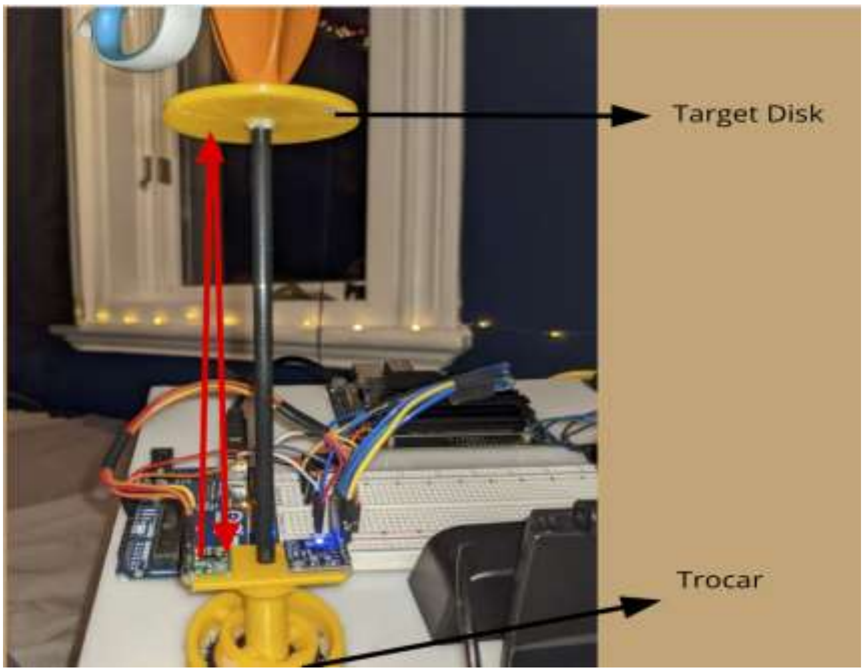

Figure 21: VL530X laser pathway (red arrows)

4.5 Instrumentation Decisions

The initial sensor selected to measure surge was the PMW3360 IR sensor but was unsuccessful in measuring accurate surge data for the following reasons shown in the table below -

Table 4: VL530X v.s. PMW3360 sensor

	VL53L0X (Time-of-Flight technology)	**PMW3360 (IR technology)**
How distance is measured	Directly measure the distance to an object based on the time for emitted photons to be reflected	Measure distance to an object based on the amount of light bounced off
Variables affected	Not affected by object characteristics: Size, dimensions, materials used, etc.	Affected by object characteristics, Affected by environmental factors; lighting conditions
Optical Lens	No optical lens required	Optical lens required
Lift detection limit	No limit	2-3 mm
Size	4.4 x 2.4 x 1.0mm	28mm x 21mm x 9.25mm

From the table above we can conclude that the most suitable sensor for the constructed simulator would be the VL530X sensor in terms of accuracy, size, and overall consistency.

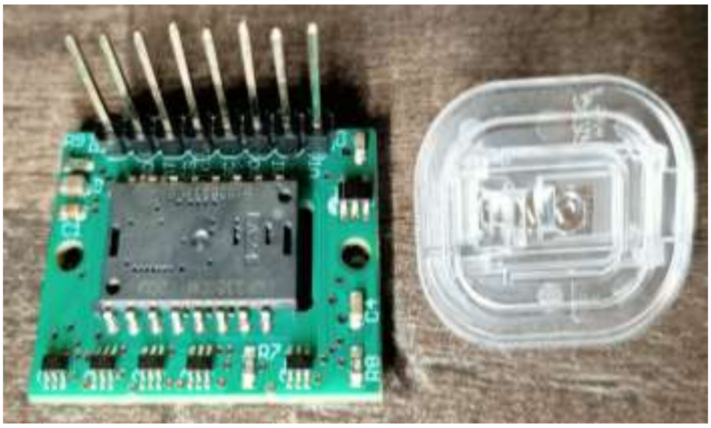

Figure 22: PMW3360 IR sensor

4.6 Future motion analysis development

There are various ways the current motion analysis system can be enhanced. Integration of more sensors to measure the roll of the tool can be incorporated. Based on the data extracted the tip of the tool can be tracked during the task. Complete 3D visualization of the simulator can be developed in order to enhance motion representation and feedback to the trainees using the simulator.

Chapter 5: Augmented Reality

The main focus of this project was initially to research the use of Augmented Reality in Laparoscopic Training Apparatuses based on the apparent benefits of AR training. Over the course of the term, this focus was expanded to include building our own training apparatus and a software program to run that apparatus. The scope of the Augmented Reality work was eventually narrowed down into research, a basic prototype including guidance and feedback, and the discovery of improvements and future work for the project. The following sections outline the above considerations in detail.

5.1 Benefits of Augmented Reality in Surgery Training

The figure below (Figure 6) (shown previously in the background section) showcases the advantages and disadvantages of the various surgery training module types.

Table 1: Advantages and disadvantages of PR, VR and AR in MIS simulation training

	PR	VR	AR
Advantages	- Realistic haptic feedback- - Cost-effective setup	- Objective assessment -Interactivity	-Realistic haptic feedback-Objective - assessment -Interactivity
Disadvantages	- Subjective assessment -Lack of interactivity	- Unrealistic haptic feedback -Lack of assessment protocol	-Lack of assessment protocol

Figure 6: Advantages and Disadvantages of PR, VR, and AR systems
Source: [14]

Physical training modules are widely used because of their simplicity and the realistic nature of the physical environment in which the tasks can be completed. However, basic physical simulators often lack the ability for guidance in real-time as well as a system for assessment. To fill this need for interactivity and assessment Virtual Reality simulators were developed.

Virtual Simulators allow for more complex tasks with real-time guidance and feedback as well as an analysis of the trainee's performance while they complete the tasks. These virtual simulators however do not provide the realistic physical environment and haptic feedback that physical simulators so simply and perfectly provide. Augmented Reality trainers combine the benefits of realistic haptic feedback that physical trainers can provide with the interactivity and assessment of virtual simulators. In response to these apparent benefits, this project was designed to further explore the use of Augmented Reality in a surgery training apparatus.

5.2 Apparatus Training Program

In order to create a module for the Augmented Reality program to reside on we first had to build our own functional training apparatus with a training program to host the augmented reality. This program takes the video feed from the USB camera mounted on the apparatus and displays it on the attached monitor through the use of python and OpenCV. The training program is a key part of the apparatus as it allows users to view tutorials and see demos of the tasks as well as tell the system which task they will be performing. The figure below (Figure 23) shows the main menu screen of the training application. From there the user can place either the Ring Task or the Wire Task (Both discussed in more detail later) into the apparatus and then use the attached mouse to start the task they have chosen to perform.

Figure 23: Training Apparatus Program Main Menu

Beyond its basic frontend functional features, the training apparatus program was also responsible for creating the Serial Interface between the Jetson Nano and the Two Arduinos that collected the sensor data. This data stream was taken into the program and used to adjust the augmented reality feedback based on the movements of the tools. This data also had to be recorded and stored locally in order to later be read by the evaluation program (Discussed in the next chapter). In order to complete all these tasks simultaneously, the training application had to be multithreaded using python’s threading library. The training program was designed to run both on the Jetson Nano as well as a laptop for streamlining the development process.

5.3 Augmented Reality Research

Due to the limited experience that the students had in regards to Augmented Reality at the start of the project and the lack of defined scope on how Augmented Reality was to be utilized in the project. The first semester of the project was mainly devoted to research into the various methods in which Augmented Reality could be utilized for the apparatus. This resulted in a few simple proofs of concept demonstrations being created that were later turned into the main prototype for the project.

5.3.1 Path Highlighting (Guidance)

Through python's OpenCV library we were able to create a practical proof of concept for a guidance method utilizing color detection and modification. This simple proof of concept was later turned into a key feature in the apparatus. The following three distinct screenshots of the python application (OpenCV window) show how the color of the pre-drawn guiding line can be modified to warn the user if they are using excessive speed or bad technique.

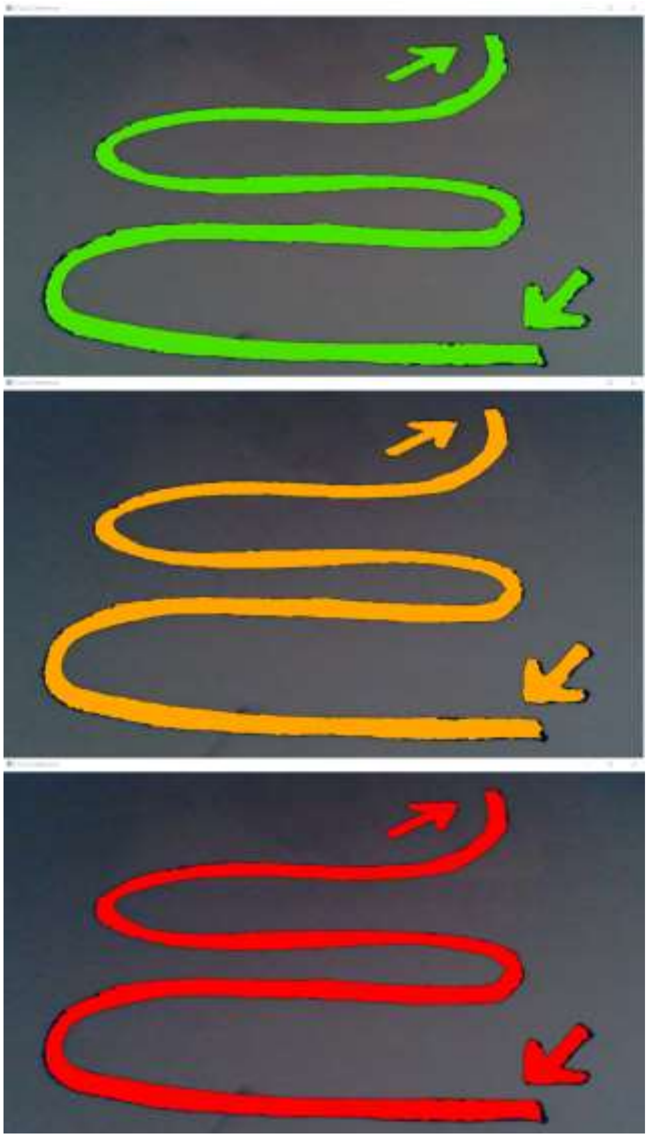

Figure 24: OpenCV Application showing the Guidance Path

6.1.2 Warning Text (Guidance)

In this experiment we were able to display any desired text to the user in the OpenCV window and the desired color. The following figure shows some snippets of example text edited together.

Figure 25: Snapshots of example texts displayed to the user by OpenCV

6.1.3 Recording and Replay of Footage

The last proof of concept developed in the first semester later utilized in the final project was the ability to record and playback footage from the simulator. This was used both to display demo tutorials on the application and also to record the video feed from every time a user completes a task.

Figure 26: OpenCV Displaying a Replay of Footage Previously Recorded

6.1.4 Additional Augmented Reality Features Demoed

In addition to the previously shown progress we also come up with two other features that were not included in the final application. This first concept showed how OpenCV’s color detection abilities were able to be used to detect when the user moved the surgical instrument into one of the four corners of the camera display. By doing this it was thought that the user could interact with the application without the need for a mouse or keyboard. This was just a preliminary experiment and was not included in the final creation apparatus. However, the research and work done could easily be utilized in the future to add this functionality to the system in the scope of another project. The following figure shows an example of the application recognizing when the surgical instrument is placed in the corner of the display.

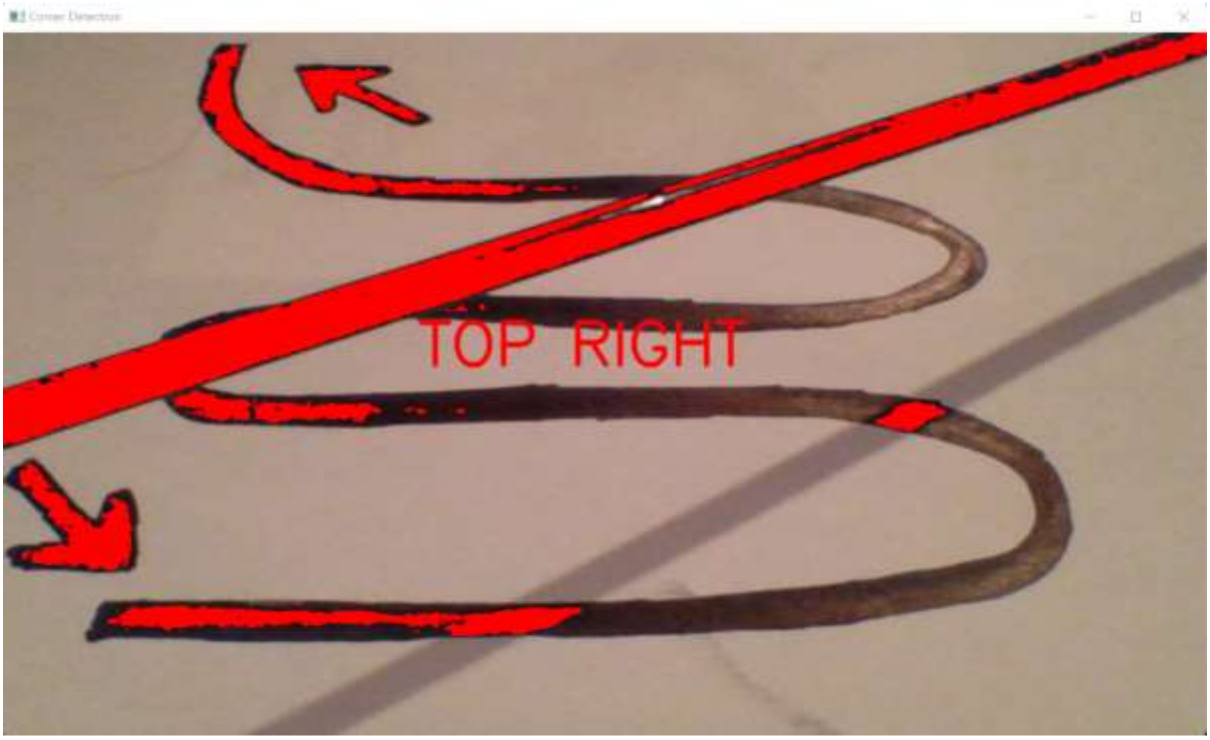

Figure 27: Interactivity with the Application by Detecting the Instrument in a Corner

The second concept was the ability to track the end of the tool based on its colouring. This was a very basic form of Computer Vision that could be greatly improved in the scope of another project. This Computer Vision technique was used to record and draw the visual path of the tool. The following figure showcases this functionality by tracing out the word “Hi” with the tool tip.

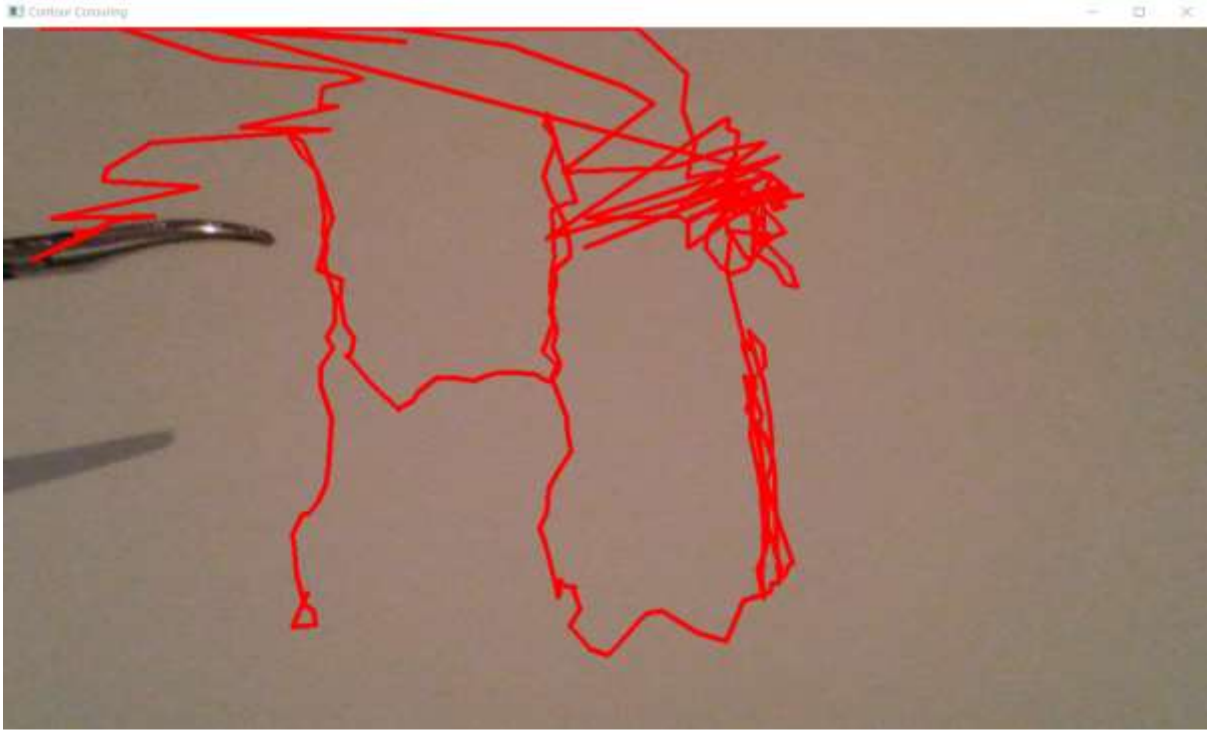

Figure 28: Using Computer Vision Tool Tip Tracking to say “Hi”

5.4 Augmented Reality Training Prototype (Guidance and Feedback)

By the second semester we had narrowed down the scope of the project to building a simple prototype Augmented Reality Training apparatus including the Augmented Reality features of guidance and real-time feedback. Based on the research completed, it was determined that the best way to achieve these goals for the scope of the project was by utilizing the color detection and augmentation features we developed. Each of the two tasks required slightly different augmentation for both the guidance portion and real-time feedback portions of the augmented reality.

5.4.1 Augmented Reality Guidance

For the guidance portion of the Augmented Reality prototype two simple guiding protocols were determined. For the ring task, the user would be directed to which ring to move to which peg based on their matching colors. The figure below (Figure 29) shows a sample of the programs highlighting the ring and destination for the user as well as showing some basic text describing how to use the task for a complete beginner.

Figure 29: Augmented Reality Guidance for the ring task

Using a very basic computer vision technique of masking the areas of the image that fell within a specific HSV color range was replaced with the bright green highlight. By tracking these highlighted areas we were also able to determine approximately when the user had successfully moved the highlighted ring to the target peg. Then using the same masking technique with a different HSV color range we could highlight the next ring and peg required to be moved in order to complete the task (Figure 30 below). Improving this rudimentary task completion technique is one of the ways the project could be improved in the following semesters.

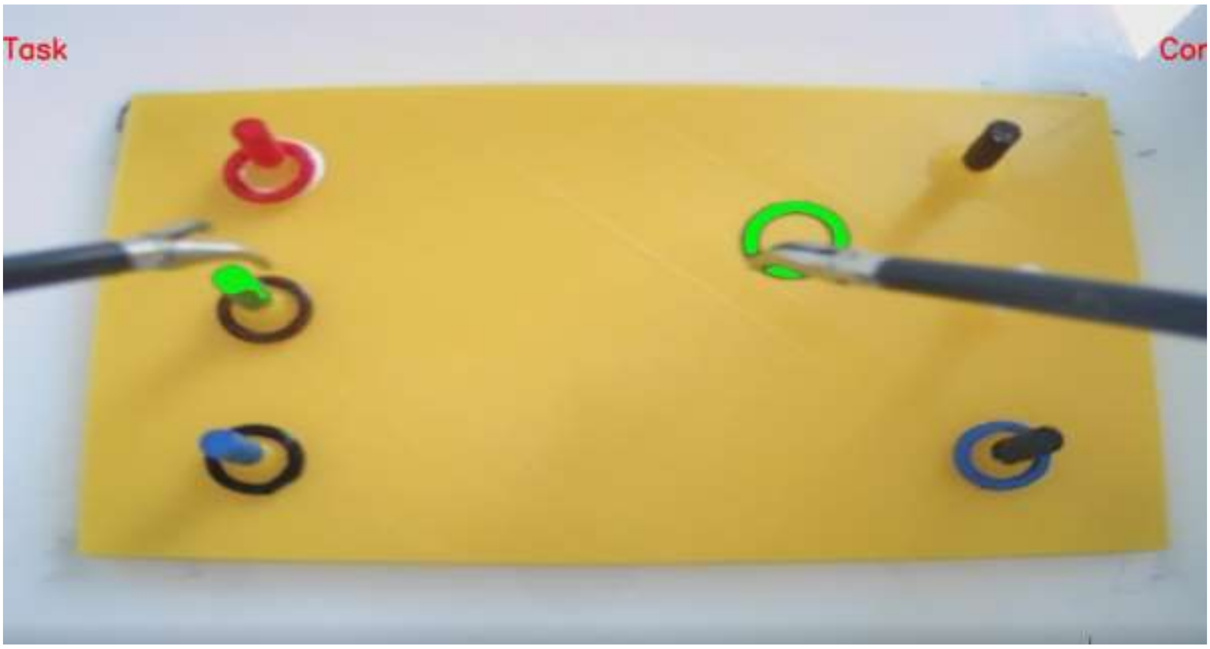

Figure 30: AR Guidance highlighting the next ring based on CV task completion

Guidance for the Wire task is more simplistic as the main development time was spent focusing on the Ring Task as a proof of concept. The basic idea is the same, using an HSV color mask and image segmentation to highlight the part of the task where the user should direct the needle. The first 10 seconds of the task highlight the different segments of the path demonstrating to the user the path through the loops that the wire must take. As this task is quite straightforward, there was no need for a complex guidance regiment at this point for this task. The figure below shows the first frame of the augmented guidance.

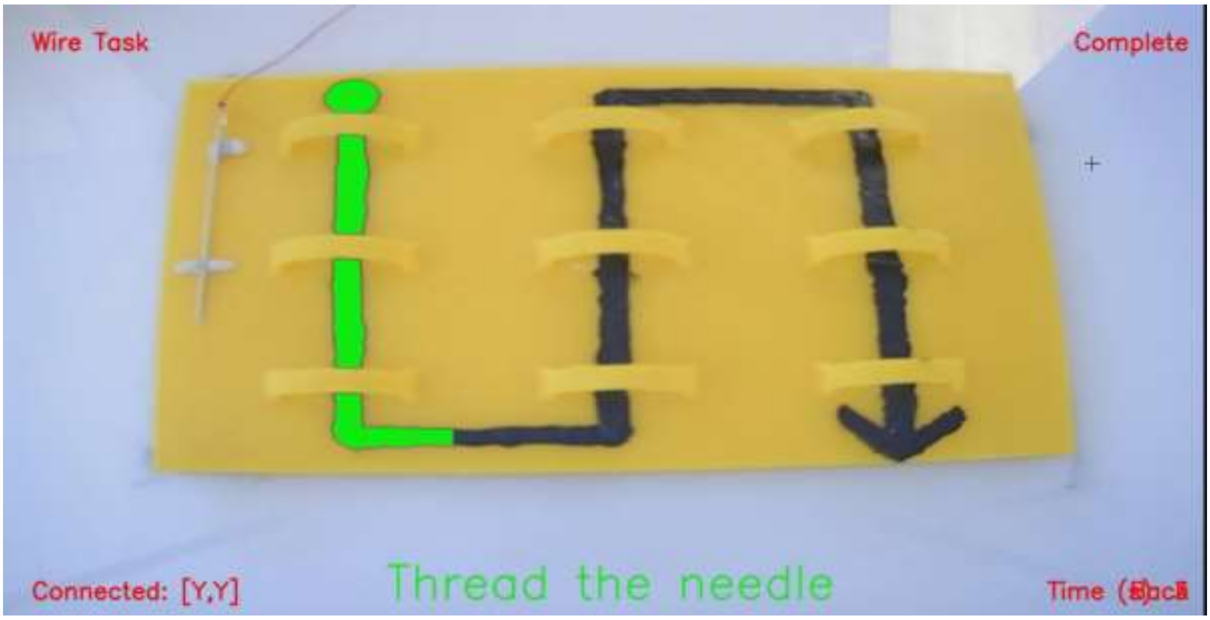

Figure 31: Basic guidance for the Wire Task

5.4.2 Augmented Reality Real-time Feedback

The main focus of the augmented reality work in this project was real-time feedback. By incorporating the motion data from the sensors as discussed in the previous sections we were able to have the program augment the video display with warning and visual queues when the user exceeded specific thresholds for velocity or acceleration of the tools. The thresholds for the velocity and acceleration we determined from indicators from Dr. Nsar’s research paper on motion analysis. This is discussed in further detail in the following Chapter. When the user passed the acceleration threshold an orange visual highlight is displayed and text is included to indicate what axis of tool moment caused the warning to be triggered. The figure below shows an example of the Acceleration threshold being violated by the right tool’s Yaw acceleration (Degrees/sec^2) while performing the wire task.

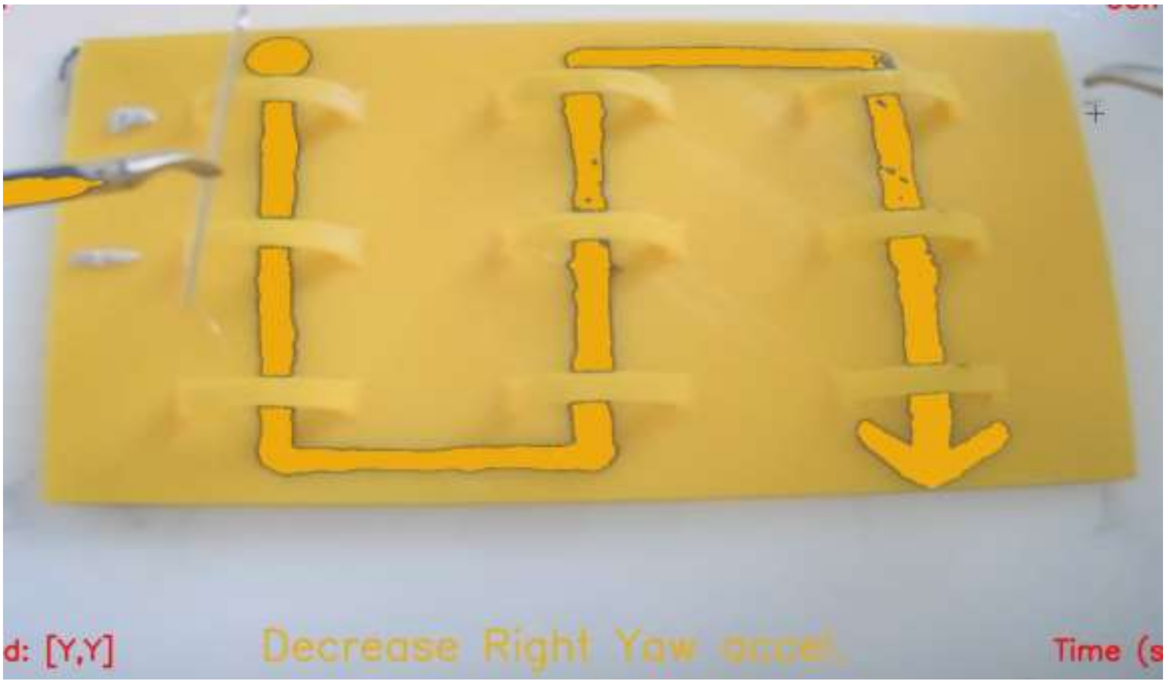

Figure 32: Real-time Feedback for Acceleration Threshold on the Wire Task

When the user exceeded the threshold for velocity on the yaw, pitch, or surge axis the same highlighting was done in red with the corresponding text displayed. The following figure showcases the velocity threshold being violated by the surge of the left tool (mm/s) while completing the Ring Task.

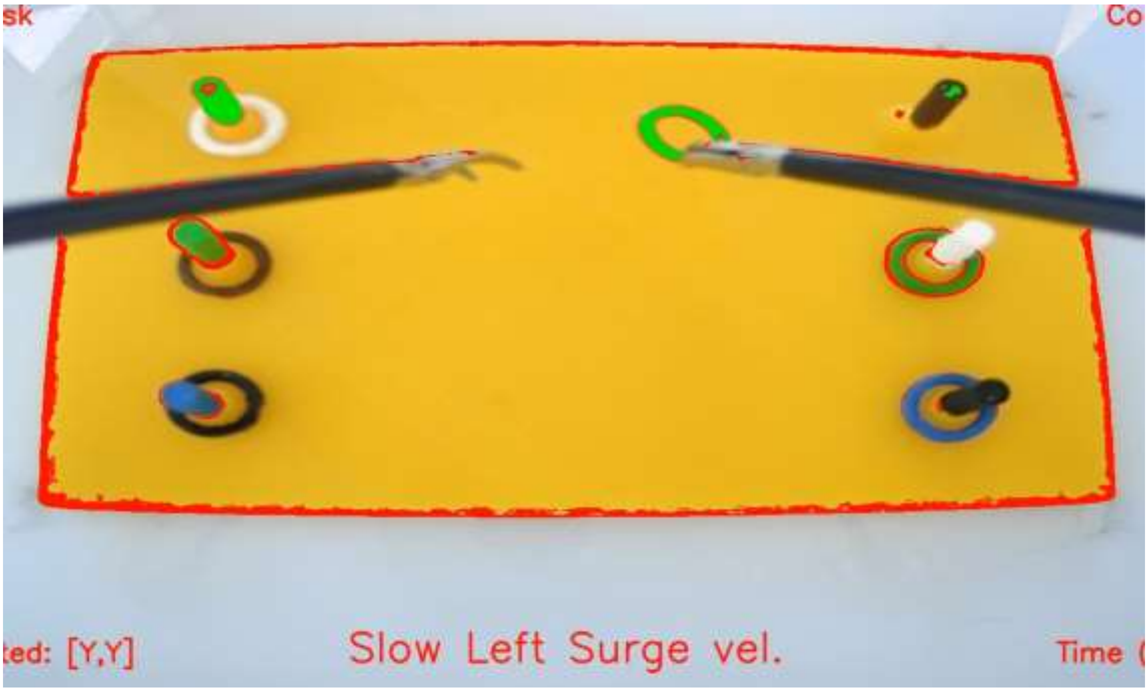

Figure 33: Real-time Feedback for the Velocity Threshold on the Ring Task

These visual cues and textual indicators help teach the surgeon in real-time how they need to improve their skills in order to complete the task like an experienced surgeon. These violations of the threshold are recorded and later displayed again to the user in the analysis window. By being shown these visual cues in real-time based on their movements, trainees are able to build an understanding of what movements are too fast or too reckless while still being able to move quickly and carefully in order to complete each task in a timely manner.

5.5 Improvements and Future Work in Augmented Reality

There are a number of improvements that could be made to the above work to make it more reliable and expandable for other tasks. There are also a number of other ways Augmented Reality could be used in future semesters. This section discusses some of those improvements and possibilities.

Firstly, the HSV color masking technique described above that is used for the majority of the Computer Vision and Augmented Reality work is very susceptible to changes in the lighting conditions. In order to combat that in this project a method for real-time color calibration was created to allow for color ranges to be recalibrated if the lighting inside the apparatus changed dramatically from the currently saved values. The figure below shows the color calibration window created to allow for this real-time color correction. In the future, more robust and complex techniques than HSV color masking should be explored and more detailed work should be focused on improving the reliability of the computer vision segments of the augmented reality work.

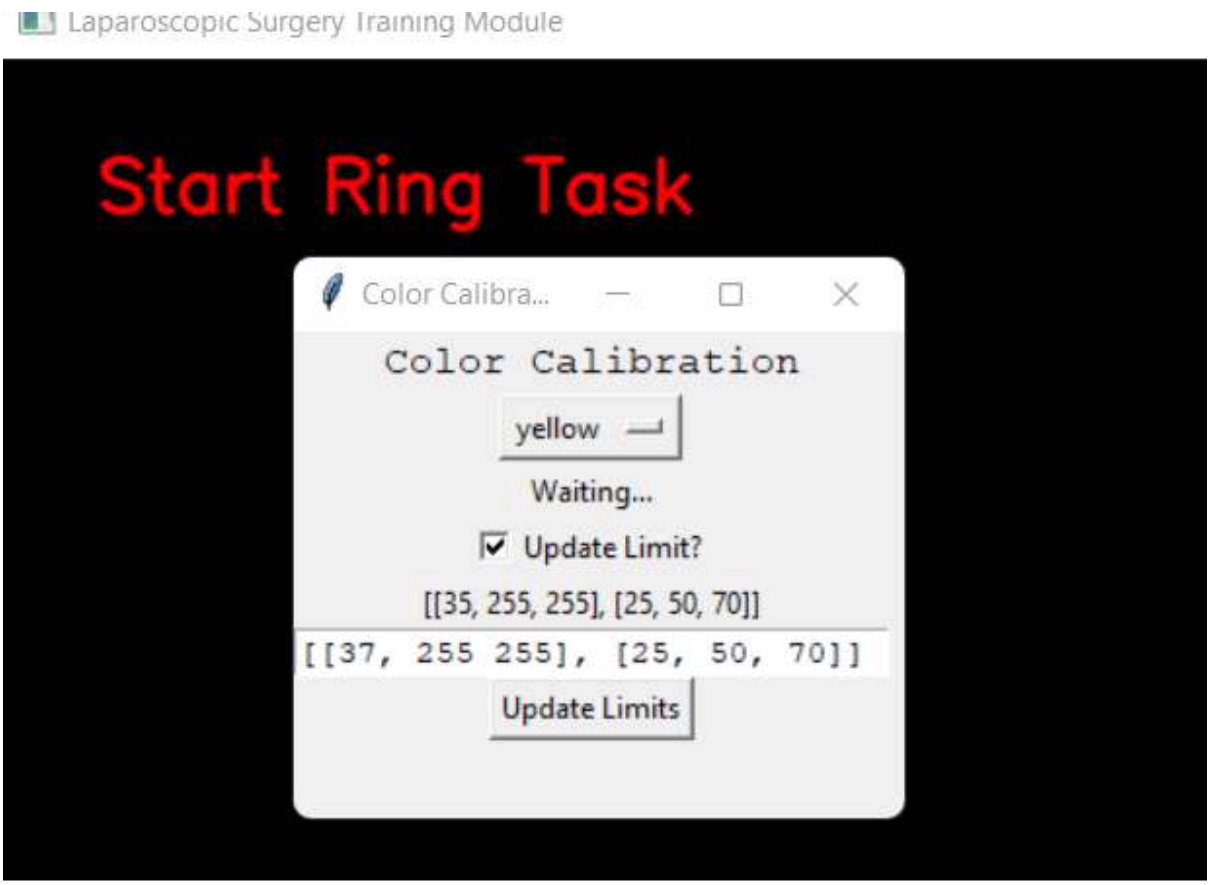

Figure 34: Colour Calibration Window for HSV Masking Calibration

Although the augmented reality visual cues utilized in this project were deemed useful when experimenting with the apparatus ourselves, it would be beneficial to have real training surgeons experiment with the apparatus and comment on how the augmented reality cues could better serve them in training. More levels of feedback could be implemented, visual cues could be shown in different areas or in different colors, depending on what would be most beneficial to actual trainees.

Finally, there are a number of ways in which advanced techniques in Computer Vision could be used to add complexity and sophistication to the Augmented Reality feedback. This includes more reliable task completion, Augmentation based on object detection rather than color detection, and the ability to control the apparatus with computer vision rather than the need for additional mouse input. Further improvements and next steps for the project as a whole are discussed in Chapter 7.

Chapter 6: Evaluation

It is important for future surgeons to develop laparoscopic surgical skills and ensure they have a high level of manual dexterity. The scope of the evaluation process is to evaluate participants' yaw, pitch, and surge while they conduct certain activities that were developed and 3D printed, as well as view their results on a screen and obtain feedback on where to improve and what mistakes they made.

6.1 3-D Task Designs

OnShape provides important features such as assembly, component drawing, and configurations, as well as the ability to practise 3D design. This software allows us to share our work with a group member and can both change and adjust the measurements of the projects before they are printed, unlike other 3D model applications with limited options.

Because it gives participants more freedom and room to practise hand motions and depth perceptions, the Ring activity (Figure 35) has been created with six pegs. This will also be an easy practice for beginners, as it will be their first hand-movement activity. Because the pegs are higher and the rings are greater in size, a participant with no prior understanding of laparoscopic surgery would be able to accomplish this task. The participants begin by using the surgical grasper to take the first ring from the right side of the board and passing it to the left side of the board and over the mirrored peg.

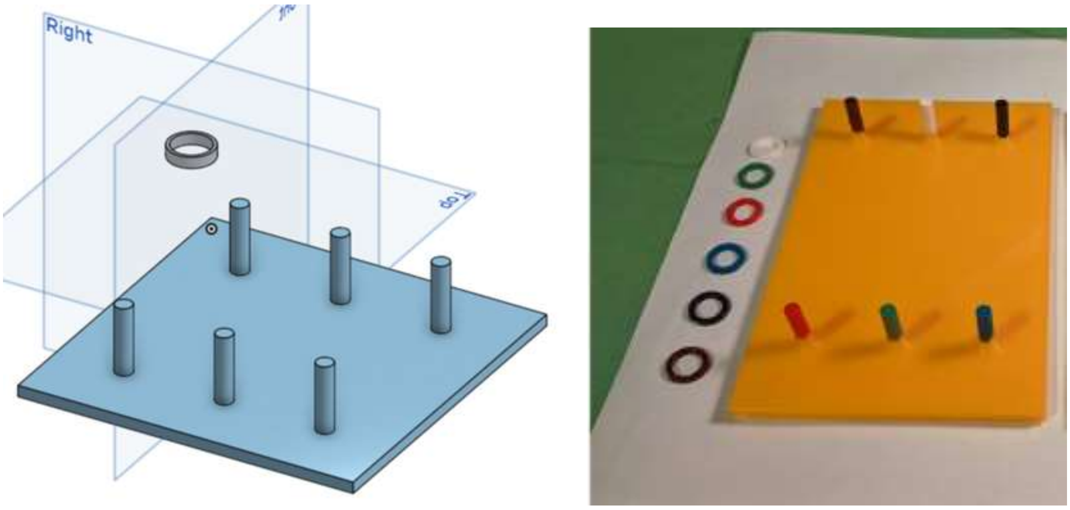

Figure 35: Ring Task

The second task is Wire the Loops (Figure 36), it is purposed to connect the loops and thread the pipe cleaner using the surgical grasper through the loops. This exercise is useful because it allows the user to practice hand movements and accuracy while using graspers. A laparoscopic surgeon's ideal posture is with the arms retroverted, slightly abducted, and rotated inward at the shoulder level. Furthermore, the elbow should be bent at a 90–120° angle, and the hands should hold the tools with the wrist slightly extended. Participants should use their grasper tips to grasp the pipe cleaners and put them through the loops, trying their best to practice and execute the appropriate posture and position of a surgeon.

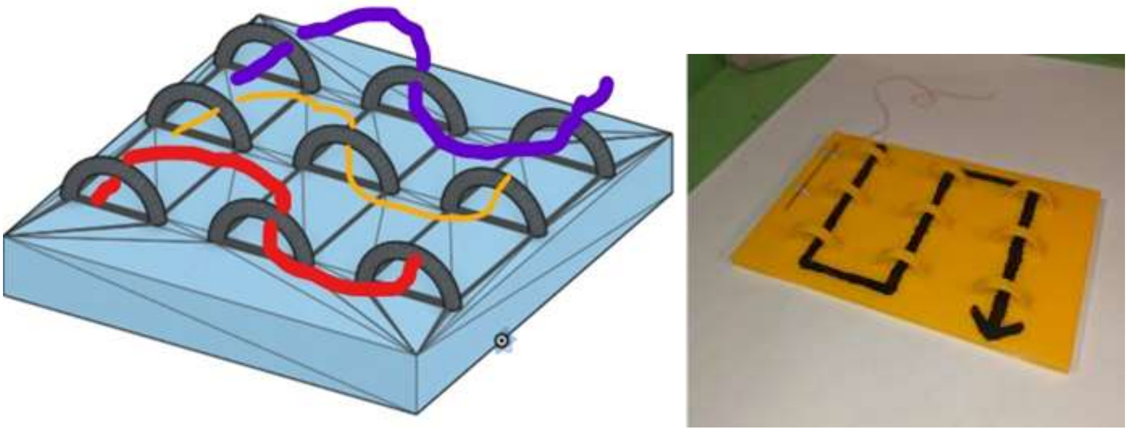

Figure 36: Wire The Loops Task

These two activities will be utilized to instruct the user on the fundamentals of laparoscopy while also providing the structure for the project to construct tool-tracking and augmented reality around. The user will interact with the Augmented Reality interface using their tracked tools, and they will be able to indicate when they start a task. Their performance will then be reviewed until the task is completed. The user will be able to indicate when a task has been done by interacting with the augmented reality interface and after a task has been performed, an evaluation of the task for the user will be presented on the monitor. The task completion of the user will be evaluated in two categories. They will first be evaluated based on how long it took them to complete the task. Obviously, a shorter time is preferable to a longer one, given that the activity was not completed at an excessively fast pace. Second, they will be assessed depending on the movement of their instruments. In the paper with which we have been collaborating, Nasr et al. detail how they are able to categorize surgeons' skills based on the motions of their tools, notably noting that experts employ less range (in and out movement of the tools) and slower roll speeds throughout the task.

6.2 Evaluation done by the Python Program

Surge, pitch, and yaw will all be evaluated by the software. The surge would detect movement and translation along the linear axis generated by pushing or pulling the hand in or out. The pitch function would then search for vertical (up/down) axis motion/rotation, i.e. the effect of moving the hand up and down. Finally, yaw would look for motion in the lateral (side to side) axis, which would be caused by moving the hand from side to side. These are assessed using velocity, which is the rate of change of the instrument's position, comparable to the speed and direction of motion.

6.3 Python Libraries/Classes and their benefits

To assess tasks, a Python script is written and numerous libraries are utilized. The first library used is Tkinter, which is a standard framework for constructing GUI applications. With Tkinter, one can create windows, labels, buttons, sliders, and so on. The second library used is Pandas, which assists in data manipulation and analysis. For example, in the code used, we read the csv file and retrieved the dataframe, then we used the dataframe to access the data and convert the x-axis data to datetime. Matplotlib is a plotting library that is used to display the data. Using this library helped in manipulating the graphs in several elements such as changing the colours, labels, applying legends, the kind of graphs, formatting the x and y axes, and much more. Finally, vertical lines are added to the graphs when there are instant changes between consecutive points which helps in visualizing mistakes a trainee made.

A slider for scaling class is constructed with its four functions, which comprise a function constructor to help generate two sliders, one for lowest and one for maximum, to help in counting the number of readings in the x-axis, so the graph will present data proportionate to the slider. The minimum slider function is then created, with the objective of determining if the slider is greater than or equal to the maximum slider, and whether it is correct for the minimum slider to be greater than the maximum slider. The maximum slider function is the same as the minimum slider function, however it works in the other direction. And updating plot's function was constructed to accurately update the x and y axis limits based on the sliders. Finally, the analyzer class is built. This class is made up of four separate methods, the first of which is the velocity calculation class, which examines the input and calculates it. Second, the acceleration function is calculated using the same manner as the velocity from the csv input. Third, there is the analyze function, which reads the file and processes the function data. Finally, drawing graphs for position, velocity, and acceleration results in the creation of a GUI class object, which results in the creation of a window with data for position, velocity, and acceleration.

6.4 Derivation of a basis of evaluation from the data of Dr. Nasr

Table 2
Comparison between novice, intermediate and expert.

	Novice (N = 26)	Intermediate (N = 12)	Expert (N = 37)	P value
PITCH				
– Velocity >2 SD	52 ± 44	29.4 ± 19	13.6 ± 6	0.001
– Acceleration >2 SD	85.8 ± 60	45 ± 32	29.6 ± 13	0.002
– Range	150.3 ± 50	90.2 ± 68	26.3 ± 12	0.02
YAW				
– Velocity >2 SD	46.3 ± 38	29.8 ± 16	8.6 ± 4	0.002
– Acceleration >2 SD	80 ± 70	30 ± 28*	20 ± 7*	0.001
– Range	178.2 ± 20	122.8 ± 42	26.3 ± 16	0.02
ROLL				
– Velocity >2 SD	16 ± 18	6.2 ± 6.2*	3.8 ± 0.9*	0.001
– Acceleration >2 SD	30 ± 27	15 ± 5	3.7 ± 1.1	<0.001
– Range	10445 ± 2404	8697 ± 1973	3923 ± 988	0.007
SURGE				
– Velocity >2 SD	26.6 ± 21	15.7 ± 7.5*	7.8 ± 0.6*	0.002
– Acceleration >2 SD	38 ± 33	19 ± 11.5	7 ± 2	<0.001
– Range	1004 ± 450	931.8 ± 562	753.6 ± 111	0.6

Figure 37: Comparison between Novice, Intermediate, and Expert

The table from Dr. Nasr's journal (figure 37), assisted in developing the basis for the evaluation process; it can be seen that participants were divided into three categories: novice, intermediate, and expert. Furthermore, it was discovered that the trainees with the lowest velocity, acceleration, and range were classified as an expert. Individuals in the expert category exhibit higher dexterity when dealing with the surgical graspers. So, this offered an idea as to how to identify faults in graphs. When a trainee moves quickly (loses control), it appears that they committed an error and went over the threshold.

6.5 Analysis of the Position Data

Figure 38 shows the motion data collected from the tools as described in Chapter 4. The blue line represents yaw (in degrees), the green is the pitch (in degrees), and the purple represents surge (in mm). The position data for the yaw, pitch, and surge are sent into the Python software over a serial interface from the Arduino Uno. It is recorded to a CSV file while the task is being done, and after the task is finished, the analyzer reads that CSV file with all the saved data and evaluates it. Therefore, two files are saved every time, one for the left grasper and one for the right grasper, the analyzer analyzes each grasper individually.

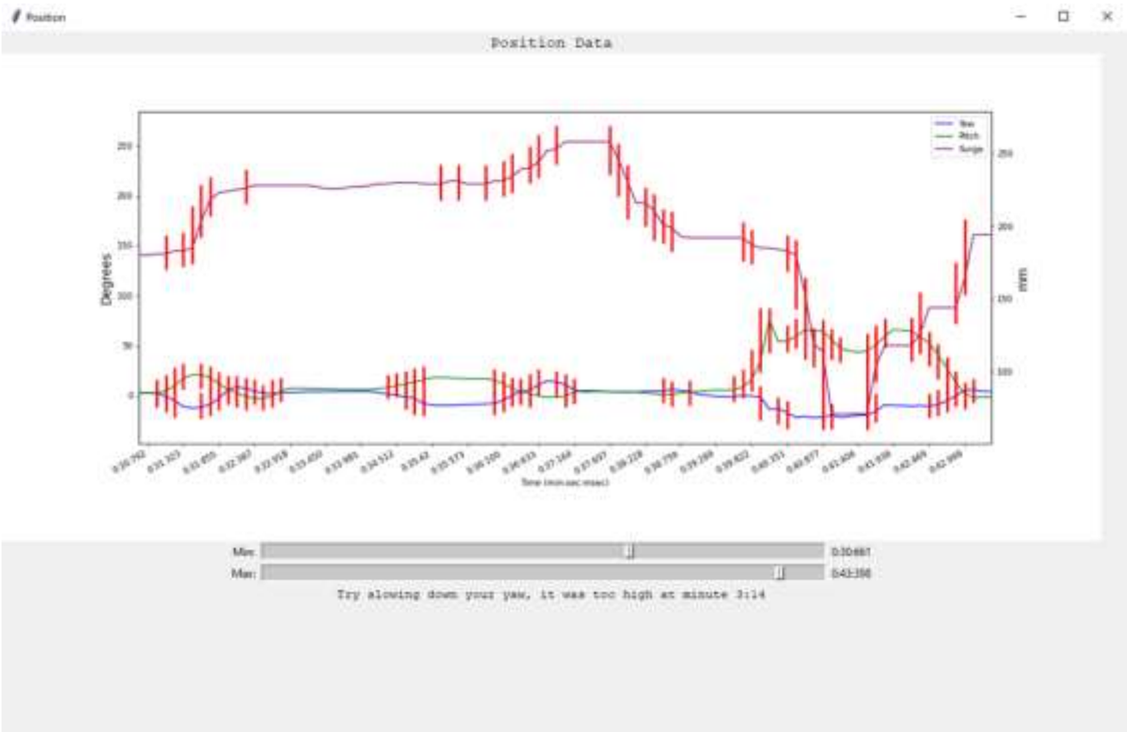

Figure 38: Position Data Graph

On this graph one can see a number of red markers. These markers indicate places where the user exceeded thresholds of instantaneous velocities. Thus, no matter what values are shown on the graph, the script validates the consecutive y values. A vertical line is drawn where the difference between consecutive y values is larger than the threshold.

6.6 Analysis of the Velocity and Acceleration Data

The next figure (Figure 39) shows the velocity and acceleration analysis that the evaluation program produces. In the top graph, you can see the instantaneous angular velocity of the yaw and pitch in degrees per second, and the instantaneous velocity of the surge in millimeters per second. These values are derived from the position data between each pair of subsequent data points.

Figure 39: Velocity and Acceleration Data Graphs

In the second graph of Figure 39 one can see the instantaneous angular acceleration of the yaw and pitch in degrees per second squared, and the instantaneous acceleration of the surge in millimeters per second squared. These values are derived in the same manner as the velocity is obtained but now from the velocity data between each pair of subsequent data points. The acceleration graph is simply marked with horizontal lines indicating where the threshold for maximum accelerations is set. Each mark on the velocity graph is indicative of the yaw and pitch accelerations exceeding these threshold bounds.

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6.7 Example of a Feedback of the Position and Acceleration Data Graph

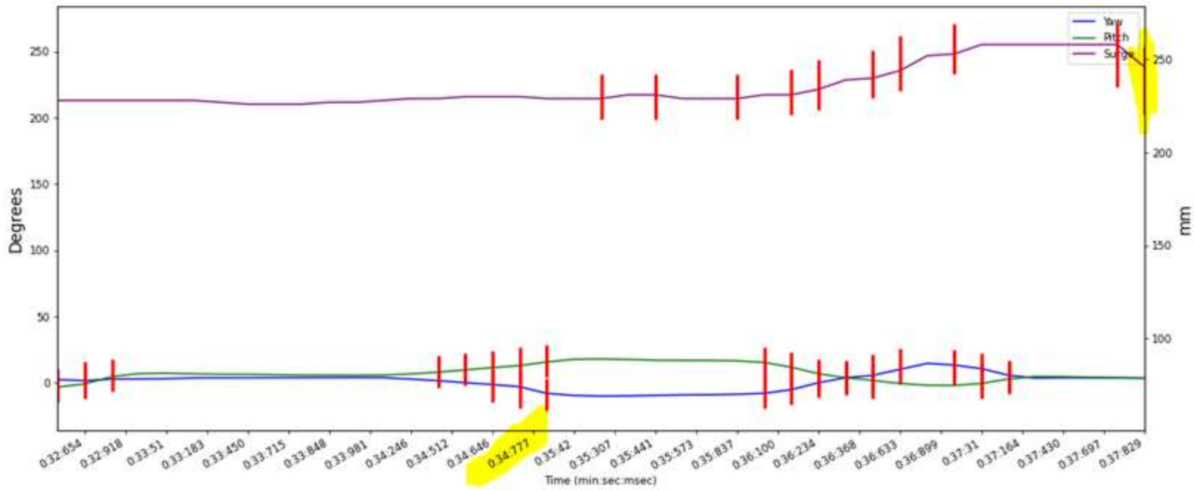

Figure 40: Feedback of Position Data

Figure 40 above depicts a mistake made by a learner while doing the task. This error indicates that the user surpassed instantaneous velocity thresholds and went above. The subject has sort of lost control of the surgical grasper when they have moved rapidly and over the threshold, resulting in a greater velocity at 0:34:777 (min: sec: msec).

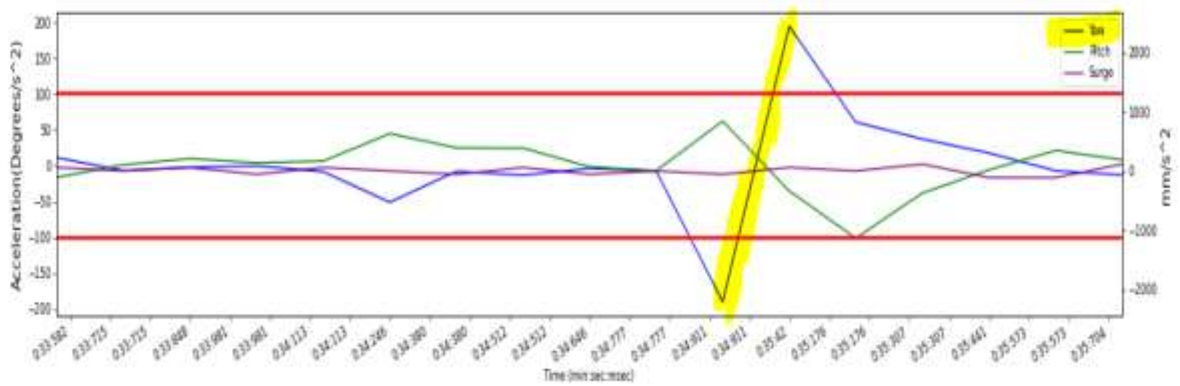

Figure 41: Feedback of Acceleration Data

Another example of feedback that the python software detects is in the figure 41. This demonstrates that the acceleration of the grasper has a significant move on a participant's hand which has moved faster from being somewhat steady in the middle, then dropping to approximately -190 m/s^2 and all the way up to 190 m/s^2 at 0:34:911 (min: sec: msec), then to a more balanced yaw where the trainee tried to lower their acceleration resulting in a more steady and balanced yaw acceleration.

6.8 Improvements and Future Work for Evaluation Process

A lot may be done to enhance the evaluation process. For example, a live plotting approach can be used by utilizing the Python Animation function, which allows participants to have real-time charts of their yaw, pitch, and surge while executing the tasks. This is beneficial because individuals will be able to watch their position, acceleration, and velocity and check for trends as they occur. This will aid in task mastery by giving them better control over the graspers and avoid vertical lines. The second recommendation is to use Matplotlib's Bar graphs instead of a step graph to plot participant movements. Bar graphs in Python are easy to understand and can represent changes over time, so they are great when changes are large. Furthermore, it would be beneficial to have a flowchart that an individual may examine prior to beginning the activity, an example can be shown in (Figure 42). A flowchart would be beneficial in providing clarity and efficiently communicating with a trainee, as well as providing documentation of the activities.

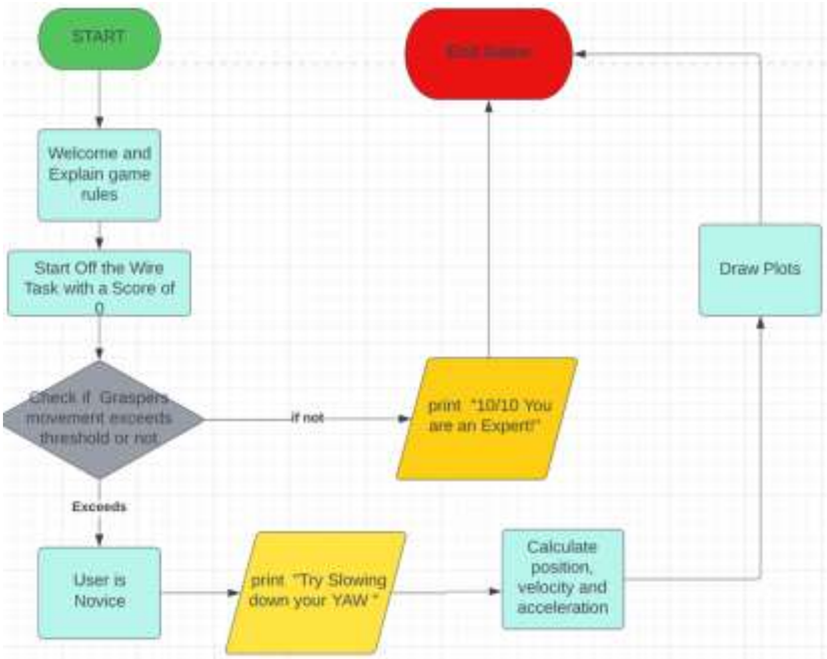

Figure 42: Flow Chart Example for the Wire The Loops Task

Finally, it would be great to observe actual surgeons execute these activities and then use their data of yaw, pitch, and surge depending on how well they performed as a threshold for our evaluation process. Using their data, we can adjust the Python program to set a scoring system for individuals and see how well they performed based on the surgeon’s data.

Chapter 7: Conclusions and Recommendations

Laparoscopic Surgery is a relatively new surgery technique boasting many benefits over traditional open surgery techniques. These benefits however come at the cost of increased complexity. Due to the relative novelty of the practice, advanced training procedures are required to ensure trainees are properly prepared for this difficult procedure. By combining the benefits of existing Physical and Virtual training modules we have been able to create a stand-alone augmented reality training apparatus capable of collecting motion data from the trainee as they complete two basic tasks, display real-time guidance and feedback, and present the trainee with an analysis of their data to aid in their training process. Our apparatus opens up new guidance and feedback capabilities not provided by most existing state-of-the-art training devices. Our apparatus is also highly expandable for new features and projects in the future.

As stated in detail in the previous sections there are many ways this project could be extended in the future or even branched into several projects. To summarize, improvements could be made in the instrumentation to allow for consistent and more accurate tracking of the tools. This could take into account tracking the roll of the tool as was originally planned before switching to the VLX sensor. The Augmented Reality work could continue to be better calibrated to improve accuracy as well as other methods could be explored in utilizing complex computer vision techniques as discussed. Finally, much more work could be done in determining a more precise basis for evaluation for trainees by collecting data on the apparatus from real surgeons and determining more accurate thresholds for velocities and accelerations. Working in conjunction with these surgeons could also reveal how the analysis provided to the surgeons can help them improve their skills.

While working towards our goal of building the Apparatus we also explored the possibility of using the instrumentation to calculate the position of the tooltip in real-time. This was something that the professors were curious about pursuing but did not quite fit in the scope of our project. We did however spend a number of weeks researching this possibility and creating a prototype demonstration by passing the data collected from the sensors into Blender (A 3D modeling application) running a python script similar to the one utilized for the final project. The following figure shows a 3D model of the surgical grasper represented in 3D space based on the current readings from the yaw, pitch, and surge of the tool.

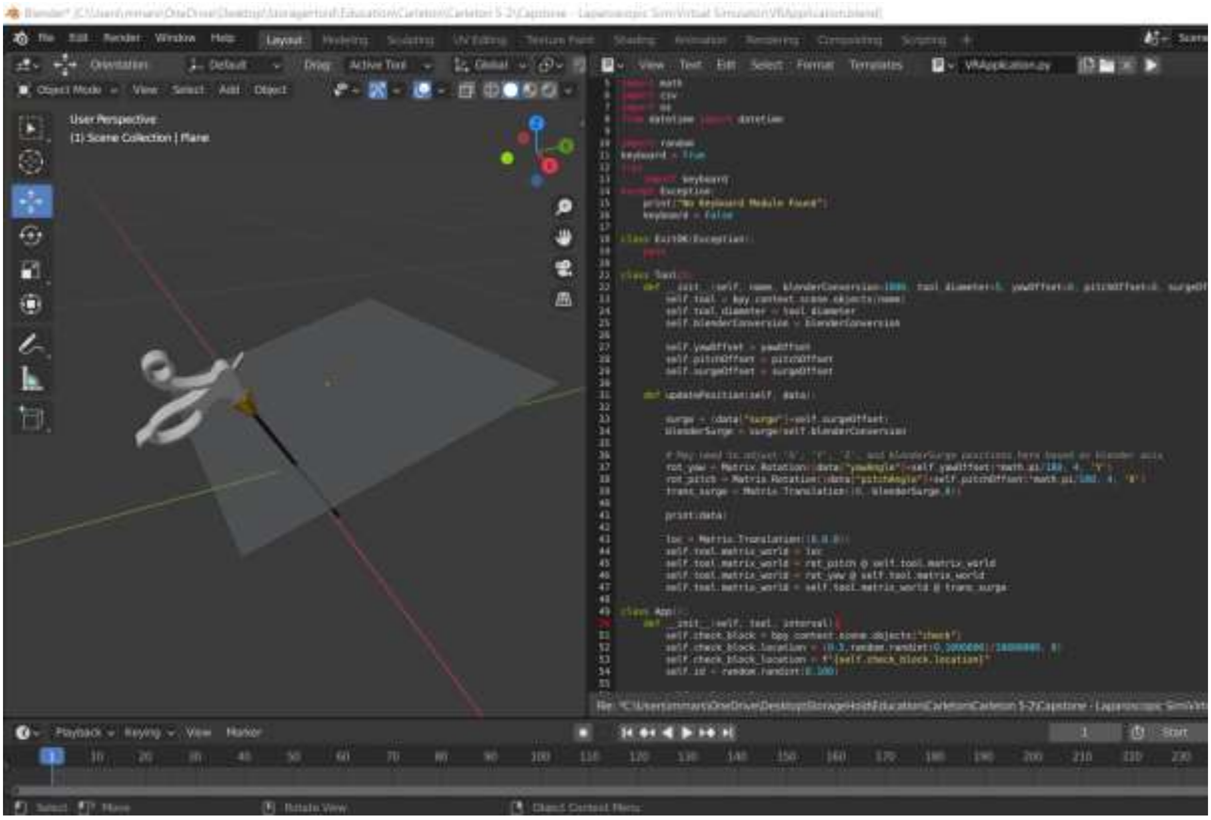

Figure 43: Blender Prototype for Tool Tip Position Calculation and Virtual Representation

Using simple matrix multiplication for the rotations and position of the 3D model of the tool we were able to show the 3D model in space. This math could easily be expanded to get the exact positions of the tool tips in space based on the fixed reference point provided by our custom 3D printed trocar mounts. Determining the position of the tool tip could open a whole new area of motion analysis beyond the analysis of the individual components of the tool's movement. This could also be used to build a virtual simulator or perhaps combine this virtual simulation with the physical simulator with computer vision to create a full virtual representation of the apparatus that could provide more augmented reality guides to the system based on various virtual factors.

Chapter 8: Reflections

This has been the longest consecutive project that any of the members have been a part of this brought about a few difficulties in project and team management throughout the term. In the beginning, a lack of communication developed in the group which resulted in the group losing track of the objectives of the project. It was difficult for Rahme to choose a part of the project to claim in the first semester, but following conversations with the Professors and group members, assisted in selecting the task evaluation section which he was able to take for his own and work hard to develop in the second semester. Overall, our team dynamics have been very good since then and were able to communicate effectively after switching from communication over Discord to WhatsApp.

We worked very effectively as a group as we were able to divide the project work into discrete sections for each of us to focus on while also assisting one another with our components and linking them together. The multi-layered process of our capstone project was at times uneven and challenging. The main learning outcomes came with the lessons learned in team communication and management and figuring out how our work could manifest and come together to be operational. We learned quickly that teamwork and effective time management were needed for the fluent flow of the project. Maintaining a detailed logbook of individual progress updated before each weekly meeting with the professors helped all the students stay on track and up to date with each other's progress.

A great deal has changed since the project's inception. Initially, we expected to get a fully constructed and instrumented box from Dr. Nasr, but our scope was expanded early on to include the construction and instrumentation of our own box, which consumed the majority of the project's resources. In terms of the project's following phases, there are numerous possible extensions to the work we performed this year. We established an excellent foundation for another group to build upon, whether it is by adding additional instruments, continuing AR research, expanding data analysis, or proving the effectiveness of AR training through studies. Moreover, there is the option of continuing tool tip tracking work to expand the scope of motion analysis, as well as the possibility of developing a VR simulator or side-by-side module. Thanks to all the efforts and eventual devotion, the project has achieved and excelled in its sought-out goal of creating a stand-alone prototype system, as well as, leaving space for improvement and modification to the apparatus due to its modular nature.

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Appendices

Appendix 1: Project Proposal

SYSC 4907

Project Proposal

Laparoscopic Surgery Simulator

Augmented Reality Surgery Trainer for Pediatric Surgeons

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October 22nd, 2021

Abstract

The main objective of the project is to develop a stand-alone laparoscopic surgery training module at a low-cost that is capable of providing training and guidance to the user as well as real-time feedback based on the motion of their tools inside the module. The module will then evaluate the user during their completion of two distinct tasks. The field of laparoscopy is relatively new in the surgery world but it has very clear benefits over traditional “open” surgery techniques. However, these benefits come at the cost of added difficulty of the procedure and lack of skills and training with the required equipment. In order to combat this required skill many various training aparati have been developed and tested the most valid of which seems to be augmented reality simulators into which little research or production has yet to be done. This project plans to utilise our team's skills with sensors, data evaluation and programming to create an augmented reality training module capable of combining the benefits of existing physical and virtual reality simulators into an augmented reality trainer that is capable of guiding the user and providing real-time feedback based on their actions. The timeline for the project runs from November to April during which time many outlined milestones will be reached. The project will also require a number of hardware components in order to build the stand-alone module with the necessary features to achieve the project's goals.

Introduction

This proposal outlines the intentions for the “Augmented Reality Surgery Trainer for Pediatric Surgeons” capstone project. It begins with the major objectives of the project followed by a discussion on the background for the project, some context of some of the advancements currently taking place in the field, and reasons for the project's specific goals. We discuss the relation of the project to our studies and how our experiences will give us the ability to achieve the project's goals within the timeframe. After an introductory outline on our proposed plan there is an in depth discussion on our specific parts of the project written by each team member. We have included a Gantt Chart timetable outlining the schedule for the groups major milestones as well as an individual breakdown of what each team member will be working on each week. We discuss some issues the project may face and proposed solutions on how we can still achieve our goals in case of these setbacks. Lastly we list all the components and facilities that we will need to procure in order to complete the project.

Objectives

The objective of the project is to develop a module for laparoscopic surgery training at a minimal cost that can be used by beginners wanting to gain experience in laparoscopic surgery without having access to expensive equipment and constant observation of a senior surgeon. Building off of a previous design for a laparoscopic surgery training box, specifically designed for pediatric laparoscopy, we intend to re-create the training apparatus and add additional instrumentation to the module in order to provide independent feedback and guidance to the trainee.

Our main functional goal is to produce a stand-alone laparoscopic surgery module that can provide guidance and feedback to the trainee in real-time as well as evaluate their performance. In order to achieve these objectives there are a number of other objectives we must achieve. We will need to build a replica of the existing box design and add instrumentation to gather data from the trainee. From that data we can provide feedback to the user through augmented reality display on the simulator’s monitor. We will also set up a number of tasks in the simulator for the trainee to complete and we will evaluate their scores to track their training progress. We will be measuring our progress towards these goals by following the processes outlined in the methods section and ensuring we meet milestones outlined in the timeline section. A few of the major functional milestones outlined later include procuring all the required hardware and assembling the basic training box, instrumenting the hardware with sensors and collecting data into the Raspberry Pi, displaying augmented reality guidance and feedback on the monitor and displaying an evaluation of the trainee’s progress as they use the box.

Background/Context

Over the past few decades, a new technique for abdominal surgery has emerged replacing traditional “open” surgery techniques. “Laparoscopic surgery is a means of performing diagnostic and therapeutic procedures after gaining access to the abdominal cavity [1].” By substituting large “open” abdominal incisions for a few much smaller incisions through which a Laparoscope (Camera) and tools can be inserted, patients experience less pain and have faster recoveries than traditional methods. Laparoscopic surgery is also advantageous since it results in less bleeding, shorter hospital stays, and a faster recovery time. The use of this “Minimally Invasive Surgery (MIS) [2]” technique benefits however come at the cost of a more difficult and complex procedure. It is critical for surgeons to have appropriate ergonomics, which refers to how individuals interact with their working environment. This is important in laparoscopy since ergonomics is concerned with the design of medical instruments as well as risk management. Using the incorrect surgical instrument or failing to comprehend where a surgeon should place it, for example, can raise operation costs and timelines while also increasing the risk of infection. Because of the many difficulties and complexities and relatively new techniques involved in laparoscopic surgery, a need has arisen for advanced training procedures.

The use of laparoscopic surgery has become widely established in clinical practice, with the acquisition of laparoscopic skills now essential for surgical trainees. The technical skills required are, however, distinct from those needed for open surgery; depth perception is impaired due to visualisation on a two-dimensional screen, there is limited tactile feedback, and long laparoscopic instruments create a fulcrum effect and amplify tremor. There is a significant learning curve associated with laparoscopic surgery, and these skills cannot be easily learnt using the traditional apprentice model of surgical training [3]. Simulation is widely regarded as the way forward, and its use has been shown to improve trainees' laparoscopic surgery skills [3, 4]. Simulation provides an opportunity to improve technical skills in a structured low-pressure environment outside the operating room without compromising patient safety [5]. Different simulation methods have been described, from high-fidelity virtual reality systems and animal models to low-fidelity box trainers. The interface of the Box trainer is usually not realistic and is designed to practice general skills required for laparoscopic surgery, such as instrument manipulation, cutting, and internal suturing. Virtual reality simulation uses computer-generated graphics and tactile feedback to recreate the operating environment and promote the practice of specific procedural skills and general laparoscopic skills [6, 7]. Virtual reality systems are, however, very cost prohibitive and may be inaccessible to many trainees for regular personal use [8]. Virtual reality simulators are useful educational tools, but do not show proven significant advantages over traditional models. The lack of standardisation and a scarcity of articles makes comparative analysis between simulators difficult, requiring more research in the area, according to the model suggested in this review [9].

The top mobile physical laparoscopic simulators which are currently being used are - Surgery simulator ecoSim SurgTrac Elite by Twin medical (Figure 1) , Laparoscopic simulator Pyxus HD by Innovus medical (Figure 2) and Mini-invasive surgery simulator 815.021 by Zhejiang Geyi Medical Instruments (Figure 3).

Figure 1: Surgery simulator ecoSim SurgTrac Elite

Source: [*10*]

Figure 2: Laparoscopic simulator Pyxus HD

Source: [11]

Figure 3:Mini-invasive surgery simulator 815.021
Source: [12]

The above available simulators provide users easy accessibility as none of them require a constant power source, they are compact and mobile and their prices range between 500$ - 700$. The simulators do not include virtual reality software or any form of computer assisted guidance. The ecoSim SurgTrac Elite (Figure 1) does come with FLS software which helps users track their skill progression by measuring time taken for task completion. The time is then converted into a score which is then compared to all online profiles who use the same interface. All the mentioned simulators do come with basic task tutorials which show the users how to perform the task in the most effective method but do not have any tool tracking system or real time feedback, which helps users observe their speed and position during the task.

Beyond these basic physical simulators there is development being done to use more advanced technology to assist with laparoscopic training. One study by the Universidad Politécnica de Madrid discusses how a group of researchers created a tracking system to assist with laparoscopic surgery [13]. The goal of this study was to undertake more objectively assessment procedures of surgeons in simulation settings by focusing on this specific surgery. These researchers' EVA tracking system provides a surgical instrument monitoring system that allows for the evaluation of surgical tools by tracking their motions, location, speed, volume and average acceleration within a simulator (Figure 4).

Figure 4: EVA Tracking system for laparoscopic surgery
Souce: [10]

Furthermore, the EVA tracking system employs computer vision to determine the three-dimensional position of the instruments through an endoscopic camera and can properly estimate a surgeon's skill in a simulator. As a result of these features, a low-cost portable tracking system without the need for instrument modification is created. In addition, researchers demonstrated that the estimated metrics may be used to distinguish between beginner and experienced surgeons, as well as to establish a link between the stated metrics and those acquired by other optical tracking systems. Second, the metrics data were utilised to train a classifier that accurately predicts a surgeon's skills in a simulator resulting in an 83.3 percent success rate. Therefore, this result demonstrates a clear correlation between the surgeon's experience and the simulation task performance. Finally, the EVA system is now integrated into an application that will allow us to save and manage surgeon data while tracking their progress.

Another study showcasing great technological advancements in the field of laparoscopy shows how two trained bariatric surgeons collaborated to create AI systems to recognise laparoscopic sleeve gastrectomy surgical stages (LSG) [14]. AI enables computers to analyse video quantitatively in order to detect objects and patterns. Moreover, artificial intelligence may be employed as a quantitative data source for study in intraoperative clinical decision support, risk prediction, and outcomes studies. The visual model which consists of the residual neural network that includes two layers, an input *x* to create a hidden output *h* using a layer with the function *F*. The input of that block can bypass F via an identity connection. Weak connections via F have less of an influence on the information sent down to future blocks with the objective of creating an output y as a result of this. Then, the temporal model LSTM which is composed of two cells: cell 1 and cell 2. Cell #2 gives information about cell's inner workings and will be used as a reference point, as well as it can take input from the data (x2), the state (C1) from Cell #1, and the hidden layer output (h1) of the previous cell that can be processed further to form a new hidden output h2. This provides early-acquired knowledge to be conveyed down the network as "memory" to aid in computations later on.

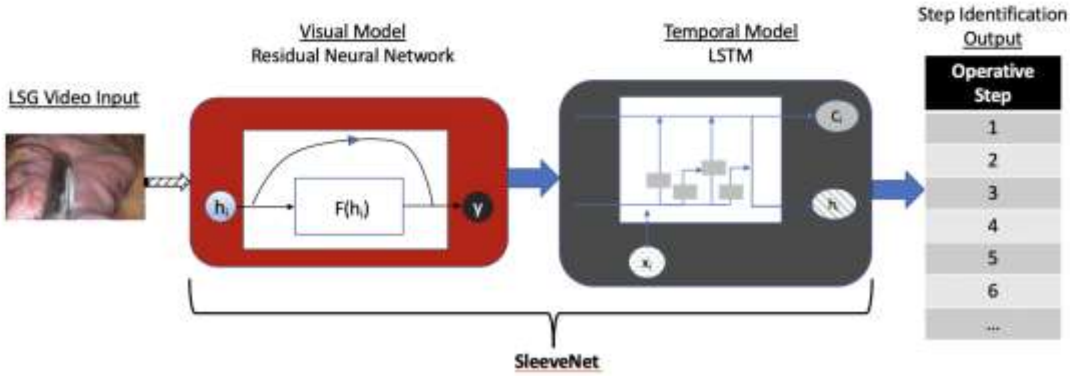

Figure 5: Tracking of surgeon progress through the RNN
Source: [14]

The two surgeons divided the films into the following steps: 1) port placement, 2) liver retraction, 3) liver biopsy, 4) gastrocolic ligament dissection, 5) stomach stapling, 6) specimen bagging, and 7) final examination of staple line. To evaluate videos, deep neural networks were utilised. Therefore, the accuracy of the AI's operational step identification was tested by comparing it to surgeon annotations resulting in a 85.6 percent accuracy.

Along with these other technological advancements, there have been important advances in the area of Simulation trainers for Laparoscopy. In a paper published in 2016, Lahanas et al. [15] compare the advantages and disadvantages between physical reality (PR), augmented reality (AR), and virtual reality (VR) simulators. Traditionally only PR box trainers have been used in the simulated training of laparoscopic surgery but technological advancements have brought forth the creation of fully virtual simulators. The LAP Mentor VR system by 3D Systems shown in the figure below demonstrates an example of a completely virtual training system.

Figure 6: LAP Mentor VR

Source: [16]

There are many companies who have developed VR trainers with extensive virtual tasks for trainees to complete. These virtual simulators allow trainees to complete more complex tasks compared to those in physical trainers and get guidance and feedback from the virtual reality environment as they perform the surgery unlike normal tasks in physical simulators. However, these systems are extremely costly to develop, require advanced hardware to run and lack the real-world haptic feedback of a physical system. This is where the benefits of Augmented Reality simulators shine. Figure 7 below, taken from the paper, shows what they were able to classify as some advantages and disadvantages of the various systems.

Table 1: Advantages and disadvantages of PR, VR and AR in MIS simulation training

	PR	VR	AR
Advantages	- Realistic haptic feedback- - Cost-effective setup	- Objective assessment -Interactivity	-Realistic haptic feedback-Objective - assessment -Interactivity
Disadvantages	- Subjective assessment -Lack of interactivity	- Unrealistic haptic feedback -Lack of assessment protocol	-Lack of assessment protocol

Figure 7: Advantages and Disadvantages of PR, VR and AR systems

Source: [15]

From the advantages we can see that Augmented Reality provides the haptic feedback that VR simulators cannot while also providing the interactivity that physical simulators lack. However, in the field of Laparoscopic Surgery Trainers very little research or work has been done on using augmented reality. In the paper they acknowledge that there is a “clear gap in the current literature for AR laparoscopic simulation platforms. [15]”

One example of an augmented reality platform is the ProMIS augmented reality. In the paper “ProMIS Augmented Reality Training of Laparoscopic Procedures Face Validity” by Botden et al. [17] they discuss the validity of the ProMIS AR simulator. The simulator shown in figure 8 below utilizes a physical space with physical tasks and tracks the movement of the instruments with three cameras inside the mannequin in order to provide results to the user. The AR augmentations are shown on the monitor and include demonstrations, explanations and feedback, which are often lacking in physical simulators.

Figure 8: ProMIS AR Trainer

Source: [17]

In another paper by Botden et al. comparing the VR simulator LapSim and the AR simulator ProMIS they conclude that “In comparison with the VR simulator, the AR laparoscopic simulator was regarded by all participants as a better simulator for laparoscopic skills training on all tested features[17].” This conclusion was a result of the fact that the augmented reality simulator was able to provide real tasks with haptic feedback as well as demonstration, guidance, and feedback to the trainee, all of which are critical to the training process.

From the context of the current state of the field we can conclude that there is a need for more research and development in the area of Augmented Reality in laparoscopic surgery trainers. While maintaining the benefits of current low-cost physical simulators we will provide access to the advanced features that come from more complex systems.

Relation to Studies

Michael is studying Computer Systems Engineering focusing specifically in Robotics. His degree is applicable to the project in its bridging between software guidance and real physical systems. By utilizing real-time data to provide AR feedback and guidance to the user he will use developed skills and continue progressing in real-world data input and output that is a major part of his robotics specification.

Ahmad Rahme is studying Biomedical and Electrical engineering focusing on biological and electrical applications. His degree is relevant to this project because it focuses on biological medical systems, products research, design, development, evaluation and management. He will be able to use his knowledge of digital circuit implementation and verification, as well as digital signalling technologies, to this project by employing these skills.

Raqib Khan is studying Biomedical and electrical engineering. His degree covers courses such as, switching circuits, electronics I, digital electronics, bioelectrical systems and physical electronics. These courses have instilled the knowledge and skill required to incorporate sensors to microprocessors by assembling and developing circuits, code to extract or analyse data captured by the sensors.

Proof of Skills

At its roots the project encompasses three important areas. The building of the box and instrumentation of the sensors for data collection, the ability to provide feedback to the user through augmented reality, and the evaluation of the users skill when completing tasks. Through his courses Raqib has obtained knowledge of sensor, circuit design, and physical circuit integration which will help in the assembly of the sensor, microprocessor and circuit board. Knowledge of C programming which is required to interface the motion sensors to the processor and data analysis of bioelectronic systems helps in understanding and extracting data from the accelerometer and gyroscope are also key skills he has for the project. Once the simulator box is constructed Michael will be able to add Augmented Reality guidance and feedback on the monitor by utilizing his experiences with Python and Machine

Learning. He has also previously worked with Arduino processing boards which will help with the project’s sensor wiring to the Raspberry Pi Board. His propensity for project and group management and organization will help keep the project on track as we work to complete our collective goals. Rahme is familiar with 3D modelling, schematic design, and visualisation in PTC Creo, which will be key in designing and creating the simulator tasks. He has also developed skills in data analysis through his courses that will allow him to process and understand the data from the sensors which can be turned into an evaluations score for the user. With each team member maintaining special experience in each of the areas of the project, by working together we will be able to complete goals in all areas of the multifaceted project.

Outline

In order to achieve the objective of the project we will be assembling a simple pediatric laparoscopic surgery trainer design that can be built at low cost and used for basic training. The design will include a simple plastic box with laparoscopic surgery tools for grabbing and manipulating objects inside the simulator. The tools will be instrumented with sensors to track the forces of acceleration applied to the tools and gather information about their position inside the simulator. The box will include a webcam and monitor to display the view inside the box as it would inside the abdomen of a patient. Feedback will be displayed to the user in real-time to warn them if they are using excessive force at any time during the surgery. The monitor video feed will also be adapted with augmented reality to display simple guides to the user to demonstrate the tasks and aid in independent training. Finally the box will evaluate a user based on their movements in the box during task completion and assign them a score to track their training progress.

Methods

The figure below (Figure 9) shows a depiction of the simulator set-up that will be established over the course of the project. It will consist of a plastic box in the range of 18 by 14 inches. By keeping the dimensions small we are able to create and design a simulator that is simple to develop and resembles the approximate area for laparoscopy surgery on the interior.

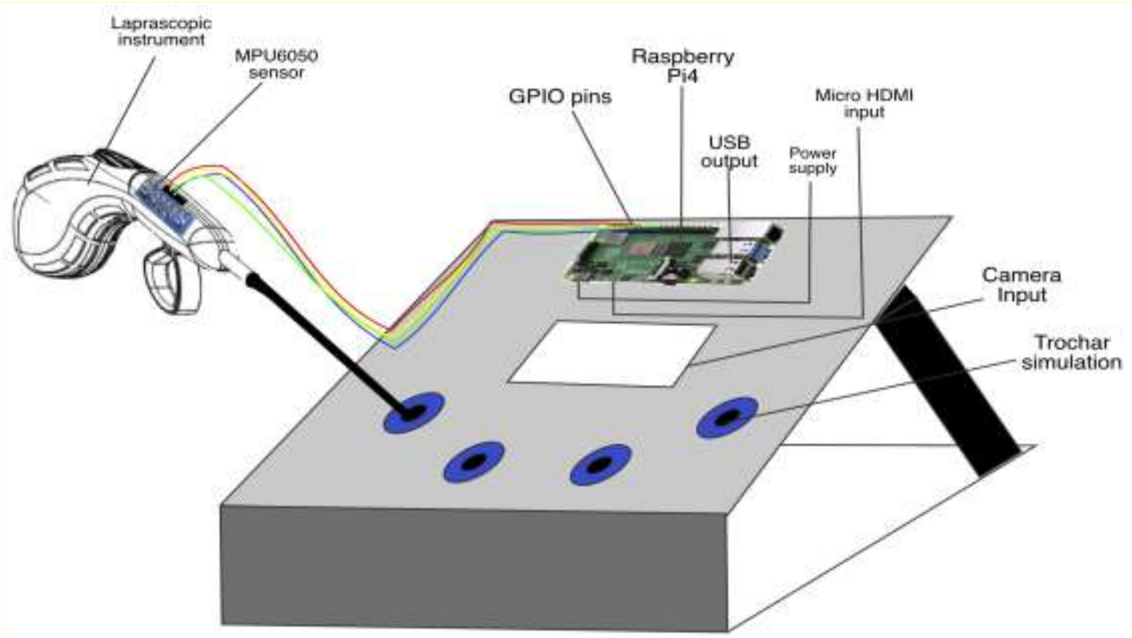

Figure 9: Laparoscopic Simulator Design

The simulator will comprise a number of systems including the tool-tracking system, the internal tasks, and the augmented reality system display which will be shown on a monitor positioned near the box off angle slightly to replicate the conditions of laparoscopic surgery. Each of these systems will be discussed in detail in the subsections below.

Tool-Tracking System and Data Collection

The tool-motion tracking system will help identify the position and the acceleration of the tools used in order to rectify the path length during execution and the speed of the tools. The tracking system will consist of a MPU6050 (Figure 10) sensor module which consists of a 3-axis Gyroscope, 3-axis Accelerometer and Digital Motion Processor. The sensor will be interfaced with Arduino Uno microprocessor (Figure 11) which uses an ARM Cortex-A72 processor microcontroller. The sensor will measure position using a 3 axis MEMS(MicroElectro Mechanical Systems) gyroscope which will measure rotation in roll mode , yaw mode and pitch mode. In the roll mode which will measure angular rotation along the x axis , representing the Pronation and supination of the hand and in turn the instrument. Pitch mode measures rotation in the y axis, representing the instrument moving up and down. Yaw mode measures rotation in the z axis, representing the instrument moving from side to side. We will also integrate the ADNS 7530 mouse sensor to measure depth of the tool or the surge motion.

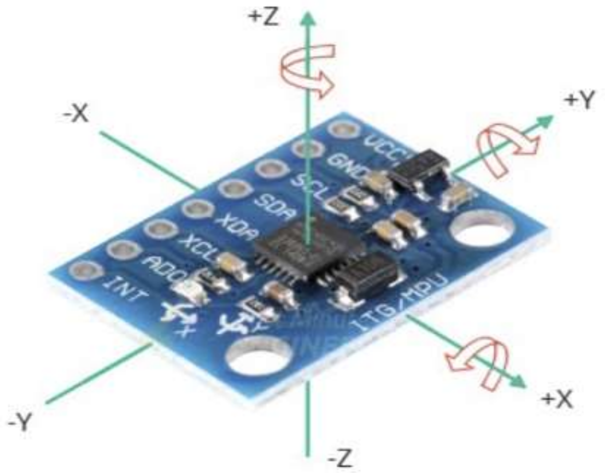

Figure 10: MPU6050 sensor.

Figure 11: Raspberry Pi 4 microprocessor

The sensor will be placed at the top of the laparoscopic instrument handle (Figure 12) of both instruments, as the position will enable us to pinpoint the location of the tooltips and provide easy accessibility to rectify sensor connections to the Raspberry Pi and or any other sensor complications that may arise.

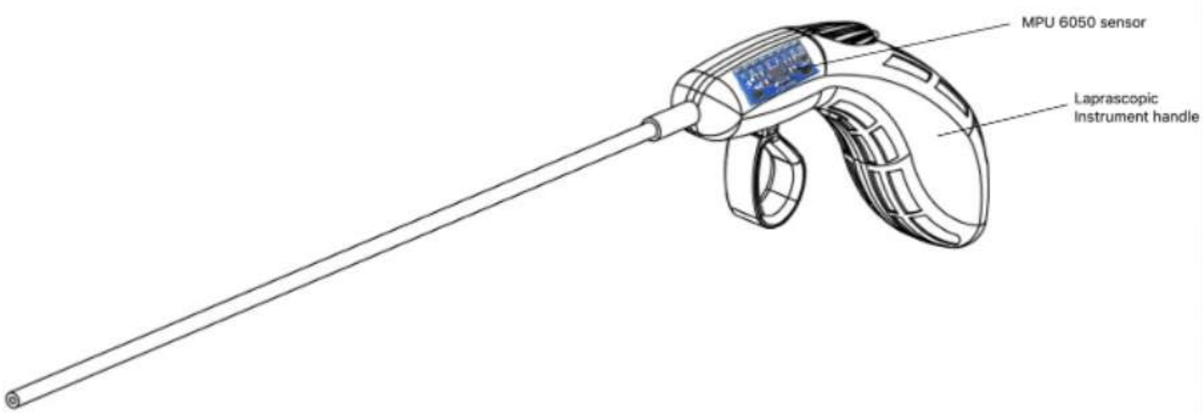

Figure 12: MPU6050 sensor placement on laparoscopic instrument

The raw data (Figure 13) generated by the accelerometer and the gyroscope from both the instruments will be measured and processed using Python or C code developed for the Raspberry Pi interface. The output data will be used to evaluate the skills of the surgeons undergoing training to provide augmented reality tracking and display which will enhance the skills of the users. By implementing acquired knowledge throughout the program such as, hardware configuration of sensors and circuits, data manipulation by developing code, and the integration of sensors, the simulator will be created as described.

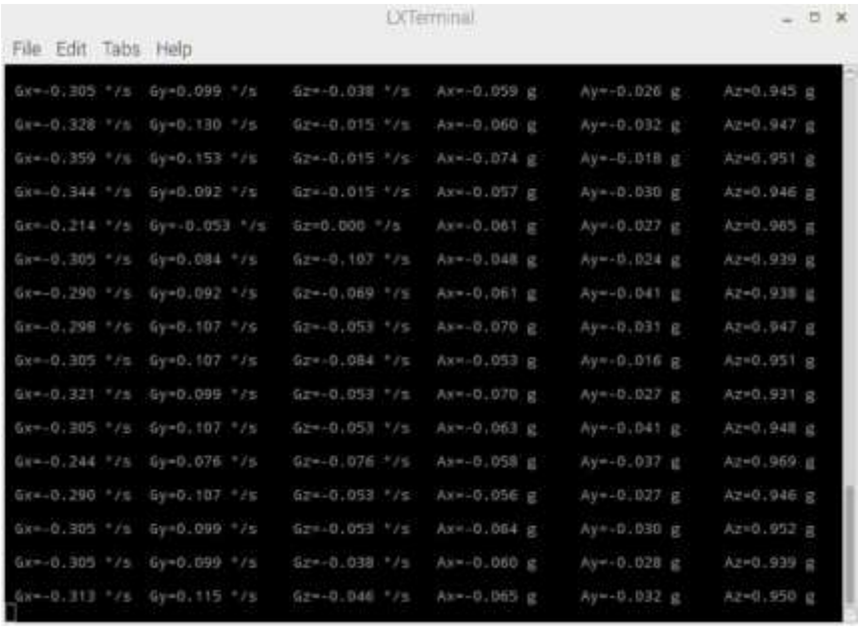

Figure 13: Raw Accelerometer and Gyroscope Data Output Example

Task Design and Evaluation

Hand-eye coordination, manual dexterity, depth perception, and the interplay of the dominant and non-dominant hands are all tested to improve laparoscopic abilities. The first game is a pegboard that will be placed on a rectangular board which includes 8 pegs (cylinder-shaped) and 6 or more coloured rings that will be 3D printed and put in the trainer box that will permit a participant to move the coloured rings from one side to the other using laparoscopic graspers, with the task being accomplished if the rings are returned to their initial location. The participants begin by taking the first ring from the right-hand side of the board and passing it to the left-hand side of the board and over the mirrored peg. Then, the activity is acted in the alternate manner, beginning with the left hand, when the members have effectively moved the six rings to the opposite side. At last, when all rings are back to their beginning position or the principal peg, the activity is effectively finished.

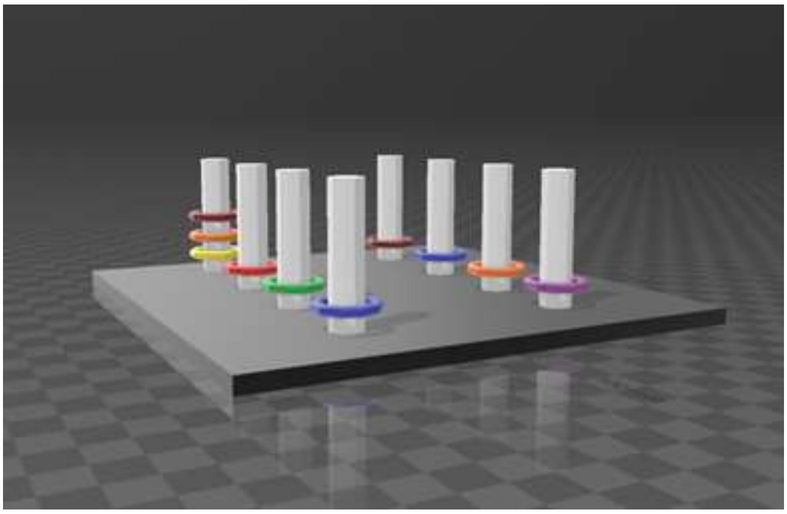

Figure 14: 3D model of the Pegboard Task

The second exercise will include a 3D printed rectangular board with 14 loops and two pipe cleaners or shoelaces. The objective of this game is to thread both pipe cleaners through the two rows of loops; once that is done, the task is finished. The first pipe cleaner should be inserted from the left side, starting with the purple loop and progressing through the loops until the pipe reaches the red loop, which is the last loop, and then the second pipe cleaner should be inserted from the right side.

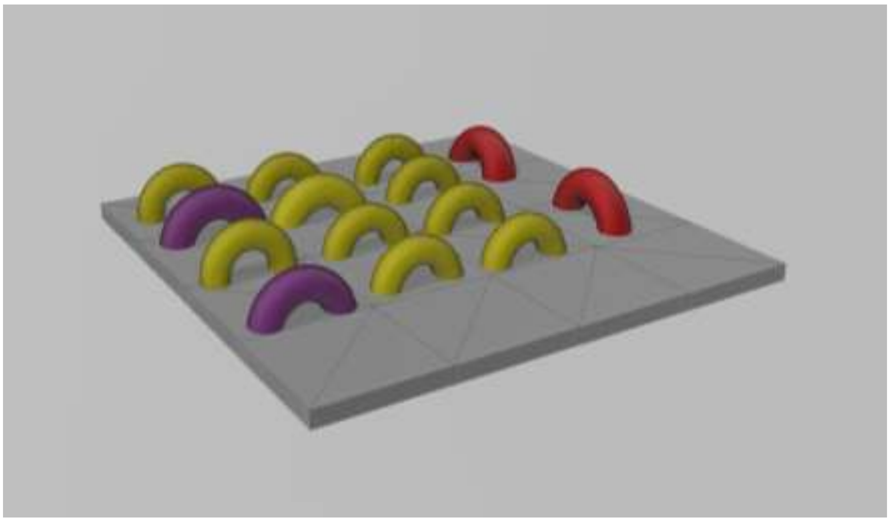

Figure 15: 3D figure of the Second Task - Wire the Loops

As a result, this exercise is beneficial since it can help the individual practise hand motions and precision while utilising graspers. The optimum position for a laparoscopic surgeon is with the arms retroverted, slightly abducted, and turned inward at the shoulder level. In addition, the elbow should be bent at a 90–120° angle; and the hands should grip the tools with the wrist gently extended [18]. Participants should grasp the pipe cleaners with the grasper tips and insert them through the loops doing their best to rehearse and execute the optimal posture and position of a laparoscopic surgeon [19].

These two tasks will be used to train the user on the basic skills of laparoscopy and also give the project the framework it needs to build tool-tracking and augmented reality around. The user will interact with the Augmented Reality interface through their tracked tools and will be able to indicate when they begin a task. At that point their performance will be evaluated until the task is completed. The user will be able to indicate when the task is completed by interacting with the augmented reality interface (described below) and once a task is complete an evaluation for the user on the task will be displayed on the monitor. The user's completion of the task will be evaluated in two categories. Firstly they will be evaluated by the duration it took them to complete the task. Obviously a shorter duration is preferred over a longer one assuming that there wasn't excessive speed used in completing the task. Secondly, they will be evaluated based on the motion of their tools. In the paper by Nsar et al. we have been working closely with, they discuss how they are able to group surgeons expertise by the movements of their tools, specifically noting that experts use less range (in and out movement of the tools) and utilize slower roll speeds over the course of the task [20]. We will be utilizing their results to set a framework for evaluation based on the users movements of the tools during the task.

Augmented Reality (Guidance and Real-Time Feedback)
The surgery trainer will utilise the relatively new technology of Augmented Reality (AR) as an effective and intuitive method for conveying information to the user. Augmented reality will be used to guide the user through the task providing basic training for the method of completing the task and also warning the user if they are moving too quickly or dangerously throughout the test. By using Augmented Reality we can display real-time feedback to the trainee without having to distract them from the training task at hand. We can also give step-by-step guidance to the trainee without having to have another surgeon watch and guide the training exercise. Augmented reality features will be added via the python program running on the Raspberry Pi. The video stream from the webcam will be run through the raspberry pi application and augmented before being displayed on the attached monitor display. The figure below shows the current Raspberry Pi and HD camera being used on loan from the university that will later be replaced by our own hardware purchased through funding we will acquire.

Figure 16: Raspberry Pi and HD webcam currently in use

The two important features that an augmented reality system can use to improve on a physical system (as explored in the background section) are guidance and feedback. In order to achieve these goals the python application will be used along with the openCV python library [21]. OpenCV is an open-source computer vision library that can be used to access the video stream and add augmented reality features to the video. In order to add guidance to the application we will use openCV to display paths instructing the user on how to complete each task. The figure below shows a mock-up of what this AR guidance might look like on a task.

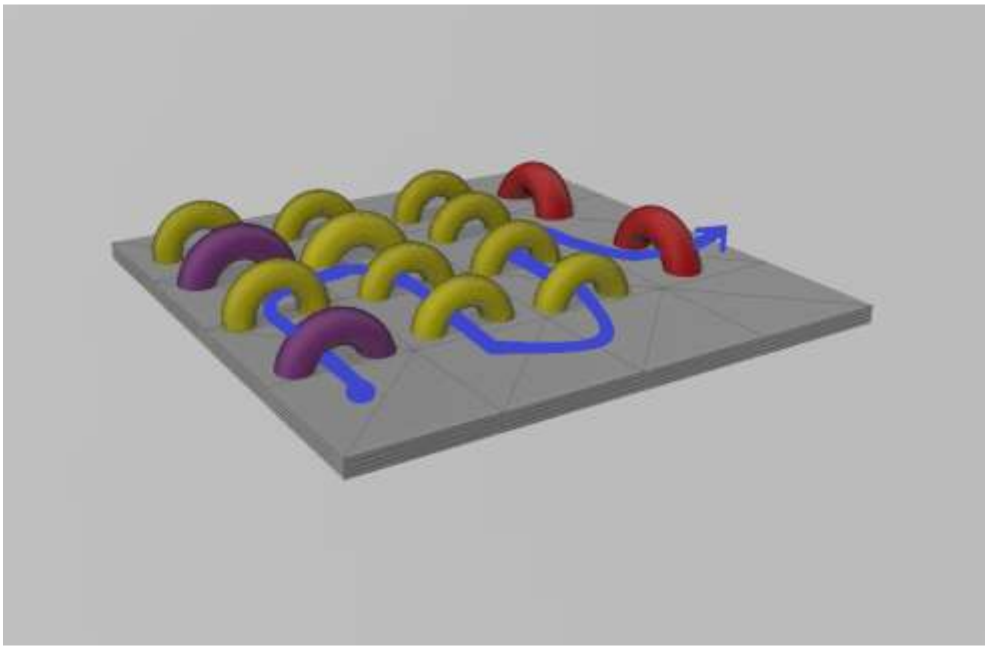

Figure 17: AR guidance path for a task

The augmented reality application will also use OpenCV augmentation to display feedback to the user in real-time by warning them if they exceed set acceleration limits or leave range limits as determined by the motion sensor and the evaluation criteria described in the previous section. The figure below shows the application warning the user of their excessive speed by changing the colour of the guidance line to red and displaying a warning message. We may utilize other task specific warning methods as development continues.

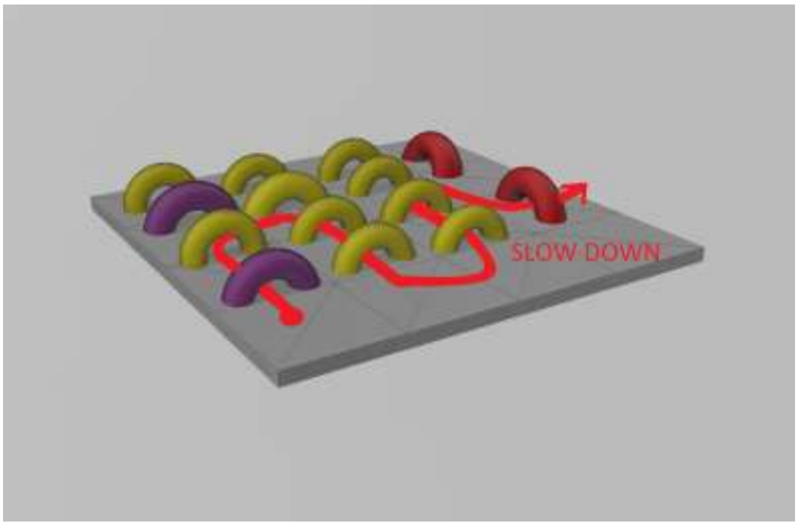

Figure 18: Augmented Reality warning system demonstration

In addition to adding the augmented reality features the python application will also collect all the data from the motion sensor in order to evaluate the user at the end of a given task. Evaluation will be determined by how long the task took to complete and the movements of the instruments during the task (as discussed in the previous section). All this to say, the application will both provide guidance and feedback to the user. A mock-up of the applications user-interface is presented in the figure below. The user will be able to select the options (Either with a mouse initially or through movements of the instruments) and watch augmented reality explanations of the tasks before performing them or select to be evaluated on a given task which will start their time and begin collecting motion data for their run.

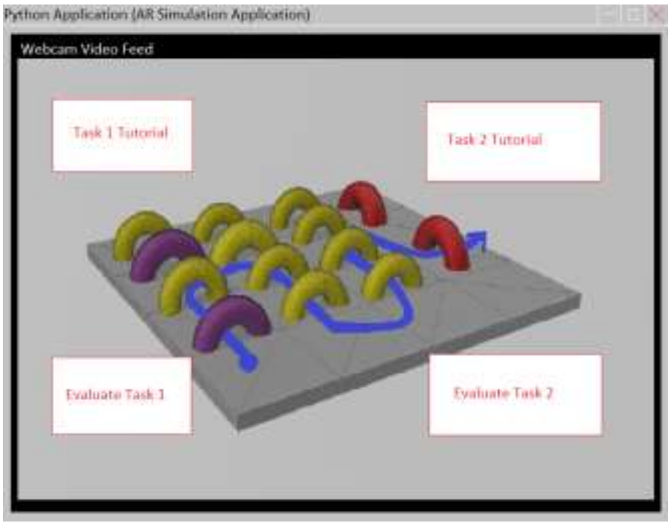

Figure 19: Python Application UI Mock-up

By providing guidance, real-time feedback, and evaluation results to the trainee we will be able to combine the benefits of physical simulators with the benefits of virtual reality simulators.

Through these systems of tool-tracking, task design, evaluation, and augmented reality will be able to actively provide training to the user while evaluating their skills and assisting their training through guidance and real-time feedback. Therefore achieving our goals for an augmented reality laparoscopy training system.

Timetable

The gantt chart below outlines a projected timeline for the project's major milestones and the independent work each team member will be completing over the course of the project. The project's major milestones are listed in cyan and highlight when specific deliverables of the project will be achieved. For example, we hope to have procured all the required basic hardware and have a physical trainer assembled by the week of November 22nd. Below the General Milestones sections are our planned individual work broken down on a week by week basis. These work specifics are very likely to change as we go forward and as needs arise but there are also key milestones in our individual sections that could be noted and maintained.

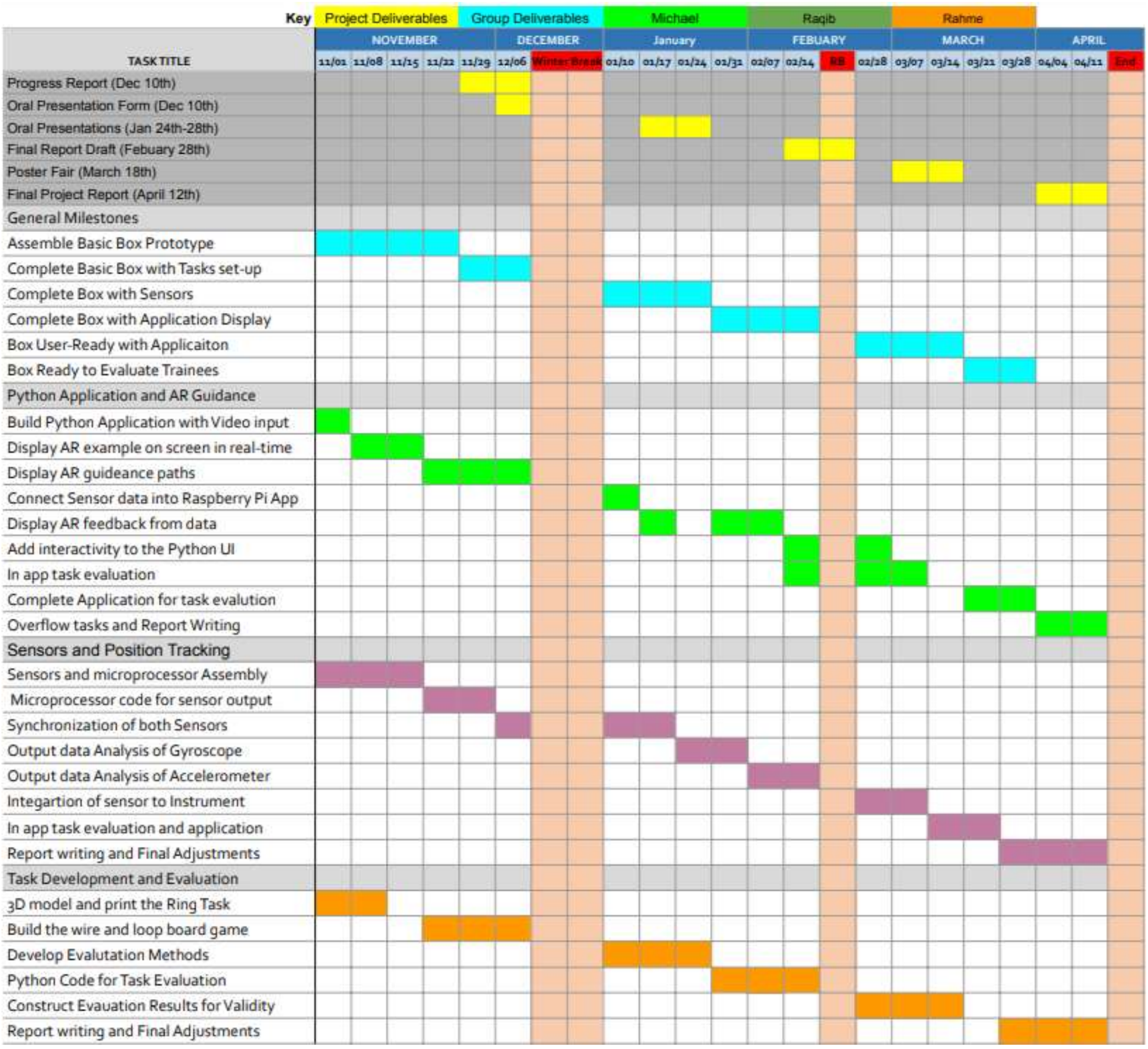

Figure 20: Gantt Chart of Project Milestones and Individual Work

Risks and Mitigations

Outlined in this section are some potential risks the project faces in problems we may encounter and potential mitigations so we can still achieve our goals.

There are continual concerns regarding potential for another Covid-19 lockdown. If the situation gets worse and we are placed back on lockdown we will continue to have online meetings like we have been doing so far. We have structured the project in such a way that most of our work can be completed individually from each other and we will mostly each have our own stand alone equipment. By making the Augmented Reality code able to run on any Raspberry Pi, the code and instructions can be shared between team-members. All team members have also received their vaccinations so we will be less likely to be overtly affected by the pandemic.

As we are basing our starting point of the project based off of the box designed by Nsar et al. we are expecting to receive some parts of their box design. We are currently however not entirely sure what parts we will receive and when so in order to mitigate the risk of not receiving the parts we need on a timely schedule we have decided to work to procure our own parts and assemble a box of our own based on their design.

During the planning phase of the project it became apparent that as development of the Augmented Reality application on the Raspberry Pi Progresses there may be some latency issues caused by trying to collect, process and display the data all in real-time in a critical visual display service. If it turns out that the Raspberry Pi cannot handle the processing required, the application can instead be run on a stand-alone laptop running Python until a different processor such as NVIDIA's Jetson Nano can be ordered and integrated.

There is a possibility that the chosen MPU 6050 sensor might produce data that is inadequate or insufficient for position tracking, due to faulty nature, sensor accuracy, or positioning. This risk can be mitigated by acquiring and using alternative sensors such as the ADNS - 7530 mouse sensor or an ICM-42605 sensor. There is also the possibility of using the HD camera and raspberry pi to produce some sense of position tracking with computer vision inside the box if the sensor data is not giving the accurate position and movement results we are hoping for.

Components and Facilities

The following is a detailed list of all the components and facilities required for the project. It is our hope that through the pieces given to us and other various funding sources we can procure all of the required components so the project can maintain a standalone system for the year and future years to come.

Components Required

- Plastic Box Frame (Given to us or milled from plastic sheets)
- Two Laparoscopic surgery graspers
- A Raspberry Pi 4 Model B (With Starter Kit to connect to monitor)
- An HD Webcam compatible with a Raspberry Pi
- A basic HDMI monitor (such as the Phillips monitor currently borrowed)
- MPU6050 sensor (gyroscope)
- ADNS-7530 Mouse Sensor
- Wires required to connect the sensors to the Raspberry Pi
- Soldering iron (to incorporate the sensor and instrument)

Facilities Required

- 3D printer access for printing our training tasks or…
- Equivalent craft supplies (i-hooks, shoelace, wooden board, rings, pegs)
- Access to a Soldering Iron to connect the sensors
- Tools required to cut, form and mill plastic sheets to create our own box

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