DAYANANDA SAGAR COLLEGE OF ENGINEERING
(An Autonomous Institute affiliated to VTU, Belagavi - 590018)
Accredited by NBA, National Assessment & Accreditation Council (NAAC) with 'A' grade

Project Report on

"HAPTO – VR MEDICAL SIMULATION PLATFORM"

Submitted in partial fulfillment for the award of degree of

BACHELOR OF ENGINEERING
IN
ELECTRICAL AND ELECTRONICS ENGINEERING

Submitted by

ARUN M JAYAN	**1DS16EE018**
OM PRAKASH C	**1DS16EE064**
PAVAN H S	**1DS16EE066**
PREM KUMAR T S	**1DS16EE071**

Under the Guidance of

DR. P USHA,
Professor and Head of Department,
Department of Electrical and Electronics Engineering,
Dayananda Sagar College of Engineering, Bengaluru

VISVESVARAYA TECHNOLOGICAL UNIVERSITY
JNANASANGAMA, BELAGAVI-590018

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Shavige Malleshwara Hills, Kumaraswamy Layout
Bengaluru-560078
2019-2020

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

CERTIFICATE

Certified that the Project report entitled **"HAPTO – VR MEDICAL SIMULATION PLATFORM"** carried out by **ARUN M JAYAN (1DS16EE018), OM PRAKASH C (1DS16EE064), PAVAN H S (1DS16EE066), PREM KUMAR T S (1DS16EE071),** bonafide students of **DAYANANDA SAGAR COLLEGE OF ENGINEERING**, an autonomous institution affiliated to VTU, Belagavi in partial fulfillment for the award of Degree of **Bachelor of Engineering in Electrical and Electronics Engineering** during the year **2019-2020**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The Project report has been approved as it satisfies the academic requirements in respect of work prescribed for the Bachelor of Engineering Degree.

Signature of the Guide	Signature of the HOD	Signature of Principal
Dr. P Usha **Professor & HOD** **Dept. of E&E Engg.** **DSCE, Bengaluru**	**Dr. P Usha** **Professor & HOD** **Dept. of E&E Engg.** **DSCE, Bengaluru**	**Dr. C. P. S. Prakash** **DSCE, Bengaluru**

External Viva

Name of the examiners **Signature with date**

1.

2.

MIMYK MEDICAL SIMULATIONS PVT. LTD.

First Floor,
Entrepreneurship Centre,
Indian Institute of Science,
Bengaluru-560012

CERTIFICATE

Certified that the Project report entitled **"HAPTO – VR MEDICAL SIMULATION PLATFORM"** carried out by **ARUN M JAYAN (1DS16EE018), OM PRAKASH C (1DS16EE064), PAVAN H S (1DS16EE066), PREM KUMAR T S (1DS16EE071),** bonafide students of **DAYANANDA SAGAR COLLEGE OF ENGINEERING**, an autonomous institution affiliated to VTU, Belagavi in partial fulfillment for the award of Degree of **Bachelor of Engineering in Electrical and Electronics Engineering** during the year **2019-2020**. It is certified that, they have completed the project satisfactorily.

Signature of the Guide	**Signature of the Head of organization**
Dr. Shanthanu Chakravarthy	**Dr. Shanthanu Chakravarthy**
Co-Founder	**Co-Founder**
Mimyk	**Mimyk**

MIMYK

IMPORTANT NOTE

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Abstract

Hapto-VR Medical Simulation Platform

Virtual Reality VR together with haptics offers an immersive, flexible, and cost-effective method for training doctors. In this project, development of a Hapto-VR simulation platform for training doctors in Minimally Invasive Procedures is achieved. The project will take a holistic approach from idea, design, development, and testing. Electronic design and integration of sensors and actuators for haptic simulation will be explored in detail. Furthermore, the sensing and the control module will be coupled to a computing system for real-time immersive simulation in a virtual environment.

Acknowledgement

First and foremost, our heartfelt praises to our parents, for their shower of blessings throughout our lives, including this project work to complete this project.

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Chapter I

INTRODUCTION

1.1 Endoscopy and its Importance

Endoscopy is used in medical field to look inside the body. Endoscopy is a non-surgical procedure used to investigate the digestive tract. It is also used in diagnosis by performing a biopsy to check for conditions in the digestive system. [1] There are several types of endoscopy used to examine different parts of body such as upper endoscopy to view oesophagus and stomach, colonoscopy to examine large intestinal area, Endoscopic Retrograde Chloangio Pancreatography (ERCP) to view pancreas, gall bladder. [2]

1.1.1 Endoscopic Handles and Endoscopes

The endoscopy procedure uses an endoscope to examine the interior of a hollow organ or cavity of the body, which are generally minimally invasive as they are directly inserted into the organ. It is a flexible tube with a light to illuminate the organ under inspection, a camera attached to it so that the doctors can view pictures of digestive tract on a colour television or monitor and an additional channel to allow entry of medical instruments or sedation. [2]

1.2 Endoscopy Hapto-VR Simulation Platform

Fig 1.1 Endoscopy Hapto-VR Simulation Platform

An endoscopy simulator is an educational and training tool used to train for learning doctors and healthcare professionals. This technological idea was introduced due to the concern that inexperienced doctors engaging in surgery with patients experiencing increased discomfort, pain and errors. Endoscopic simulators are considered to be a newer method of training with faster training results while maintaining patient safety achieving better results. [3]

1.2.1 Different types of Simulators:

1. Mechanical Simulators:

Mechanical or static devices were developed to assist in the acquisition of hand-eye coordination and to allow practice manipulating the endoscopic controls. These devices made use of simple, inexpensive, and widely available materials to create models of the gastrointestinal tract. In the late 1960's a mannequin was designed through which a rigid sigmoid scope could be advanced while images of the lower colon were projected. Rubber models of the colon and the upper gastrointestinal tract were developed after the introduction of flexible endoscopes. These models have included pathologic abnormalities such as polyps to allow the endoscopist to practice lesion recognition as well as intubation skills. An inexpensive model used hollowed cantaloupes connected in series to simulate colonic anatomy. After the introduction of pancreaticobiliary endoscopy, a model of the upper digestive tract and biliary tree was developed using plumbing supplies and elastic tubing.

2. Computer Simulators:

Computer simulators, first created for aviation and nuclear reactor operations training, have been developed for medical and surgical procedures. Early pioneers in endoscopic simulator development established the required features of a training module. As an endoscope is passed through the patient surrogate, sensors relay information to the computer for image display and interaction. Variable resistance devices provide tactile feedback. Images are displayed through Interactive Video Technology (IVT) where images are stored on a laser disk, Computer Graphic Simulation (CGS) where images are computer generated, or combination of both (Video Graphic Tool Technology – VGTT). Recent advances in computer technology have enabled significant improvements in graphic display. While several training modules for gastrointestinal procedures have been exhibited, none are yet commercially available. A flexible bronchoscopy simulator is available, and additional modules for gastrointestinal endoscopy are expected.

3. Animal Models:

Animal models include live anesthetized animals, and ex vivo preparations. These models have been used largely for training in Endoscopic Retrograde Chloangio Pancreatography (ERCP), Endoscopic UltraSound (EUS), and other interventional endoscopic techniques. A live canine model for ERCP, described in 1974, was anatomically dissimilar to humans and was technically challenging. ERCP in the baboon more closely simulated human anatomy, but the cost and availability of animals were limiting factors. Since this kind of simulators are not suitable for the simulation, as it can be used for limited use, also as it may not be comfortable for many of the young doctors who are in the training program. Hence, they are trying to adapt computed aided simulators.

Although, there are various types of endoscopy simulators, the project undertaken comes under Computer Simulators, aided by mechanical and electronic components to simulate and experience real endoscopy as real as possible.

1.2.2 Importance of Endoscopy Hapto-VR Simulation Platform

- To train doctors/medical students to enhance their skills in medical procedures.
- Framing best standards of care, error management and patient safety.
- Offers various strategies for comprehensive and practical training, promoting experiential and reflecting learning.
- Avoiding the risk of human life during unexpected emergencies.

1.2.3 Scope of Endoscopy Hapto-VR Simulation Platform

The major scope of the endoscopy simulation platform is train doctors, reducing the risk of error due to the involvement of human life. Although the simulator cannot ideally replace the performance of surgery on a human body over a simulation base, it is not limited to following points:

- Continuous reading of sensors and encoders values and transmission to the controller to ensure smooth performance.
- Availability of monitor to view graphically rendered pictures of internal body which is driven only by readings from sensors and encoders, preventing unwanted faults.
- Haptic feedback aided by encoders to simulate real time endoscopic performance as much as possible.

Chapter II

COMPARISON OF REAL ENDOSCOPY AND ENDOSCOPY SIMULATOR

2.1 Real Endoscopy

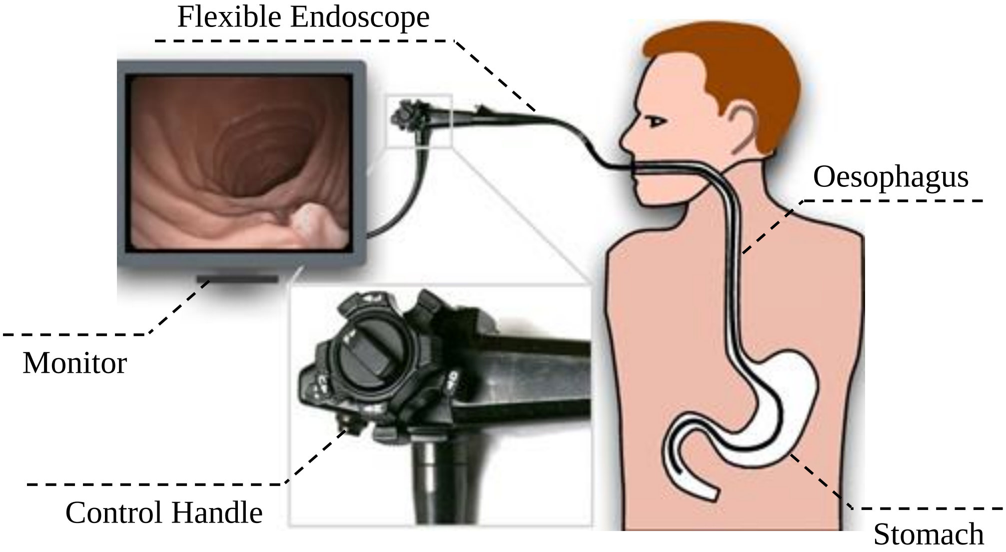

Fig 2.1 Actual Endoscopic Procedure Depiction

The actual endoscopy includes an endoscope which is inserted into a human body or a patient, where the endoscope consist of a light source to illuminate the internal organs, a camera to view the pictures inside the body, sometimes also supporting an additional channel to perform biopsy (removal of tissue) or to inject sedations.

2.2 Endoscopic Simulator and Actual Endoscopy Analogies

An endoscopy simulator is an equivalent working model consisting of a similar flexible tube containing sensors, encoders and a controller to mimic the real endoscopy performance into equivalent haptic based experience. Haptic based experience is an active closed loop touch experience driven by Brushless Direct Current (BLDC) motors, to simulate the real time endoscopic performance as much as possible. Linear BLDC motor is used to give opposite force experience when inserting endoscope into the base, as in real time oesophagus endoscope insertion. Rotational BLDC motor is used to give oesophagus wall surface frictional force when endoscope is not inserted properly.

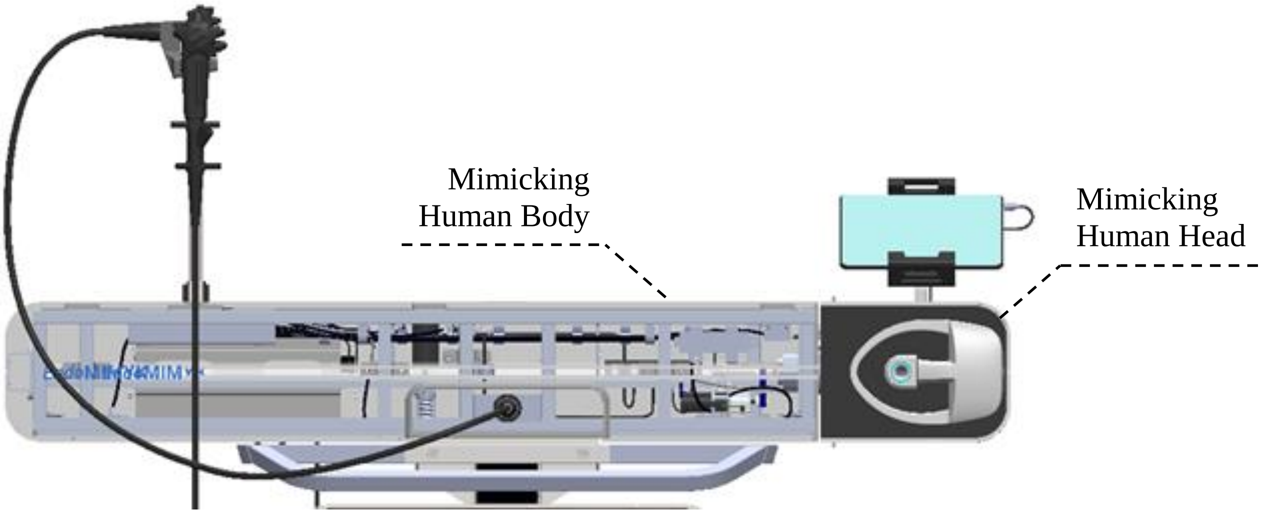

Fig 2.2 Endoscopy Simulator Base Mimicking a Human Body

There is a monitor which displays a continuously changing pre-designed graphically rendered internal human body picture using virtual reality based on the readings or values from sensors and encoders controlled by a controller.

While the actual endoscopy is performed on a human body lying in a bed and internal organs being monitored on a screen, in an endoscopic simulator, training is performed on a model which consists of a base, a hollow cylindrical or cuboidal like structure representing a lying human body with an entry point acting as mouth, with the base supported by mechanical structures.

Chapter III

ENDOSCOPY HAPTO-VR SIMULATOR MODEL

3.1 Main Components of Hapto-VR Endoscopy Simulator

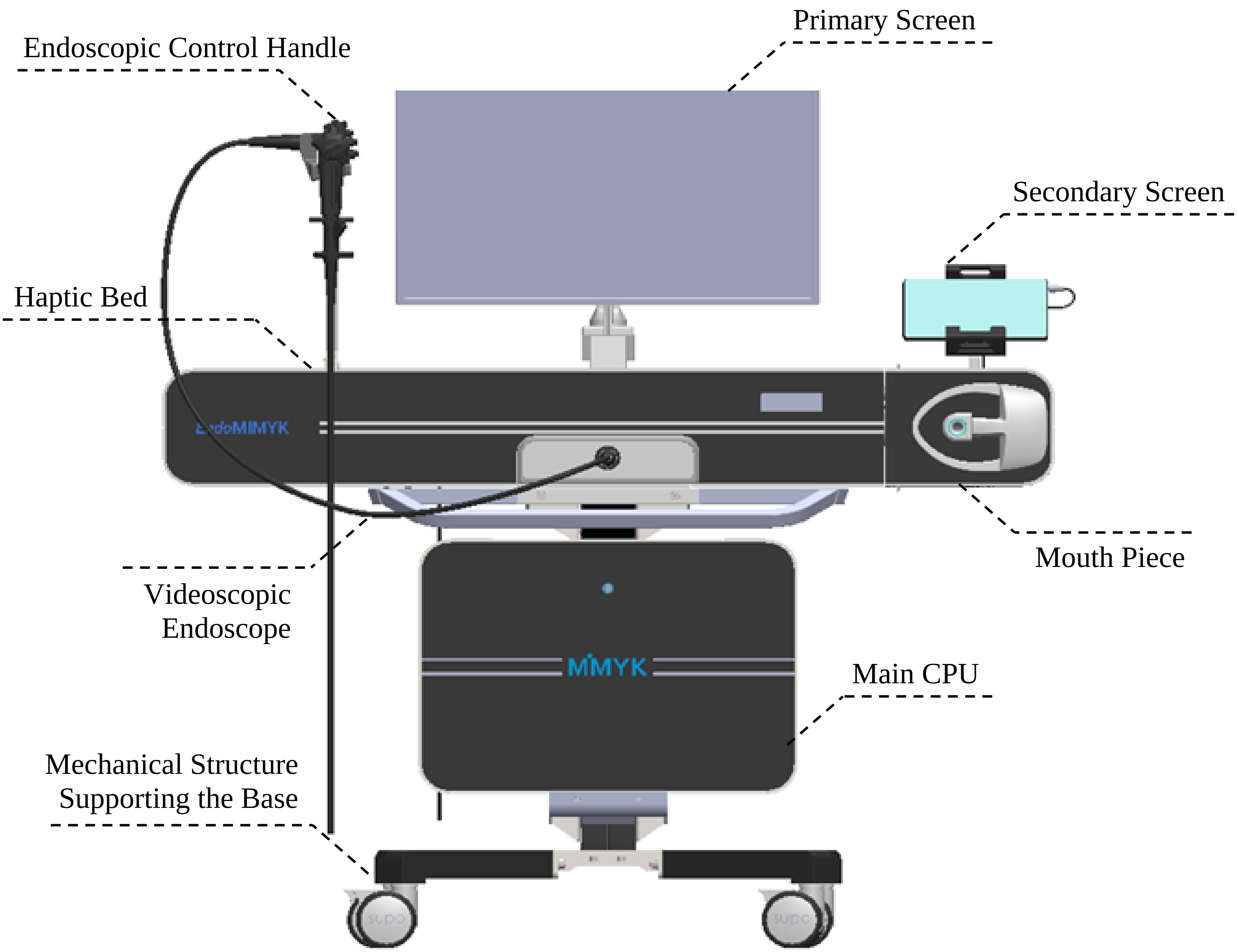

Fig 3.1 Main Components of Hapto-VR Endoscopy Simulator

Major components used in the hapto-VR endoscopy simulator are:

1. Haptic Bed

The haptic bed or base mimics the body of real-world human. The head of the simulator is a rotation enabled part. The rotation of head in each direction resembles different body position of different medical procedures. For example, the head direction towards user as shown in the diagram resembles position of the head for the endoscopic procedure.

The base is built in such a way that it is suitable for different procedures, just by replacing the handle part, which is needed as each different procedure utilizes different handle in the real-world simulation.

2. Endoscopic Control Handle

The handle shown in the picture is used for the endoscopic procedure. The handle Printed Circuit Board (PCB) is custom built, with a Cortex-M4 chip. The chip is boot-loaded with a program that is available with the developer of the M4 chip (Sparkfun).

The board is custom designed according to the limitations set by the mechanical design and aspects. Hence there are two different boards inside the handle body, one with the processor and the other with support structure i.e., the connections from the sensors that the handle supports.

3. Videoscopic Endoscope

Videoscopic endoscopes are highly flexible cable, with a Charged Couple Device (CCD) chip and supporting electronics mounted at the tip going inside the internal body of the patient or subject. A CCD chip is an array of 33000-100000 individual photocells or pixels receiving photons reflected back from the internal surface of digestive tract and producing electrons in proportion to the light received to reproduce the captured image. By enhancing design, CCDs can be made smaller, to increase the number of pixels which in turn increases the resolution and allow the use of high-definition monitors. The crucial importance is the fact that the digital signal amplifies image recording and manipulation and is convenient for image enhancement, transmission and analysis.

4. Primary Screen

Primary screen is a monitor where we can experience the simulation. The simulation is aided with the C# program that takes the raw values from various sensors. These raw values are fed as the input to the program, which with a little calibration gives the VR experience. As soon as it is switched ON, Ubuntu OS loads up as it is easy for the developers to test the components and make it Human Interface Device (HID) compatible. Unity software is installed for the simulation of the procedure. The specifications required to choose the screen were:

- Screen with 4K resolution.

- Wall mount adapter, with built in power supply.
- Speakers to support sound effects of the simulation.

5. Secondary Screen

The secondary screen is used to access the application made by the developers by scanning the Quick Response (QR) code. The screen is a smaller size screen with lesser features than the primary screen.

The users are allowed to perform the procedure by choosing the required procedure on the secondary screen such that the required program for the option chosen loads up as a virtual procedure on the primary screen. It is a tablet which is used to activate the simulator.

6. Main Central Processing Unit (CPU)

Main CPU is used for graphical rendition processing from the readings obtained from sensors and encoders send through haptic base main board in the primary screen. It also serves as processing unit for both primary and secondary screen.

7. Accessory Tools

The accessory tools used for the simulation are inserted in the simulator through the handle insertion port. There are various accessory tools which are used to mimic various functions of the original procedure. The accessory tools are assembled in the casing specially designed casings that represent the original tools. These potentiometers send the values to the computer through a different chip which is encased in a different structure.

3.2 Working Mechanism of Endoscopy Hapto-VR Simulator Model

Endoscope is handle used by doctors that is inserted into the oesophagus during the procedure (the actual handle has a camera and set of tools along with the Light Emitting Diodes - LEDs to light the path). As the user inserts the handle into the body of the simulator, the simulator operates in 3 different stages given as:

- Force - Reflecting Mechanism
- Force Controller
- VR - Interface

The endoscopy simulator basically works on the principle of haptics and compliant mechanism. It uses the forces applied to the handle by the user during the procedure. With the help of virtual environment created graphically, returns the feedback of the force fed. The feedback forces are sensed and sent to the user through the handle via the motors. [4] The working of the simulator can be best explained by the block diagram shown below.

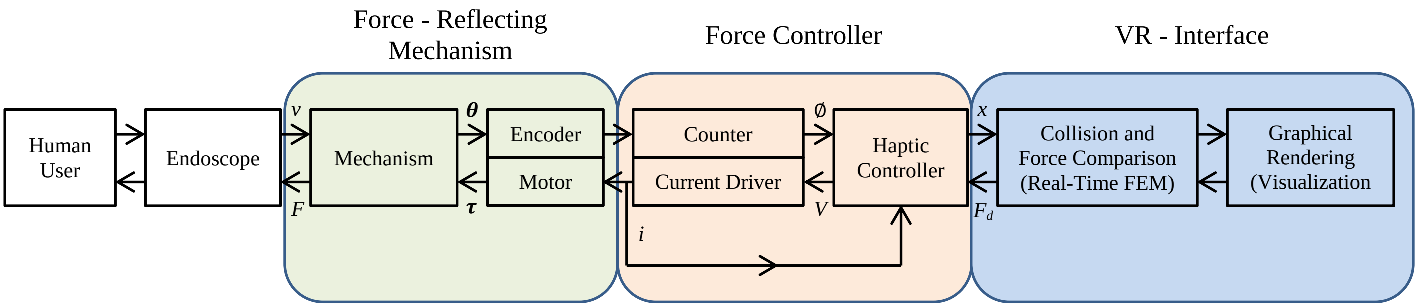

Fig 3.2 Block Diagram Representing Working of the Simulator

1. Force - Reflecting Mechanism

It is a mechanism which uses a pulley mechanism which is in-turn connected to two different motors.

- Longitudinal DoF motors
- Rotational DoF motors.

The longitudinal motor and the rotational motor are used to get the values of the force that is exerted on the handle by the user while performing the procedure on the endoscopy simulator.

The encoders attached to both the motors, are incremental encoders which increment the values from 0 as the user inserts the handle through the mouth of the simulator till the length of insertion tube and comes back to 0 as the user pulls it out of the simulator. As the user inserts the tube into the simulator the forces are recorded by the motor as the rotor shaft rotates in the opposite direction i.e., the direction of the insertion tube as it travels through and out of the simulator. Hence, the name Direction of Force (DoF).

The encoder records and passes the value (the linear and rotational) to the controller. Arduino Due which interprets the value from the linear motor encoder as v (velocity), and the value from the rotational motor encoder as Θ (theta), which is computed by the program given as input to Arduino Due and sends the force to the motors to give the feedback force. This is a mechanism in which the rotational motor attached to the handle moves along the haptic bed, with the help of pulley thereby enabling the force to be sent to the linear motor.

2. Force Controller

As seen in the above diagram the haptic controller is the Arduino Due, the counter and the current driver together form the motor encoder. The motor encoder is an ESCON 24/2 module. The encoder can also be programmed to be active as a driver. But since the forces are calculated in the Arduino code, it is programmed to be just the current controller. Since the motor encoder is used as just the current controller, its function is basically to control the forces sent to the encoder from the controller. Hence this mechanism is called as the force controller mechanism. [5]

In this mechanism the encoder transmits the signal sensed since after inserting the scope until removing are sent to the controller. The values sensed by the linear motor encoder is sent to the controller as x-axis linear length, while the rotational encoder sends the sensed value as an angle deviation from its initial position represented as Ø.

3. VR - Interface

It is the interface between the electronics sensors, encoders and motors with the graphical representation of the procedure. For this Unity-3D software is used, in which raw data is collected sent by the controller to the CPU, which can then be used by the software team for correct graphical rendition of the medical procedure.

The force computation that helps in the haptics feedback is done here. For the graphical effects Unity-3D is used along with the C# code for the collection of data from different interfacing elements. The values input to the code are the output of the other two mechanisms, and the output of this mechanism is the virtual visualization of the procedure, and the force controlled haptic feedback mechanism.

For the simulation to start, the signal from the snap-fit sensor has to be a high during the entire procedure, which is brought about by the arrangement of the magnets and the pogo pins, which is used to just complete the circuit of the pin from the Arduino. The values along with the readings from the handle from different sensors, encoders and accessory tools complete the simulation procedure by providing the necessary raw values to the CPU which is then used by the Unity-3D. [6] The simulation runs only in a specially designed simulation app called MIMYK, which can only be accessed by scanning the QR code. The simulation is called a Virtual Reality Interface because it mimics the procedure done by the doctors in their real time.

Chapter IV

BUILDING HAPTO-VR ENDOSCOPY SIMULATOR – ELECTRICAL & ELECTRONICS

4.1 Main PCB Boards and Electrical Components

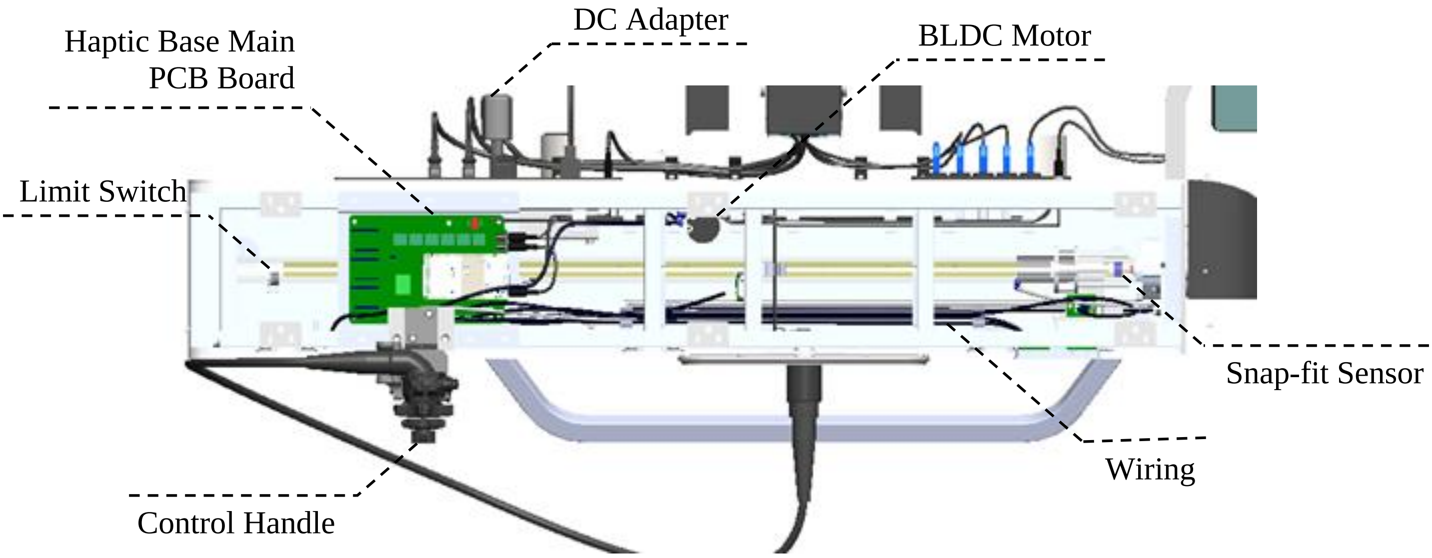

Fig 4.1 Haptic Base Representing PCB Boards and Electrical Components

The above shown figure shows the arrangement of different PCBs in the simulator. Various printed circuit boards are designed to read values from required sensors, connect one or more other boards acting as a connecting board, also controlling encoders and motors. Wirings are done from one board to other with specific core cables for flexible movement of inner components inside the haptic bed. The different board that are used here are:

- Haptic Base Main Control Board
- LED Indicator Board
- Connector Board
- Hall Effect Sensor Board
- Mouthpiece and Colonpiece LED Board
- Endoscopy Control Handle Board

These above mentioned boards are explained in the following sections.

4.2 Haptic Base Main Printed Circuit Board (PCB)

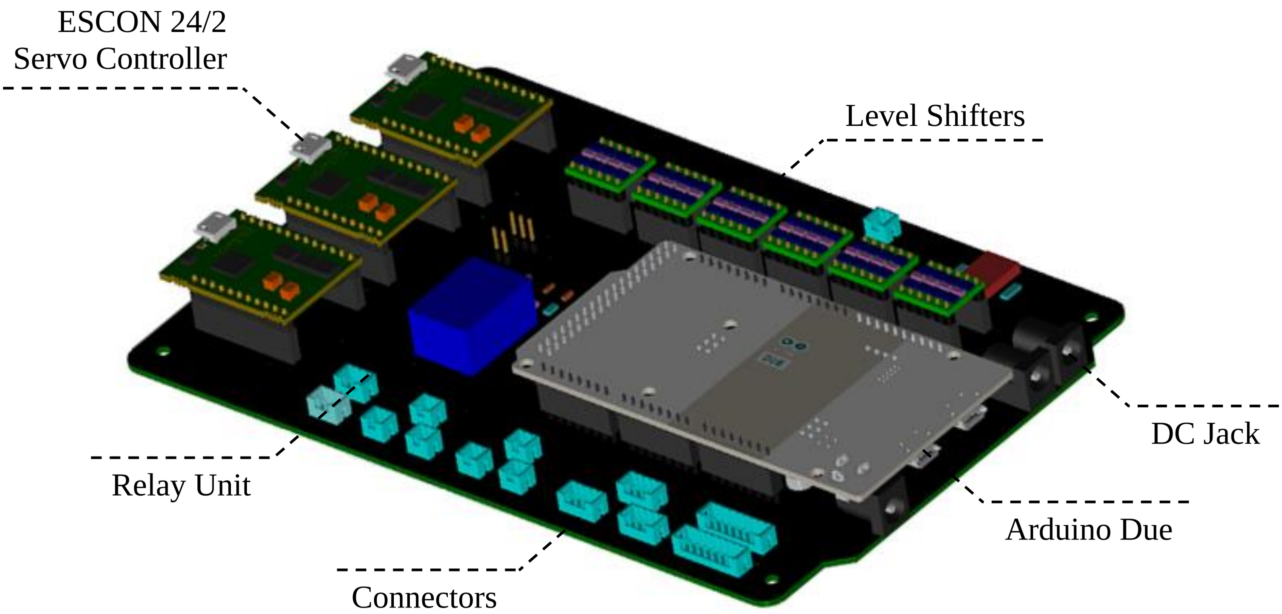

Fig 4.2 3D view of Haptic Base Main Board

Haptic base board is the main control panel of the entire simulator. The main function of this board is to connect different sensors and encoders with the microcontroller which is in-turn connected to the CPU, through which the programmer receives and sends values to these sensors and actuators, to control different processes taking place in the simulator during the simulation. It uses Arduino Due, which uses a Cortex-M3 processor for its operation and has a clock speed of 84MHz.

The main importance of the board is to help the users to monitor and experience the virtual reality experience provided by the user and to help the developer to develop the simulator and to troubleshoot if there is any problem, involving the functioning of the simulator. The board is designed using the Autodesk EAGLE software.

4.2.1 Block Diagram of Haptic Base Main Board

The diagram shown below represents the main board along with the input and output current rating and voltage rating of different sensors and level shifters.

Block diagram includes Arduino Due along with pins used, relay, motor drivers with pin configuration, motors, and motor encoders with pins indicating the signal received from Arduino Due, level shifters, proximity sensors, limit switches and snap-fit sensor. The Arduino Due, level shifters and the motor encoders are placed on the board whereas the motors and the interfacing elements shown in the below diagram are at different physical positions.

The block diagram indicates that the components are directly connected to the main board without any connector boards.

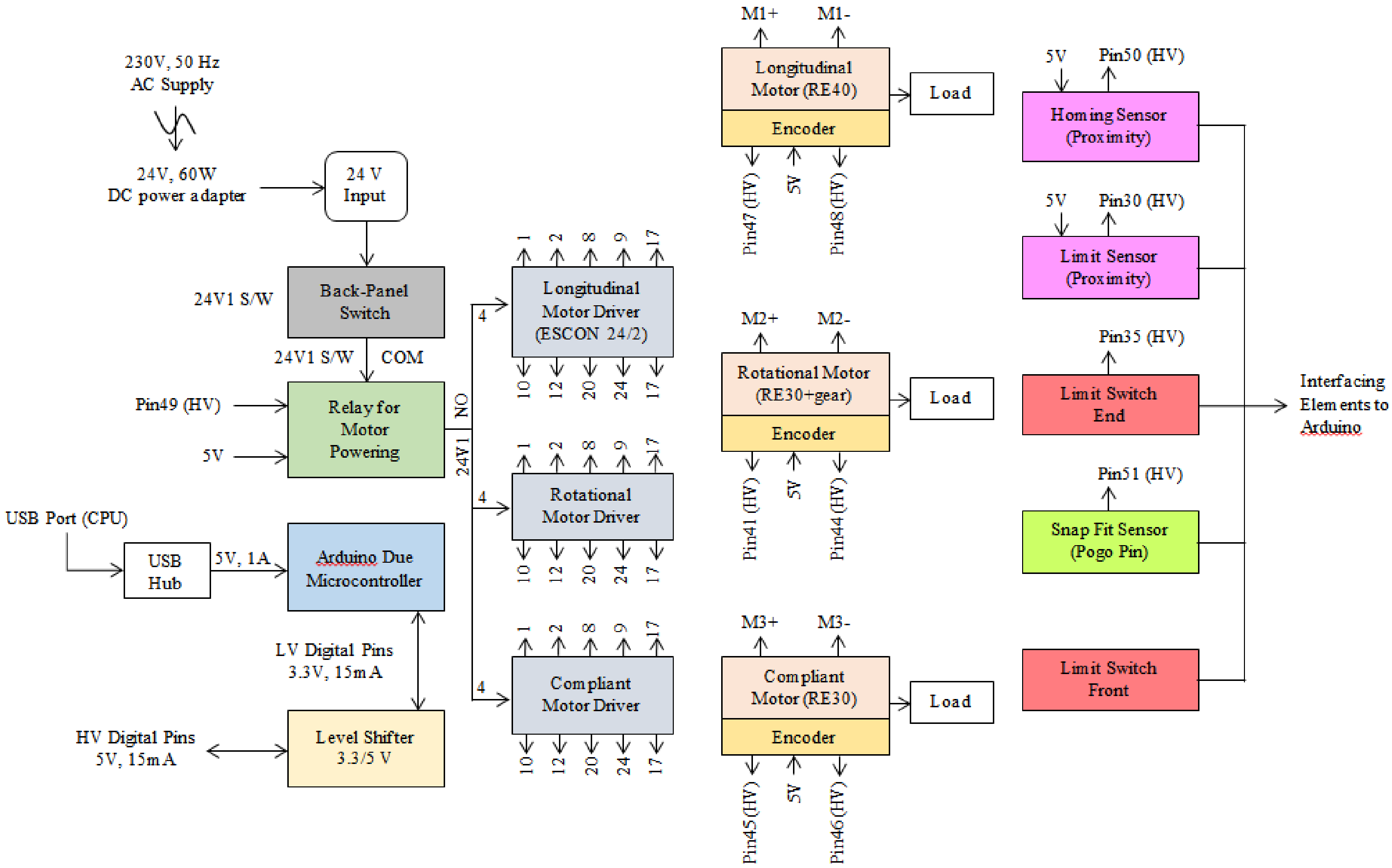

Fig 4.3 Block Diagram of Haptic Base Main Board

The brief description and the functions of different components connected to the main board is as summarized below:

1. Arduino Due

Fig 4.4 Arduino Due Board

The Arduino Due is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. It is the first Arduino board based on a 32-bit ARM core microcontroller. It has 54 digital input/output pins (of which 12 can be used as Pulse Width Modulated - PWM outputs), 12 analog inputs, 4 Universal Asychronous Receiver/Transmitter - UARTs (hardware serial ports), a 84 MHz clock, an Universal Serial Bus On-The-Go (USB OTG) capable connection, 2 Digital to Analog Converter (DAC), a power jack, an Serial Peripheral Interface (SPI) header, a reset button and an erase button.

Since it uses a 32-bit microcontroller, it is used as the main controller for the simulator.

2. ESCON 24/2 Servo Controller

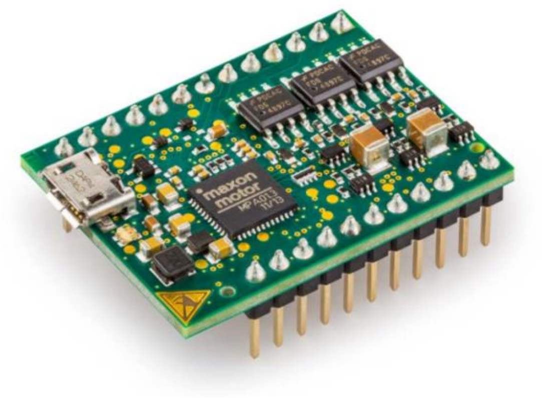

Fig 4.5 ESCON 24/2 Servo Controller

The ESCON Module 24/2 is a small-sized, powerful 4-quadrant PWM servo controller for the highly efficient control of permanent magnet-activated brushed DC motors or brushless DC motors up to approximately 48 Watts.

The featured operating modes – speed control (closed loop), speed control (open loop), and current control – meet the highest requirements. The ESCON Module 24/2 is designed and being commanded by an analog set value and it features extensive analog and digital I/O functionality. In these modes of operation it is programmed to be only a current control Encoder.

3. Level Shifters

Level shifter is an electronic circuit that is used to shift voltage level from one level to another. This action is basically brought about by a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) in a voltage divider circuit. Here, the gate of the

MOSFET is shorted with source of the MOSFET and is supplied with the low-level voltage through a resistor, while the drain is supplied with high-level voltage.

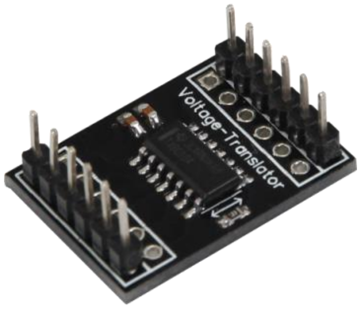

Fig 4.6 Level Shifter

The output signal of the low voltage device is given to the low voltage side and the high level of the level shifter is given to the high voltage device. Here the low voltage device being the Arduino Due supplies only 3.3V through the digital pins, the output of each digital pin is level shifted and then supplied to the sensors as they operate at a voltage of 5V up-to 12V in some cases.

The different digital pins given to the low voltage side of the level shifter is shown in the block diagram in the format PinNO (Low Voltage - LV), while the level shifted pins of high voltage side are given as PinNO (High Voltage - HV).

4. Maxon Motors (Maxon RE30 & Maxon RE40)

Fig 4.7 Maxon RE40 BLDC Motor

The motors chosen for the operation are BLDC motors. There are 2 different motors used in the simulator, the longitudinal motor and the rotation motor.

Longitudinal motor is a RE30 motor, with a 30mm diameter, 6V nominal voltage, 2.7A nominal current and 2780 Rotations Per Minute (RPM). Rotational motor is RE40 motor with a 40mm diameter, 24V, 1.09A nominal current and 2780 RPM.

The motors are used for the feedback mechanism, which uses the forces sent by the controller. The force sent by the controller is basically voltage with varying levels.

These motors are named as RE30 and RE40, because the force applied in each direction has different forces to be applied when necessary and also to differentiate them for each direction, so that control of the motor is easy for the programmers. The BLDC motor is an electronically commutated motor which does not have brushes. The controller controls the current to the motor, which is used to vary the torque through wide range of speeds.

BLDC motors are chosen as they have high speeds and also have wide range of speed control. Due to the absence of brushes, the operating noise is very low and the mechanical energy loss is very less. The motors chosen have a maximum speed of 3300 RPM in the linear direction, while the speed in the rotational direction is lesser than that of the linear motor.

5. Maxon Motor Encoder

Fig 4.8 Maxon Motor Encoder

An encoder is a sensor that generates signal proportional to the mechanical motion. It is able to provide information regarding the position, velocity and the direction of rotation of the mechanical object.

In this case, the mechanical object being the motor shaft. The encoder used is a 3 channel, 1024 counts per turn, 5V, 5mA sensor which uses Transistor-Transistor Logic (TTL) logic. Since these encoders comes mounted with the motors, these encoders are connected to the main board through a special connector board which takes the 10 pin connectors as the input to the board and sends these signals through a 4 pin connector to the Arduino Due via a level shifter (bi-directional).

The main function of the encoder is to evaluate the position and angle of the shafts and send the signal to the Arduino via the level shifter as the voltage rating on each side has to be satisfied. The advantages of the encoders used in the simulator is that it has highly accurate evaluation of speed and angle position and form a framework of highly precision control loops.

6. Proximity Sensor

Fig 4.9 Proximity Sensor

Proximity sensor is a sensor that can detect any nearby objects without any physical contact. The working principle of the proximity sensor is the electromagnetic radiation. The sensor emits electromagnetic radiation and checks for any movement or disturbance in the field. It is an active low state of device. Hence whenever a disturbance is detected it signals it to the controller by sending a low signal.

There are 2 proximity sensors used on the haptic bed, one on the front and the other at the end of the haptic bed. The main function of the sensor is to cut off the power to the motor by sending a low signal to the input pin of the relay, whenever it is at the home or at the end position. It is used to indicate whether the motor is back at the initial position (also called as Homing sensor, since it is placed at the front end of the haptic bed) and also to indicate the end of the haptic bed (called as Limit sensor, since it is placed at the end of the haptic bed).

The interfacing of the proximity sensor to the main control board is via connectors. The proximity sensor is placed at both ends of haptic bed, since it is placed at the ends it can either act as a homing position sensor or the limit position sensor.

7. Limit Switch

Fig 4.10 Limit Switch

It is basically a mechanical switch, which sends a high signal as soon as the switch is closed and low signal as soon as it is opened.

The function of the limit switch is to cut off the power to the force reflecting side as it the mechanism that consumes highest power and also to prevent damage to the motor after the handle reaches end. As the Force - Reflecting Mechanism side moves along the axis bed, the mechanisms end is made to touch the limit switch which is placed on the end of the haptic bed, thereby turning OFF the relay supplying power to the motor. Hence, it is a safety switch.

The limit switch can also be placed in the place of the proximity sensor, but since the proximity sensor gives us more accurate signalling, the limit switch is replaced by the proximity sensor.

8. DC Jack

Fig 4.11 DC Jack

The main board uses 2 dc jacks.

- To provide power to motors and to the LED board, which uses 12.5A at 12V.
- To provide the power to the Arduino, after buck converter, since Arduino only needs 5-12V for its functioning.

9. Snap-fit Sensor

Fig 4.12 Pogo Pin

This sensor uses a pogo pin that is connected to a digital pin on Arduino Due. As soon as the handle touches onto the pogo pin it completes the circuit through a metal plate back to ground on the main control board.

The cavity holding the pogo is conductive in nature, which when connects to the handle side magnet completes the circuit, thereby giving a high signal to the Arduino. Since the simulation depends on the movement of the insertion tube through the mouth of the simulator which is made possible by the handle. Hence, only when the snap-fit sensor gives a high output, the simulation starts running.

4.2.2 Board Diagram of Haptic Base Main Board

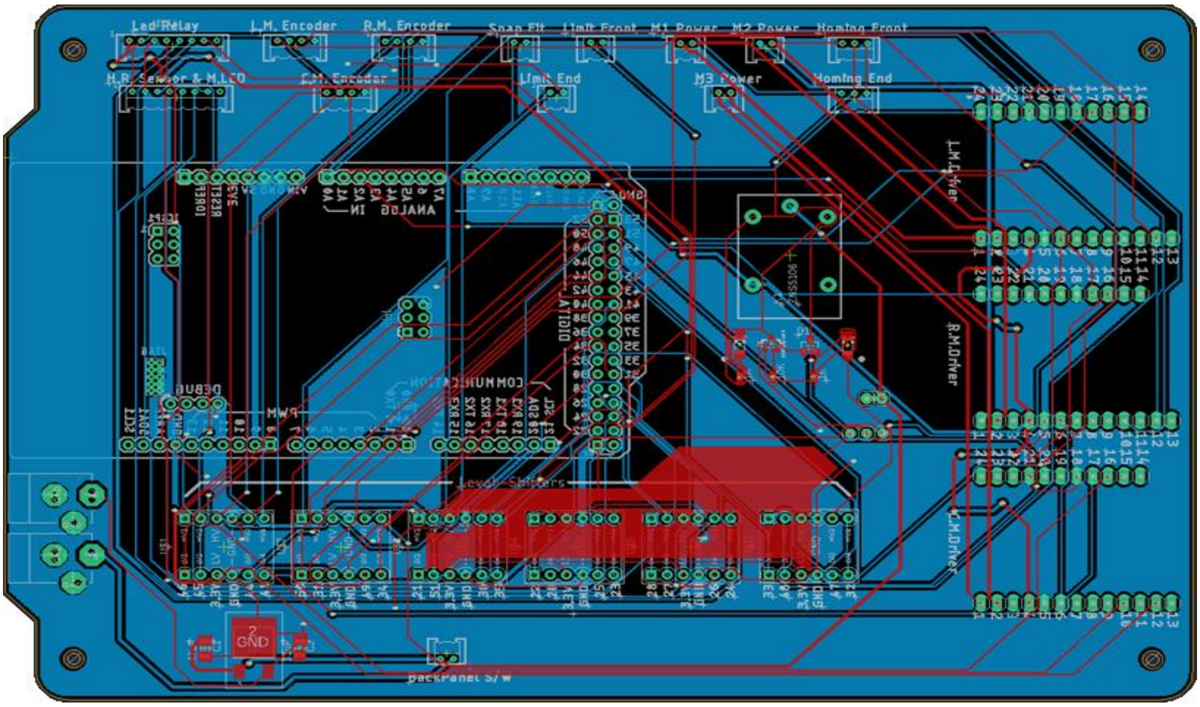

Fig 4.13 Board Diagram of Haptic Base Main Board

Haptic base main board connects various sensors and encoders, interfacing with Arduino and also main CPU, demanding unique design for various load, voltage ratings and current drawings. Hence, different track design, track clearance level, track path, drill diameter and copper plates in PCB are used for higher voltage loads and ground. [7] The design aspects for PCB considering different power usage in different loads are given as:

Copper Weight	1 ounce	2 ounce
Minimum Trace Width	0.1016 mm	0.1270 mm
Minimum Trace Spacing	0.1270 mm	0.1778 mm
Via holes to other copper feature	0.2286 mm	0.3048 mm

Table 4.1 Track Width and Drill Diameter for Various Voltage Levels

Voltage	Trace Width (mm)	Drill Diameter (mil) (1 mil = 0.0254 cm)
5V	0.2032 (8mil)	8 mil (to voltage plane, width: >=10mil)
9V	0.2540 (10mil)	8 mil
24V	0.6096 (24mil)	23.622 mil
GND	0.5080 (20mil)	8 mil (to ground plane, width: >=10mil)

Table 4.2 Track width, Clearance and Drill Diameter for Various Ounces

4.3 LED Indicator Printed Circuit Board (PCB)

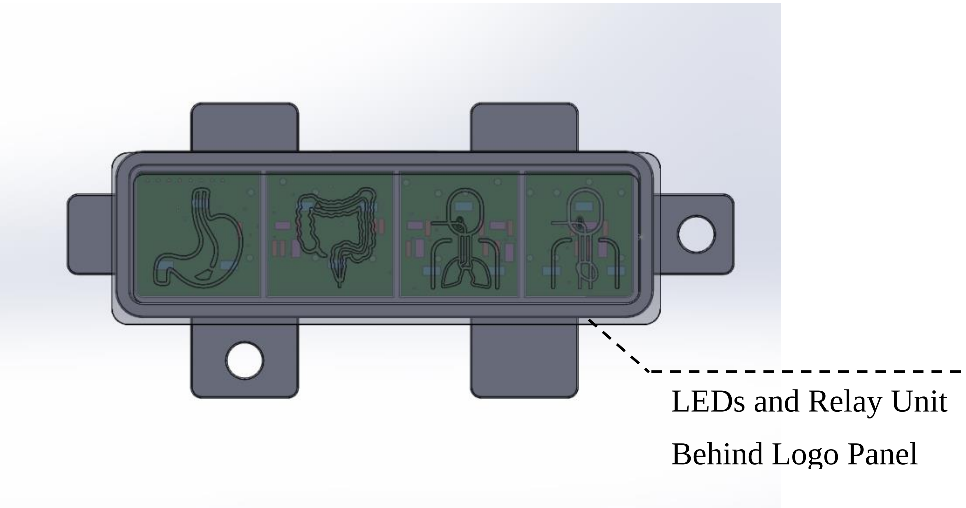

Fig 4.14 Front view of LED Indicator Board with Logo Panel

LED indicator board is a separate board that is used to illuminate the logo of the particular procedure, indicating that the user is about to simulate on the simulator. The LED board is placed near the front panel of the simulator, back side of the logo panel to illuminate the logo panel.

4.3.1 Block Diagram of LED Indicator Board

The LED panel is a small rectangular board, with configuration as shown in the below block diagram. It is a panel on which the LED's are mounted onto the front side and relay mounted on the back side. The 3D model depicts the design much clearly as shown in figure 4.14.

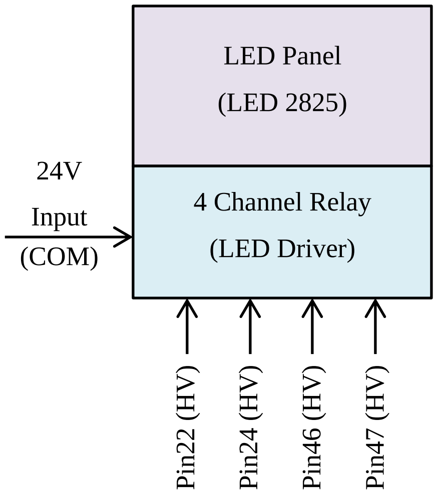

Fig 4.15 Block Diagram of LED Indicator Board

The main components on this board are:

1. LED (Surface Mounted)

Fig 4.16 Surface Mounting LED

The LEDs are supplied with 12V 2.5A supply from an adapter, via the main board. LED is provided with high voltage ratings, because the light emitted from the LED has to pass through the translucent panel of the logo panel.

The LEDs on this board are internally connected to Normally Open (NO) & Ground (GND) pin of the relay.

2. Relay Unit

Fig 4.17 Relay Unit

Relay is an electromechanical switch that either closes or opens the circuit. There are different types of relay, but in this case, a 5-pin reed relay is used. The input pin is a digital pin which receives input signals from the Arduino Due as per the program requirements as defined by the user.

The main function of the relay being electrical isolation of the 5V supply with the 24V supply i.e., isolate the 24V supply line from the LEDs on the board. Since there are 4 different relays on the backside of the LED panel, with each having its own input signalling pins, required LEDs are be turned ON as soon as the user selects the procedure to be performed.

The 5 pins of the relay are connected to the main control board as follows:

- NO (Normally Open) - 12V coming from the switch.
- COM (Common) - 12V coming through the DC Jack of the main board
- NC - No Connection
- GND - Ground connection
- Input pins - Digital pins driving selected relay from the Arduino Due as shown in the block diagram.

4.3.2 Board Diagram of LED Indicator Board

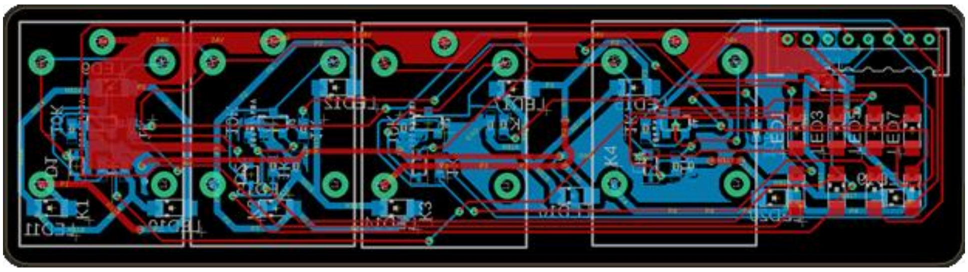

Fig 4.18 Board Diagram of LED Indicator Board

LED indicator board uses 24V line for supplying power to LEDs and has 5V lines for pins receiving driving signals to relay unit from Arduino Due, hence track line design is done considering the power usage, current drawings and other aspects. The track line details showcased in subsection 4.2.2 is maintained and replicated for respective voltage lines.

4.4 Connector Printed Circuit Board (PCB)

Connector board is an extension board used to connect one or more different boards. As some of the sensors available on each board which are physically unreachable to the haptic base main board, connector board is used connect to the main board indirectly.

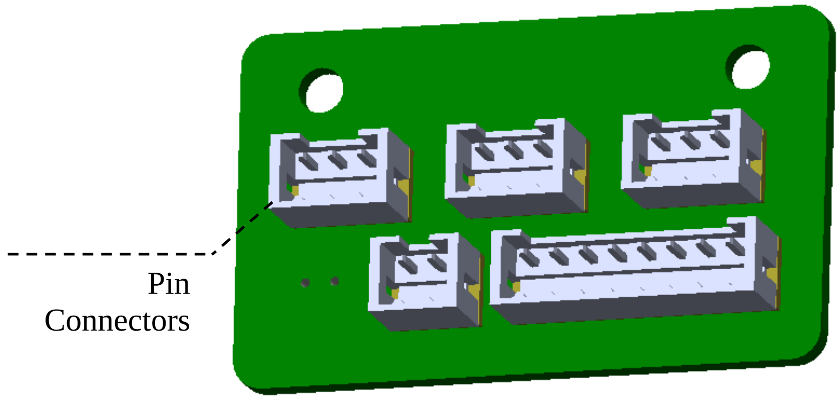

Fig 4.19 3D view of Connector Board

The different boards consisting sensors and interfacing elements that are connected to the main board via the connector board are:

- LED Indicator Board
- Mouthpiece and Colonpiece LED Board
- Hall Effect Sensor Board

4.4.1 Block Diagram of Connector Board

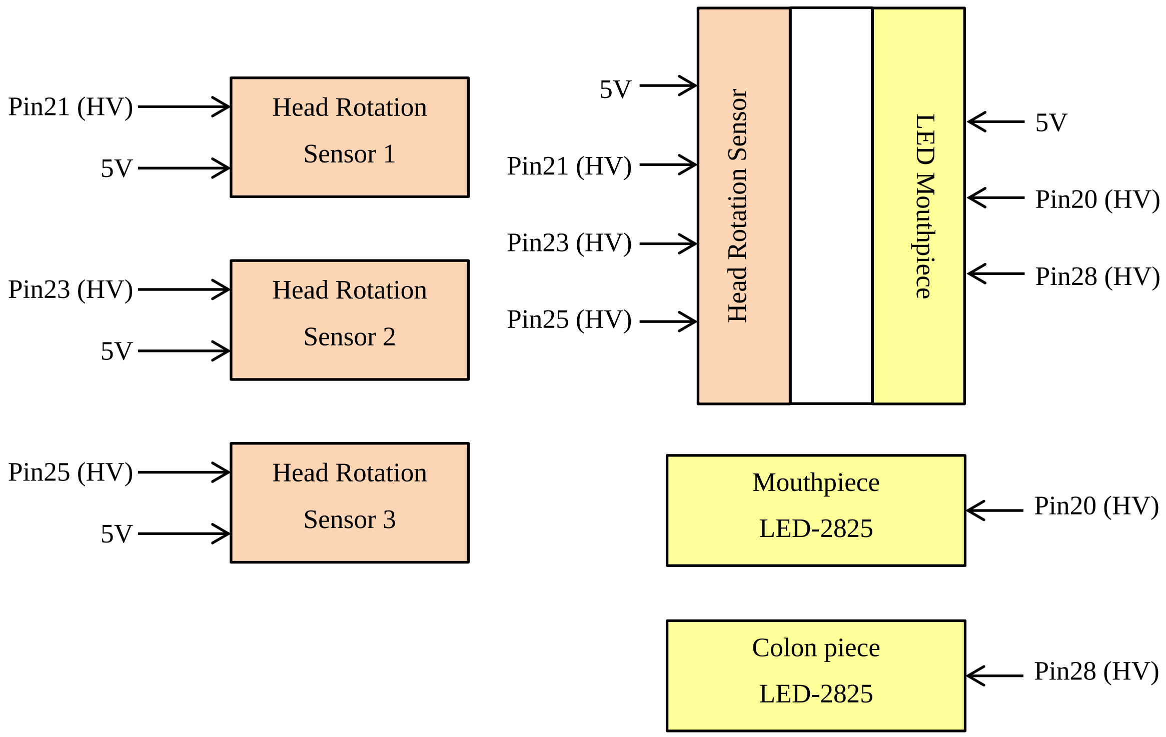

Fig 4.20 Block Diagram of Connector Board

4.4.2 Board Diagram of Connector Board

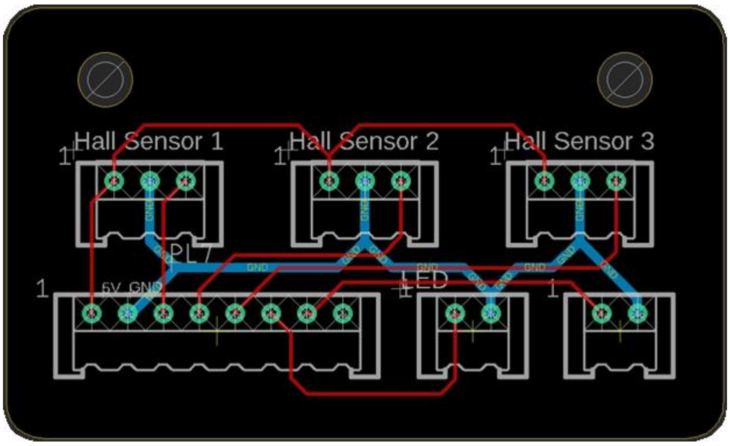

Fig 4.21 Board Diagram of Connector Board

Connector connects LED indicator board which uses 24V line for supplying power to LEDs and has 5V lines for pins receiving driving signals to relay unit from Arduino Due, hence track line design is done considering the power usage, current drawings and other aspects. The track line details showcased in subsection 4.2.2 is maintained and replicated for respective voltage lines.

4.5 Hall Effect Sensor Printed Circuit Board (PCB)

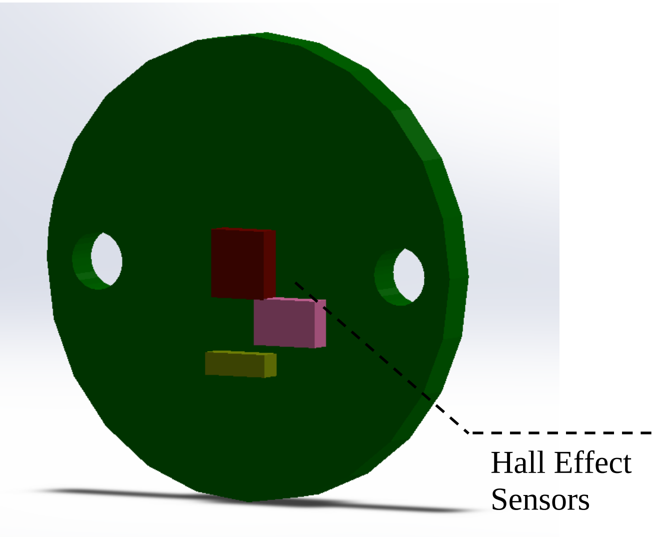

Fig 4.22 3D view of Hall Effect Sensor Board

Hall effect sensor board consists of 3 hall effect sensors. Since different procedures have different position of head, after each rotation the sensor informs the controller which direction the head is at present by placing the same sensor at different positions, thereby informing the user the procedure selected.

4.5.1 Block Diagram of Hall Effect Sensor Board

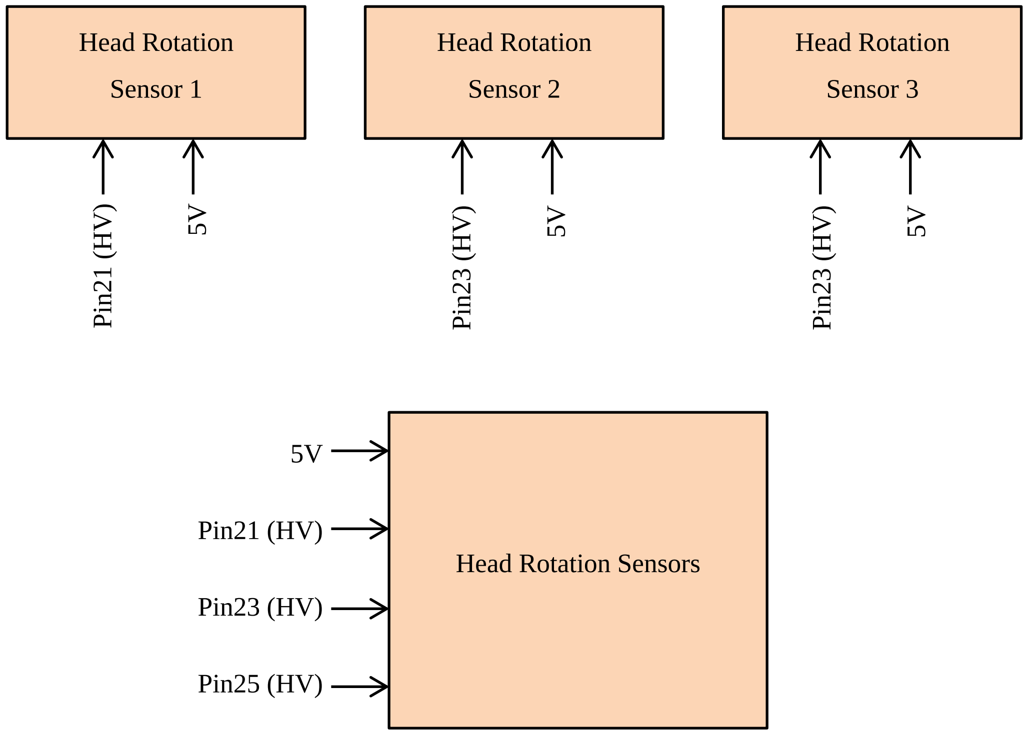

Fig 4.23 Block Diagram of Hall Effect Sensor Board

Hall effect sensor board consists of 3 head Rotation Sensors, which are basically hall effect sensors, which uses magnetic flux linkage as its operating principle. Hall effect sensors give more accurate reading only with magnets or ferro-magnetic substances like iron etc.

It is an electronic device which comprises of MOSFET and capacitors to detect the flux linkage i.e., as soon as a magnetic substance passes this circuit, due to change in the flux linkage current is induced in this circuit, this signal generated is given to the Arduino Due.

The importance of this sensor is that, since different procedures have different position of head, after each rotation the sensor informs the controller which direction the head is at present by placing the same sensor at different positions, thereby informing the user the procedure selected.

4.5.2 Board Diagram of Hall Effect Sensor Board

Hall effect sensor board uses only 5V DC, therefore, track lines are designed based on 5V line considerations showcased in subsection 4.2.2.

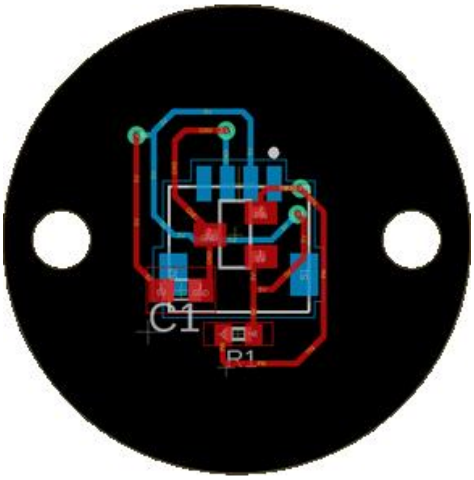

Fig 4.24 Board Diagram of Hall Effect Sensor Board

4.6 Mouth Piece LED Printed Circuit Board (PCB)

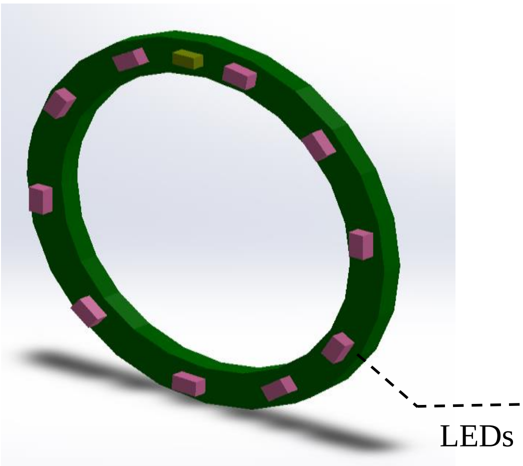

Fig 4.25 3D view of Mouth Piece LED Board

Mouth piece LED board is a circular PCB board, with LEDs mounted on it. The voltage rating of this board is 5V.

The function of the board is to provide lighting to the mouth and the colon area. When the same board is used in the colon area it is called as colon piece LED board.

4.6.1 Block Diagram of Mouth Piece LED Board

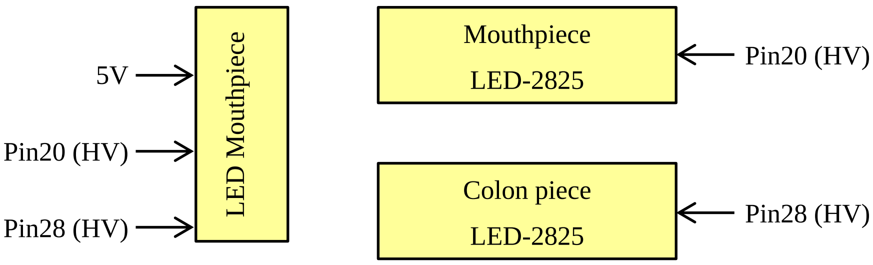

Fig 4.26 Block Diagram of Mouth Piece LED Board

4.6.2 Board Diagram of Mouth Piece LED Board

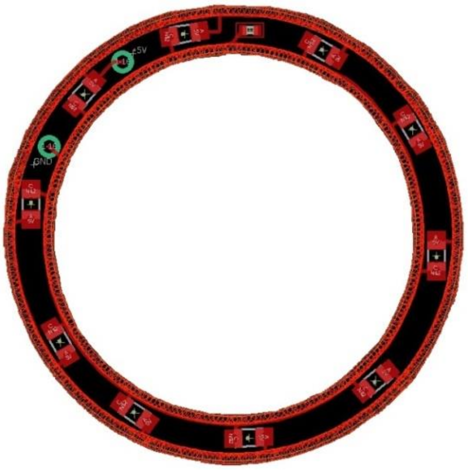

Fig 4.27 Board Diagram of Mouth Piece LED Board

Mouth piece LED board uses only 5V DC supply. Therefore, track lines are designed based on 5V line considerations showcased in subsection 4.2.2.

4.7 Endoscopy Control Handle Printed Circuit Board (PCB)

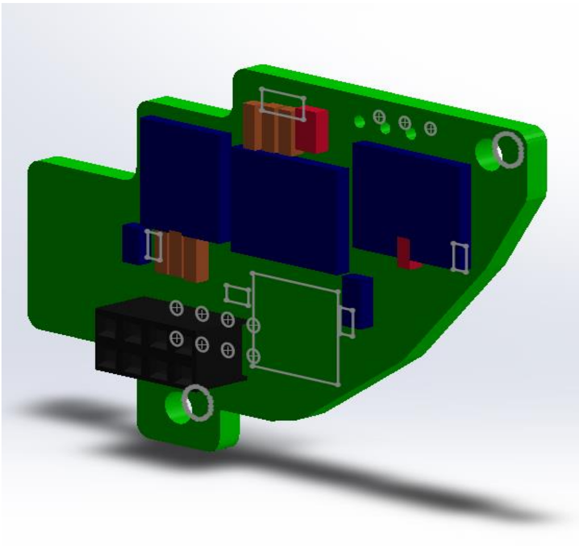

Fig 4.28 3D view of Endoscopy Control Handle Board 1

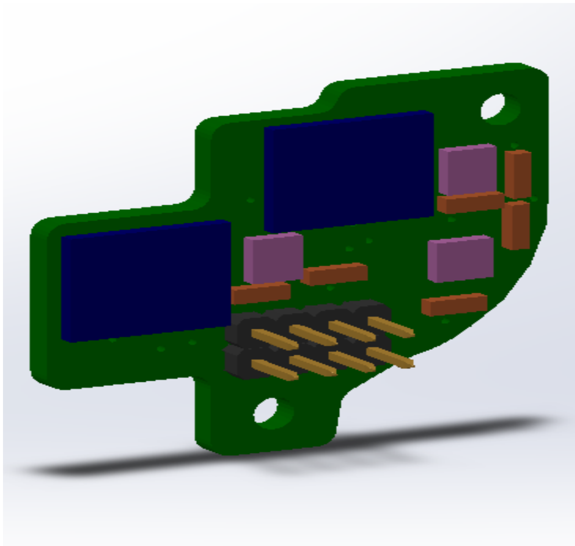

Fig 4.29 3D view of Endoscopy Control Handle Board 2

As mentioned in the chapter 3 of this document, there are two different types of endoscopes, video endoscope and fibre optic endoscope.

The main purpose of the endoscope control Handle is to control the scope that enters into the body, along with some other features. The control of the scope is brought about by rotating the camera at the end of the scope. The rotation of the camera depends on the output display on the monitor screen. There are two knobs to rotate the camera. One rotates it in the up/down direction while the other rotates it in the right/left direction.

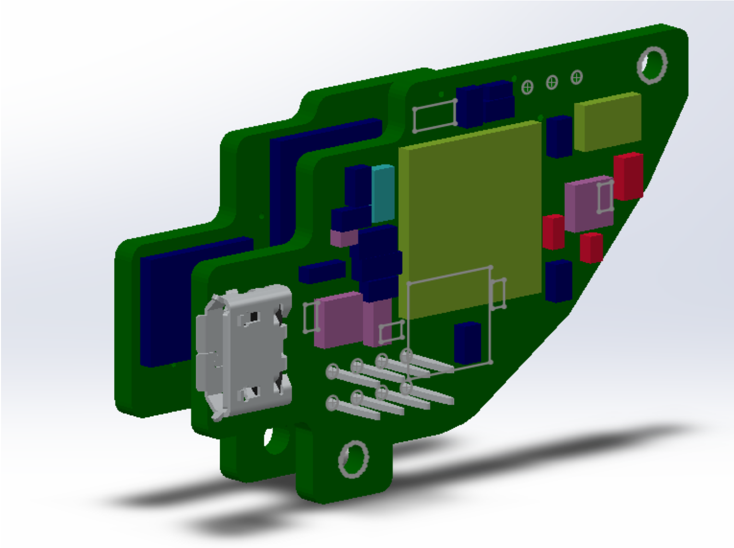

Fig 4.30 3D view Representing both Endoscopy Control Handle Boards Mounted Together

They also can help in cleaning the camera lens, capturing a photo, and air suction, with the help of side switch panel. The additional features of the endoscopy handle are insertion of different accessory tools through the accessory port of the handle. These accessory tools are used to analyse and evaluate the condition inside the body.

The above given statements explains the working of an actual endoscope, while the endoscope used in the simulator is different from the actual endoscope. The handle used in the endoscope simulator does not have a camera at the end of the scope. Instead it is used to check for proper insertion of the tool in the body of the simulator, with the help of snap-fit sensor. The readings of different sensors in the handle are received by a Cortex-M4 chip, and are independent of the main board. Hence these values along with the values read from the accessory tools are sent to the user through this microcontroller. Here, the rotation of the camera is through the simulation software. The values read from the knob encoders are received by the microcontroller and these values are translated into the graphical animations.

Since the accessory tools are connected to another microcontroller, there is no overloading on the chip. The values are read by Itsy-Bitsy (another Arduino compatible board) and is sent directly to the user. Each microcontroller's functioning are accessed or controlled by the user using the CPU.

4.7.1 Block Diagram of Endoscopy Control Handle Boards

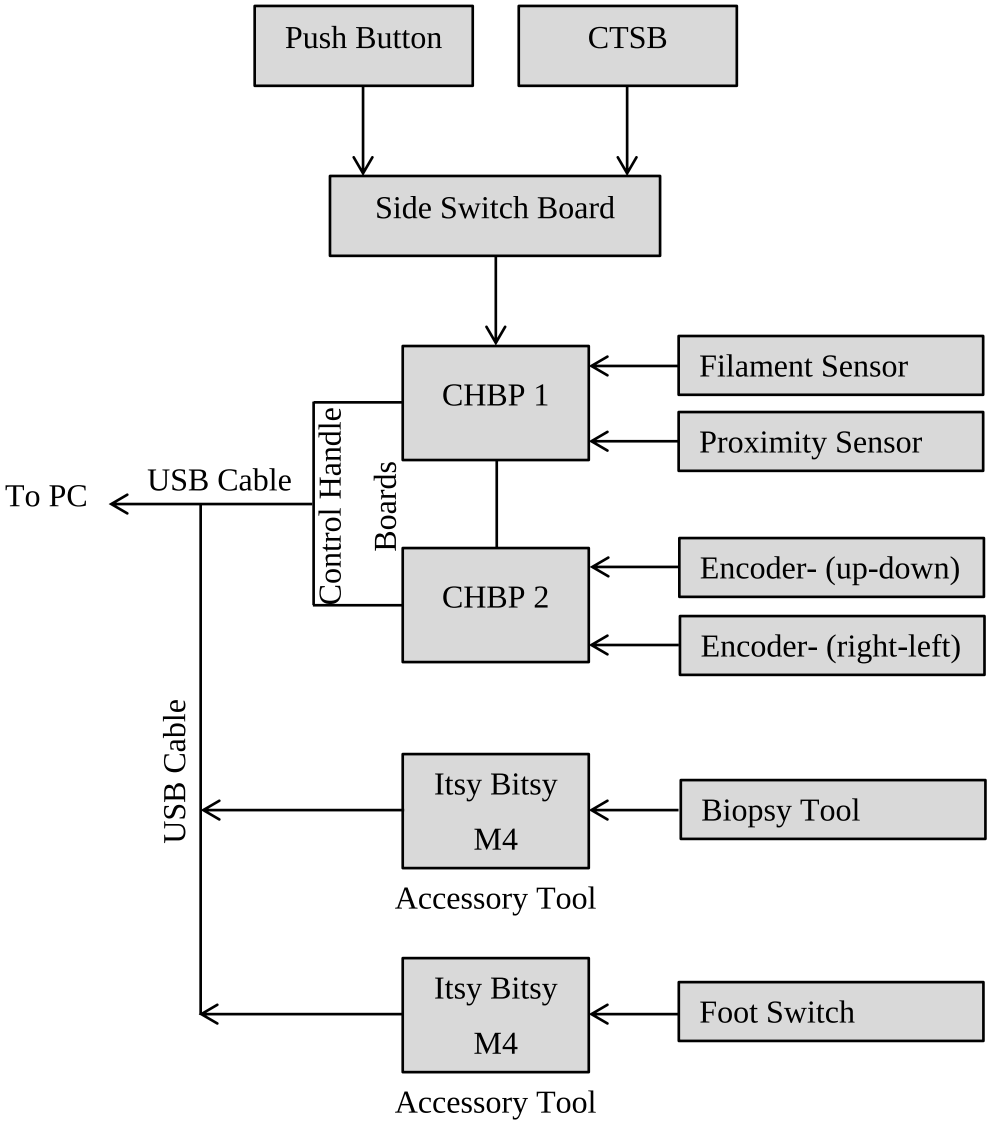

Fig 4.31 Block Diagram of Endoscopy Control Handle Board

The block diagram of the handle shows the communication of the users with the handle PCB. Here, there are 2 boards, Control Handle Board Part 1 & 2 (CHBP1&2) are the control handle PCB, where 1 & 2 represent the importance of the PCB or the order of the PCB. Therefore, CHBP1 is the main PCB while CHPB 2 is the secondary PCB.

The control handle main board is fully custom-built board, unlike the main control board which uses Arduino Due as the main controller. The PCB was custom-built to suit for the mechanical design of the control handle. It uses a Cortex-M4 chip, as part of its architecture.

The Cortex-M4 processor is developed to address digital signal control markets that demand an efficient, easy-to-use blend of control and signal processing capabilities.

The combination of high-efficiency signal processing functionality with the low-power, low cost and ease-of-use benefits of the Cortex-M family of processors satisfies many markets. These industries include motor control, automotive, power management, embedded audio and industrial automation markets. As seen in the block diagram the control handle uses two PCB's as part of its architecture.

Control handle Sensing Board (CTSB) is the board that acts as air suction in the actual scope. The Biopsy tool and the Footswitch are the different accessory tools and are connected to independent Itsy-Bitsy boards as shown. The main components on these boards are:

1. Filament Sensor (Prusa Sensor)

Fig 4.32 Filament Sensor

Prusa Sensor is an optical filament sensor that detects any movement. Prusa is a powerful sensor as the sensor alone can be used for sensing five different parameters. The different parameters that the sensors can detect are the change in position in the X-direction, Y-direction, brightness, saturation and also as an accelerometer.

Prusa uses a PAT9125 chip manufactured by PixArt. The PAT9125EL is an optical tracking miniature chip using PixArt's LASER- based optical navigation technology enabling digital surface tracking.

The main function of the prusa sensor in the control handle is to evaluate the position of the accessory tool inserted through the accessory tool insertion port.

The main advantage of this sensor is that the tracking does not require a code wheel, code strip or any special marking on the tracking surface for motion control or tracking purpose. No lens is needed and supports I2C protocol or 3-wire Serial Peripheral Interface (SPI) programming. Internal oscillator and no external clock input are needed.

2. CUI Encoders

An encoder is an electrical mechanical device that converts linear or rotary displacement into digital or pulse signals. The most popular type of encoder is the optical encoder. This consists of a rotating disk, a light source, and a photo detector (light sensor).

Fig 4.33 CUI Encoder

As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital or pulse signal output. An incremental encoder generates a pulse for each incremental step in its rotation. Although the incremental encoder does not output absolute position, it can provide high resolution at an acceptable price.

The most common type of the incremental encoder uses two channels A and B whose pulses are 90 degree out of phase. If the output of the channel A leads channel B, then the code wheel is assumed to rotate clockwise, while if channel B leads channel A, the code wheel rotates counter-clockwise.

The main function of the CUI encoder, in the control handle is to evaluate the positions of the knobs. These knobs are positioned in such a way that it rotates back to its equilibrium position.

3. Accessory Tools:

The accessory tools mostly comprises of the potentiometer other than the footswitch. The accessory tools are assembled in the casing specially designed casings that represent the original tools. These potentiometers send the values to the computer through a different chip which is encased in a different structure. The different accessory tools are:

- Biopsy Tool
- Foot Switch

4.7.2 Board Diagram of Endoscopy Control Handle Boards

Track lines are designed based on voltage line considerations showcased in subsection 4.2.2.

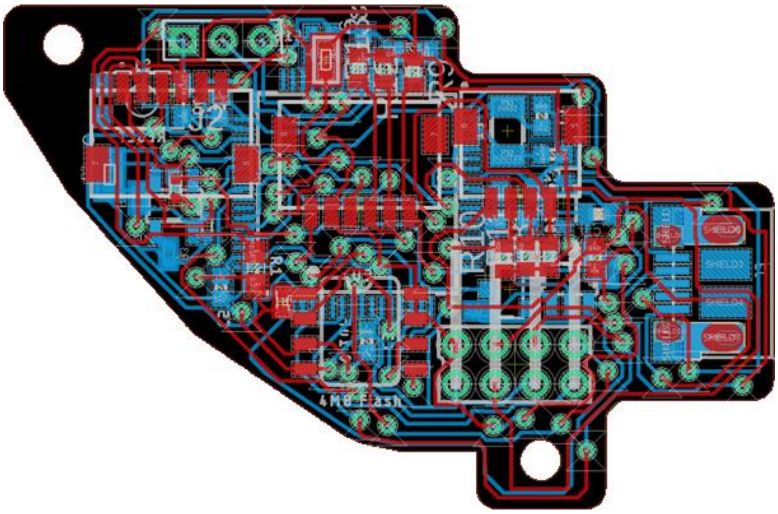

Fig 4.34 Board Diagram of Endoscopy Control Handle Board 1

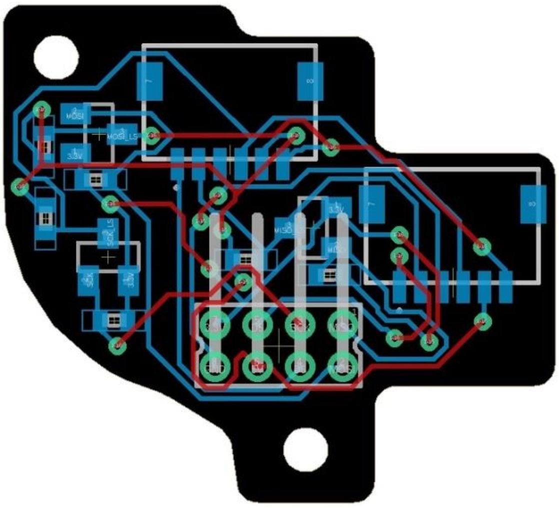

Fig 4.35 Board Diagram of Endoscopy Control Handle Board 2

4.8 Control Mapping of Haptic Simulator Base

The below table includes the control mapping of haptic simulator base, which describes the pin connections from Arduino Due to various boards which connects various sensors, relay unit, switches and ESCON 24/2 servo controller.

Sl.No.	Arduino Pin	Sensors Connected	Signal Received From	Signal Sent To
1	Pin49	Motor Relay	Relay	Arduino Due
2	Pin32	DigIN2 (LM)	Motor Encoders	Arduino Due
3	Pin48	CHA (LM)		
4	Pin47	CHB (LM)		
5	Pin41	CHA (RM)		

6	Pin44	CHB (RM)		
7	PWM2	DigIN1 (LM)		
8	DAC0	Write Force (LM)		
9	AN0	Analog Output (LM)		
10	Pin33	DigIN2 (RM)		
11	PWM3	DigIN1 (RM)		
12	AN1	Analog Output (RM)		
13	DAC1	Write Force (RM)		
14	Pin20	Mouth Piece LED1	LED	Arduino Due via Connector Board
15	Pin28	Mouth Piece LED2	LED	Arduino Due via Connector Board
16	Pin21	Head Rot. Sensor1	Hall Effect Sensor	Arduino Due via Connector Board
17	Pin23	Head Rot. Sensor2	Hall Effect Sensor	Arduino Due via Connector Board
18	Pin25	Head Rot. Sensor3	Hall Effect Sensor	Arduino Due via Connector Board
19	Pin22	LOGO 1	LED	Arduino Due via Connector Board
20	Pin24	LOGO 2	LED	Arduino Due via Connector Board
21	Pin26	LOGO 3	LED	Arduino Due via Connector Board
22	Pin27	LOGO 4	LED	Arduino Due via Connector Board
23	Pin51	Snap-fit Sensor	Snap-fit	
24	Pin31	Limit End Switch	End Switch	Arduino Due
25	Pin35	Limit front Switch		
26	Pin30	Homing End	Homing Sensors	Arduino Due
27	Pin50	Homing front		

Table 4.3 Control Mapping of Haptic Simulator Base

4.9 Haptic Bed Connections and Wiring

This section includes all haptic base connector pins connected to other boards, motors and photo electric sensors.

- 2 Pin connector used in main board for powering the motors, and 2 core (12/40) cables are used connect mainboard to motors.

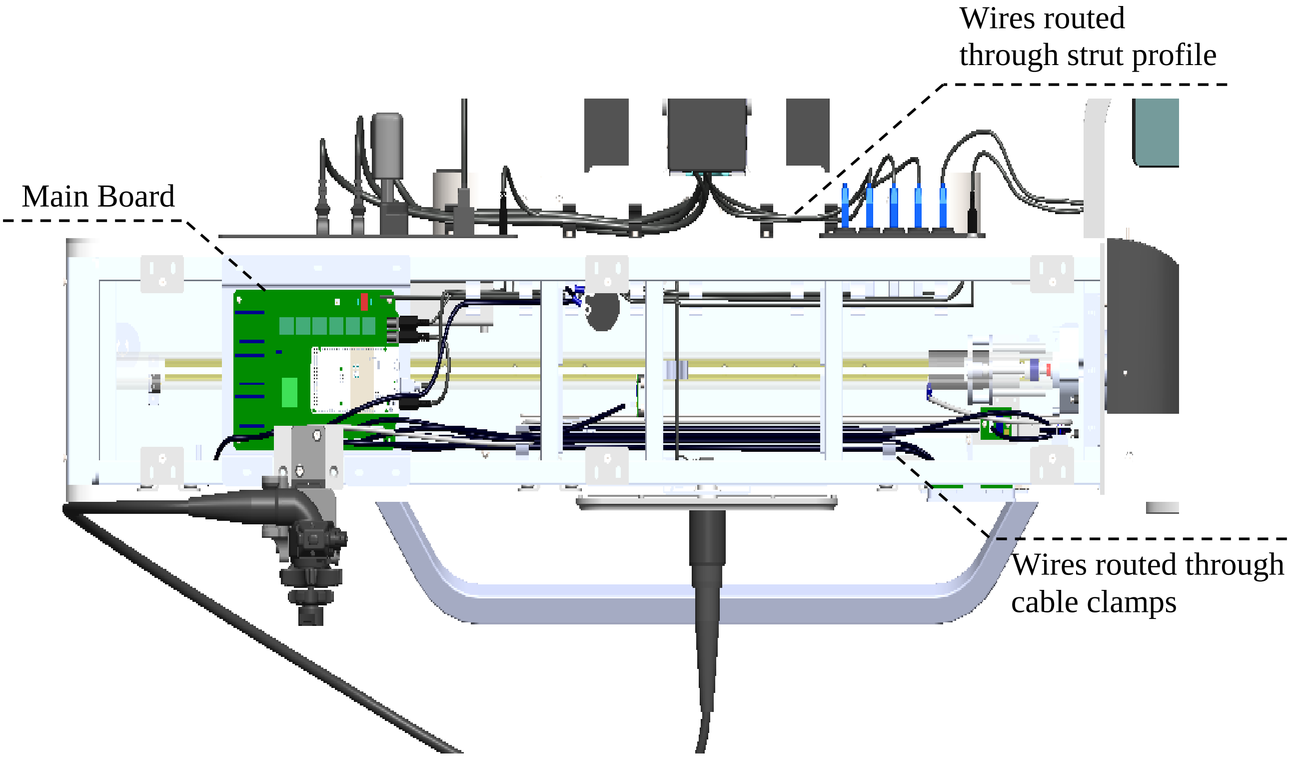

Fig 4.36 Top view of Haptic Base with Metal Sheath Hidden

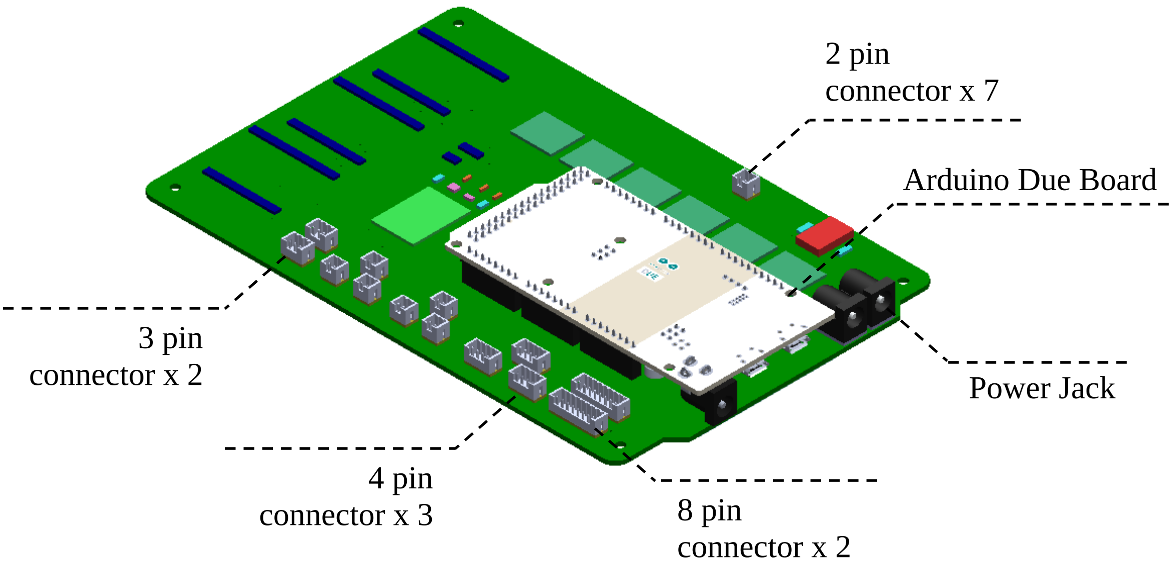

Fig 4.37 Main Board Indicating Connectors

- 3 pin connector used in the main board for Photo-Electric (PE) sensors, and 3 core cable are used to connect PE sensor to main board via connector board.
- 4 pin connector used in the rotational Motor board, and 6 core (24 AWG) cable is used for connection between them.

- 6 pin connector used in the main board for linear and Rotational motor boards and 4 core (24 American Wire Gauge - AWG) cable is connected from main board to motor driving board.
- 8 pin connector used in the LED panel board and 8 core (26AWG) cable is used for connection of LED board to main board via connector board.

4.10 Results

Results from filament sensor, motor encoders, ESCON 24/2 servo controller and proximity sensor are recorded graphically and numerically in a table. The obtained reading samples for the mentioned components are listed as:

1. Filament Sensor MK3 (Prusa)

Motion Status	Motion Status Information
Delta_X_Lo	8-bit 2's complement number for X-movement data in 8-bit movement data format
Delta_Y_Lo	8-bit 2's complement number for Y-movement data in 8-bit movement data format
Delta_XY_Hi	High nibble of X-movement and Y-movement for 12-bit 2's complement data form
Frame_Avg	Average brightness of a frame

Table 4.4 Required Output pins from Filament Sensor

The graphical plots recorded from filament sensor using serial monitor in Arduino Software is given below:

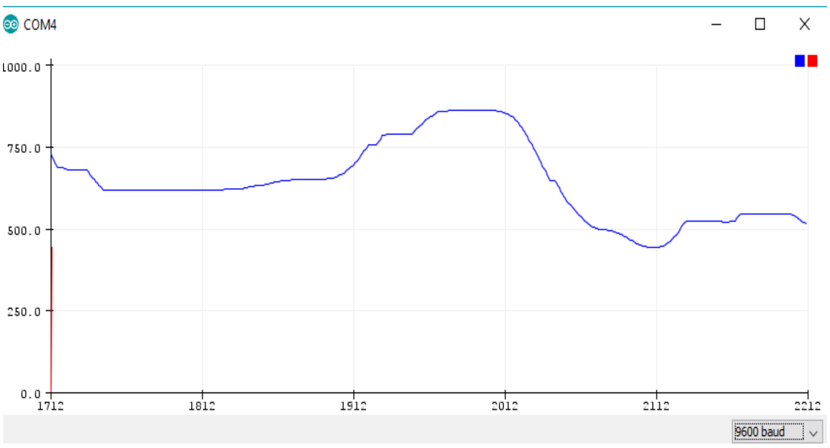

Fig 4.38 Result Sample 1 from Filament Sensor

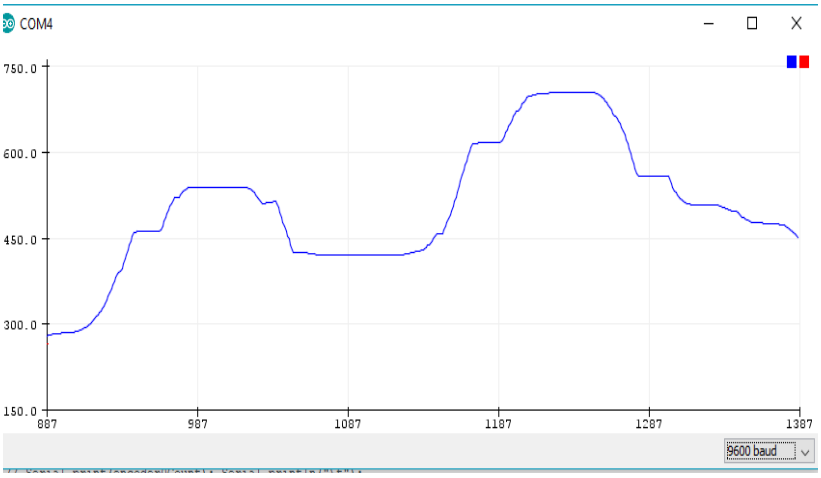

Fig 4.39 Result Sample 2 from Filament Sensor

2. Motor Encoders

The output values of these are calibrated in such a way that they provide the information about the alignment of the scope and the distance of the scope which it has travelled inside the haptic base.

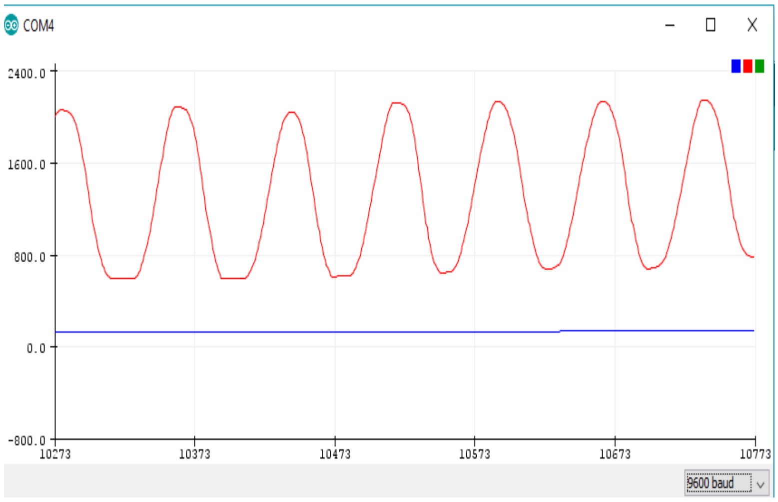

Figure 4.40 Result Sample 1 from Motor Encoder

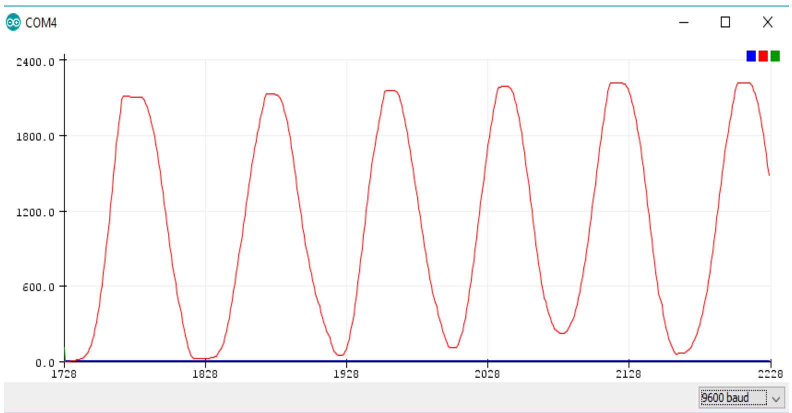

Figure 4.41 Result Sample 2 from Motor Encoder

3. Escon Module 24/2 Servo Controller

Analog input 1 Analog input 2	12-bit resolution; -10 to +10 V differential
Analog output 1 Analog output 2	12-bit resolution; -4 to +4 V referenced to ground
Digital input 1	+2.4 to +36 VDC (Ri = 38.5 kΩ)
Encoder signals	A, B

Table 4.5 Required Inputs & Outputs from Escon Module 24/2 Servo Controller

4. Proxomity Sensor

The output of the proximity sensor provides the information about the simulator activation. If it is 0, then the scope has latched and the simulation has begun, because it is configured for active low. If it is 1, then the scope has not yet been latched and simulation inactive.

Value	Implications
0	Scope latched and simulation is begun
1	Scope is not latched and simulation is inactive

Table 4.6 Outputs from Proximity Sensor and its Implications

Chapter V

CONCLUSION

Before the development of computer aided simulator, the doctors or other personnel were trained on stuffed animals or mechanical models which were not reliable.

Avoiding the risk of human life for training is highly valuable with computer aided simulators having more merits than the other models, because it is reliable and also if there is any change needed, it can be done by a mere alteration of the simulation program. The doctors and trainees also welcome the computer aided simulation as it is much easier to use.

Hapto-VR Medical Simulator has Haptics as its working principle, and also is verified by professional doctors. The trainee and the trainer can understand the concepts much clearly and are aided with the Virtual Reality. Haptic feedback from the simulator can induce human body reactions while the virtual reality environment mimics human body for much more interactive endoscopic procedure as in real endoscopy. Since this simulator uses economical sensors and encoders for its working, the simulator is much cost effective than the other simulators.

Scope for future use:

1. The simulator is presently built only for the endoscopic procedure. The same simulator can be used for at least 4 different procedures in the future, just by changing the control handle due to its compatibility.
2. Since this simulator is cost effective compared to the existing ones, the organization is aiming to introduce this simulator to train young doctors, in hospitals where they use mannequins or donated bodies. Since this simulator is user friendly and much easier to handle, one can easily adapt to this method of teaching.

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2. https://www.webmd.com/digestive-disorders/digestive-diseases-endoscopy#1
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5. Ananya, S. Chakravarthy, K. Saurabh, and G. K. Ananthasuresh, “Shape Estimation and Prediction of Locations of the Force of a Flexible Tube using Strains at a Few Points,” presented at the 2nd International and 17th National Conference on Machines and Mechanisms (iNaCoMM2015), Kanpur, India, 2015.
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7. https://www.7pcb.com/trace-width-calculator.php

(A) COURSE OUTCOMES (COs)

The Students would be able to:

1. Able to generate, develop an idea and information to carry out project work.
2. Analyze and assemble the basic information to find a tangible solution of the complex engineering problem by using suitable method/procedure.
3. Use/ implement modern Engineering tools/ technologies to get optimized results.
4. Adapt collaborative skills to work in team.
5. Develop presentation, communication and report writing skills.
6. Apply the knowledge and understanding of principles of management, finance and engineering in their project work.

(B) PROGRAM OUTCOMES (POs)

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex Electronics and engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change in engineering domain.

(C) PROGRAM SPECIFIC OUTCOMES (PSOs)

1. The students will be able to apply the knowledge of mathematics, and applied science principles to solve diverse problems in the field of power systems and control of Electric Drives catering to Industrial, Research, Service and allied areas.

2. The students would be competent in identifying, analysing and exhibiting the skills in providing solutions to problems related to control electronic systems using various modern tools.

3. The students will be able to demonstrate proficiency in applying the knowledge of project management to design different electrical and electronic systems as peer specified standards.

COs\POs\PSOs	**CO-PO Mapping**														
	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO 10**	**PO 11**	**PO 12**	**PSO 1**	**PSO 2**	**PSO 3**
CO1	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
CO2	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓
CO3	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓
CO4	✓	✓	✓	✓				✓		✓		✓			✓
CO5	✓	✓	✓		✓		✓	✓	✓	✓		✓			
CO6	✓										✓	✓			

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