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Report on Project

"Archiving of Lab Samples using a Pick and Place Gantry robot in a Diagnostic Lab"

Submitted by

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AUG - DEC 2023

Under the Guidance of
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FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND ELECTRONICS
B. TECH IN EEE

FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS
BACHELOR OF TECHNOLOGY

CERTIFICATE

This is to certify that the Dissertation entitled

"Archiving of Lab Samples using Pick and Place Gantry robot in a Diagnostic Lab"

Is a Bonafide work carried out by

Sumukh Marathe (PES1UG20EE068)
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In partial fulfilment for the completion of 7th semester course work in the Program of Study B. Tech in Electrical and Electronics Engineering (Embedded Systems) under rules and regulations of PES University, Bengaluru during the period Aug 2023 – Dec 2023. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report. The dissertation has been approved as it satisfies the 7th semester academic requirements in respect of project work.

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DECLARATION

We Sumukh Marathe (PES1UG20EE068), Vineet N Patil (PES1UG20EE074),N Ananya (PES1UG20EE100) and Shreshta Srinivas P R (PES1UG20EE111) hereby declare that the project entitled, ***"Archiving of Lab Samples using Pickand Place Gantry robot in a Diagnostic Lab"***, is an original work done by us underthe guidance of Dr.Venkatarangan M J, Professor, Dept. of EEE, and is being submitted in fulfilment of the requirements for completion of 7th Semester course work in the Program of Study B.Tech in Electrical and Electronics Engineering.

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ABSTRACT

Archiving lab samples within a diagnostic laboratory involves the identification, labelling, and preservation of diverse bodily fluids or tissues for future reference. Adhering to precise protocols is essential in ensuring the integrity of archived samples, as human involvement may introduce inaccuracies. To address this concern, an automated robot has been developed through collaboration with and funding from Anand-Neuberg Diagnostics.

Gantry robots, also known as linear robots, are a type of industrial robot specifically designed for tasks such as picking and placing, assembly, and inspection across various industries. The objective of this project is to create and implement a gantry robot for a pick-and-place application, specifically for archiving vacuum tubes within a diagnostic laboratory. The robot operateswithin a flexible workspace, executing tasks such as picking, scanning, and placing vacuum tubes into designated crates.

The project initially utilised a Gantry Robot for transferring vacuum tubes between trays. An end effector, equipped with a precise gripper, was developed to ensure accurate pick-and-place movements. The robot's control system was optimised to delicately handle vacuum tubes, considering the spacing between tubes in the tray to prevent disruptions to adjacent samples.

Gantry robot is fabricated with the needed hardware and software interfaces. In terms of hardware, the robot needed a camera and bar-code scanner as sensors while the actuation is based on stepper motors with 5 degrees of freedom. Limit switches have been added for ensuring that it goes to a homing position on every restart of the system.

This project also implements the application of object detection in identifying the vacuum tubes. The methodology involves training a model on annotated datasets, employing YOLO algorithm and PyTorch. Leveraging computer vision techniques, the system aims to accurately locate the vacuum tubes and the empty slots through real-time image feed.

A 5 DOF gantry robot was designed and built using aluminium extrusion which helps in archiving of the vacuum tubes from 4 source racks to 5 destination racks, using Digital Image Processing. The tubes are picked, scanned and placedin their designated slots by the order of the Library Information System (LIS). The average cycle time to achieve the mentioned application is 20 seconds.

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1. INTRODUCTION

1.1. BACKGROUND

In a diagnostic laboratory, vacuum tube samples are routinely collected from patients to perform various medical tests to diagnose diseases, monitor disease progression,and assess treatment effectiveness. These samples could include blood, urine, cerebrospinal fluid, sputum, and other bodily fluids or tissues.

The archiving of vacuum tube samples refers to the process of preserving these samples for future reference or analysis. This is important because, in some cases, it may be necessary to retest a sample or compare it with previous test results to detect changes in the patient's condition or disease progression.

1.2. PROBLEM STATEMENT

It is important to follow proper protocols for archiving samples to ensure their integrity. This includes labelling each sample with a unique identifier, storing them in a secure and temperature-controlled environment, and tracking their location and storage duration. Human involvement might result in inaccuracies. This system shouldaddress the challenges such as precise tube identification, safe handling, quicker operation, and seamless integration with existing laboratory workflow. To resolve this we are developing an automated gantry robot.

1.3. OBJECTIVES/DELIVERABLES

- Utilising Image Processing with Machine Learning techniques, a highly effective gantry robot for vacuum tubes
- Faster and extremely accurate archiving of samples
- Reduction of human workload

1.4. ARCHIVING & ITS SIGNIFICANCE

The significance of archiving lab samples lies in the fact that they can be used for further research or analysis in the future. For example, if new testing methods or technologies are developed, samples can be retrieved from the archive and analysed using the new methods, potentially leading to new insights or discoveries. Additionally, samples may be needed for quality control purposes, such as to verify the accuracy and consistency of test results over time.

Archiving lab samples is also important for meeting regulatory requirements and ensuring the integrity of research data. In many cases, regulatory agencies require that samples be retained for a certain period of time as part of the documentation process. Archiving samples can also help prevent data loss due to equipment failure, natural disasters, or other unforeseen events.

There are several reasons why archiving is important in a diagnostic lab:

a. **Quality control**: Archiving helps to ensure the accuracy and reliability of test results by providing a record of previous test results and enabling the lab to monitor and track the performance of its testing procedures and equipment over time.

b. **Compliance**: Many regulatory agencies require diagnostic labs to maintain accurate records of their testing processes and results, and failure to do so can result in fines, legal liability, or loss of accreditation.

c. **Research and development**: Archiving can provide a valuable resource for researchers and developers working on new diagnostic tests and treatments. By maintaining a comprehensive archive of patient samples and data, labs can contribute to the development of new treatments and therapies that could benefit patients in the future.

d. **Patient care**: Archiving allows for the ongoing monitoring of patient healthand provides a valuable resource for healthcare providers to make informed decisions about patient care based on previous test results and medical history.

2. LITERATURE SURVEY

Paper [1] : "Evolution of YOLO-V5 Algorithm for Object Detection: Automated Detection of Library Books and Performance validation of Dataset,"

The paper discusses the implementation and evaluation of the You Only Look Once (YOLO) version 5 algorithm for object detection, specifically for the automated detection of library books. The authors explain the steps involved in the training of the YOLOv5 algorithm using a dataset of library book images. The dataset was created by capturing images of library books using a smartphone camera and manually labelling them. The trained model was then evaluated for its performance on the detection of library books. The authors report an average precision of 0.9535 for the YOLOv5 algorithm. They conclude that the YOLOv5 algorithm is an efficient and accurate tool for automated object detection and can be used in various applications, including library book detection.

Paper[2] : “Object Detection Method for Grasping Robot Based on Improved YOLOv5”

The paper proposes a new object detection method for a grasping robot based on the improved YOLOv5 (You Only Look Once version 5) algorithm. The authors argue that the traditional YOLOv5 algorithm has limitations in detecting small objects and lacks robustness in complex scenarios. To address these limitations, the authors propose an improved YOLOv5 algorithm that incorporates a new loss function and a focal loss function to improve the accuracy of small object detection. They also introduce a multi-scale feature fusion module to enhance the robustness of the model in complex scenarios. The proposed method is evaluated on a dataset of real-world objects, and the results show that the improved YOLOv5 algorithm outperforms the traditional YOLOv5 algorithm and other state-of-the-art object detection methods in terms of accuracy and efficiency. The authors demonstrate the feasibility of the proposed method by integrating it into a grasping robot system and conducting experiments on object grasping tasks.

Paper[3] : "Laboratory gantry robot design and control"

The paper focuses on the design and control of a laboratory gantry robot, which is a type of robotic system that is used for various applications such as material handling, assembly, and testing in a laboratory environment. The authors describe the overall design of the gantry robot and its mechanical structure, including the motors, bearings, and other mechanical components. The paper then discusses the control system of the gantry robot, which involves the use of a programmable logic controller (PLC) and a personal computer (PC). The authors describe the software architecture used to control the gantry robot, which includes a user interface for setting up the system and defining the robot's movements. The authors also present experimental results that demonstrate the gantry robot's capabilities, including its speed, accuracy, and repeatability. The results show that the gantry robot is capable of performing various tasks with high precision and reliability. Overall, the paper provides a detailed description of the design and control of a laboratory gantry robot and highlights its potential use in various laboratory applications. The paper may be of interest to researchers and engineers working in the field of robotics and automation.

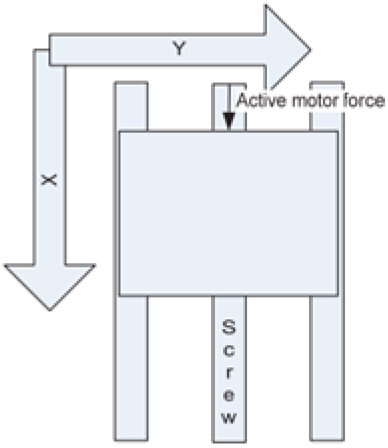

Figure 1 - Moving table in X axis and couple of linear bearing on sides

Paper[4] : "RealTime Object Detection using Machine Learning"

The paper describes a real-time object detection system based on machine learning. The proposed system uses a Convolutional Neural Network (CNN) architecture to detect and classify objects in real-time. The system is designed to work with live video streams and can detect objects in real-time without any lag. The authors of the paper conducted several experiments to evaluate the performance of the proposed system. The results of the experiments showed that the proposed system is capable of detecting objects accurately and quickly, making it suitable for real-time applications such as video surveillance and autonomous vehicles. In conclusion, the paper presents a real-time object detection system based on machine learning that can detect and classify objects in real-time with high accuracy. The proposed system has the potentialto be used in a variety of applications, including video surveillance, autonomous vehicles, and robotics.

Paper[5] : "Pick and place industrial robot controller with computer vision"

The paper proposed a system for controlling an industrial robot using computer vision to perform pick-and-place operations. The system consists of a camera that captures images of the work environment and a controller that processes the images to detect objects and determine their positions. The controller then generates commands for the robot to perform the necessary actions. The authors demonstrated the effectiveness of their system through experiments, which showed that it could accurately detect and manipulate objects in real time.

Paper[6] : "Material Handling Using Pick and Place Robot"

The paper proposed a system for material handling using a pick-and-place robot. The system consists of a robot arm that can be controlled using a computer interface, which allows the user to specify the desired pick-and-place operations. The system also includes a conveyor belt that feeds materials to the robot, and sensors that detect the presence and position of the materials. The authors demonstrated the effectiveness of their system through experiments, which showed that it could accurately and efficiently handle materials of different shapes and sizes. The proposed system has potential applications in manufacturing and warehouse automation.

3. USE CASES FOR THE PROJECT AND COMPONENT IDENTIFICATION

3.1. ARCHIVING FUNCTIONALITY OF THE PROPOSED PROJECT

The proposed project manages use of thoughts learnt in different papers that includes building a robot which includes utilisation of Computer Vision for detecting the vacuum tubes and to decide which destination rack to place it in. In general, elements of the robot have been made strong and fast, the robot is made of aluminium, fulfillingthe necessity of strength and speed ready to play out the archiving process with ideal proficiency.

The vacuum tube archiving robot model comprises of the following :

- 3 Linear actuators (1 lead screw, 2 belt drives)
- 4 NEMA-17 stepper motors
- 2 Servo motors
- Arduino Mega
- CNC Shield
- 4 DRV8825 stepper motor driver
- 3 Mechanical limit switches
- End effector with a precise gripper
- Power supply (24V)
- Camera (Amazon Basics)
- Barcode Scanner
- Aluminium Framework

3.2. USE CASE STEPS FOR PICK AND PLACE

As referenced already, the entire task depends on:

Software: Image processing and Machine Learning
Hardware: Motors and Actuators

Stage 0: This stage involves homing of each axis (x,y,z) to the base coordinate (0,0,0) which is identified with the help of mechanical limit switches attached to the framework. The actuators move in one specified direction until it hits the limit switch which is then described as the base coordinate. From here, the coordinate system for the whole workspace is defined, taking the base coordinate as the reference.

Stage 1: The camera captures a real time image of two source racks at a time. This image is analysed to produce a matrix with information on the vacuum tubes' presence. Beginning with the vacuum tube location, the actuators use this matrix as aninput to start the cycle, which saves time by not having to walk through every slot in the rack. This data is transformed into the coordinate frame using forward kinematics and the actuators move accordingly to pick up the vacuum tube for the next step of thecycle.

Stage 2: Once the vacuum tube is picked, the barcode scanner attached to the framework scans the barcode present on the side of the vacuum tube. The scanned data is integrated with the LIS (Library Information System) provided by the laboratory. This serves as a verification system to record every sample.

Stage 3: Subsequent to picking the vacuum tube, the LIS provides information about the destination rack where the vacuum tube is supposed to be placed and also the slot of that rack. This software records and archives the location, status and medical data of the sample. A new case emerges when the vacuum tube has not gone through all the tests for which there is a designated rack to the vacuum tube.

Stage 4: The vacuum tube is then taken to the rack and slot given by the LIS with the help of the actuators and is placed. The entire cycle is restarted with the next vacuum tube of the source rack.

4. HARDWARE AND SOFTWARE ARCHITECTURE

4.1. BLOCK DIAGRAMS

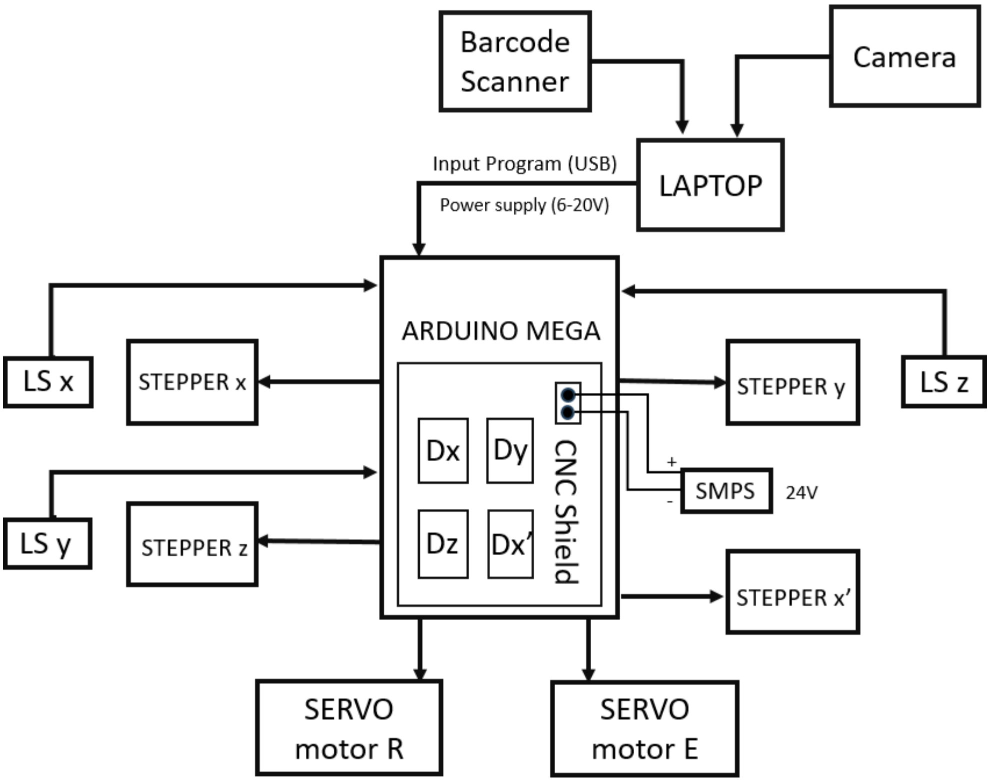

Figure 2 - General Block Diagram

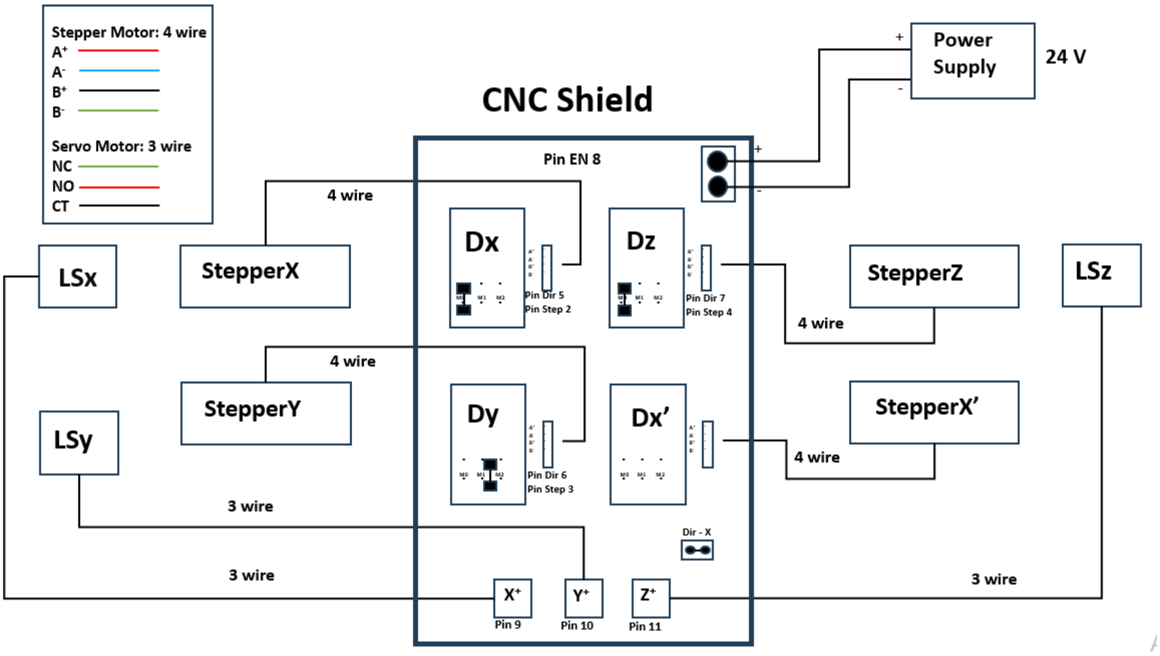

Figure 3 - Detailed Block Diagram

4.2. MECHANICAL STRUCTURE AND OBJECTS

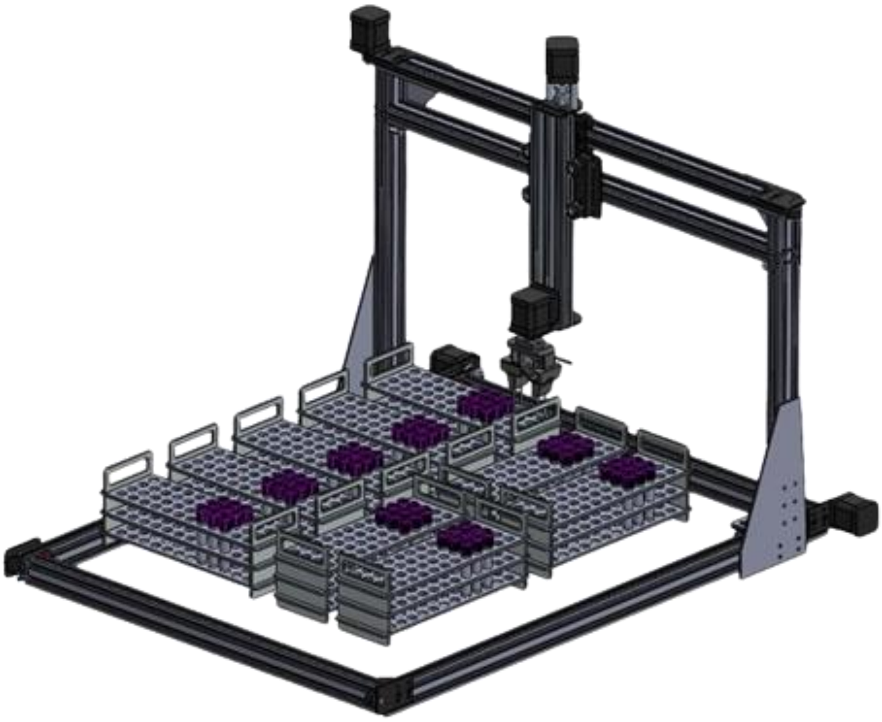

Figure 4 - 3D view

Figure 5 - Rack

Figure 6 - Vacuum Tube

4.2.1. HARDWARE USED

1. Stepper and Servo Motors
2. Arduino Mega
3. CNC Shield
4. Motor Drivers
5. Limit Switches
6. Barcode Scanner
7. AmazonBasics Camera
8. Linear Actuators - Belt Drive & Lead Screw
9. Aluminum Extrusions

4.2.2. SOFTWARE USED

1. Python
2. Python OpenCV
3. Arduino IDE

4.3. EVOLUTION OF END EFFECTOR

To design and fabricate an end effector to be able to pick and place the test tubes during the archiving process while being able to withstand the speed of the Gantry System and avoid disturbing the neighbouring test tubes in the tray.

The end effector stands as a pivotal element within robotic systems, functioning as the tactile interface between the machine and its operational environment. It can also be defined as the final end of any robotic system that interacts with real world objects and needs to be able to conceive and work seamlessly, encompassing functions suchas gripping, manipulating, cutting, or painting.

The end effector's adaptability is key, permitting seamless tool interchangeability for a diverse array of tasks without necessitating extensive structural modifications. Furthermore, its influence resonates in the realm of accuracy, as advanced sensors and control mechanisms enhance the robot's ability to perform tasks with utmost precision.

The end effector was designed in SolidWorks, a few different mechanisms were proposed and improved upon and the finalised end effector was 3D printed using PLA plastic. For the actuator itself, a servo motor was chosen as they have higher angular accuracy. The end effector features four prongs made of stainless steel on the end which grabs onto the test tubes with ease.

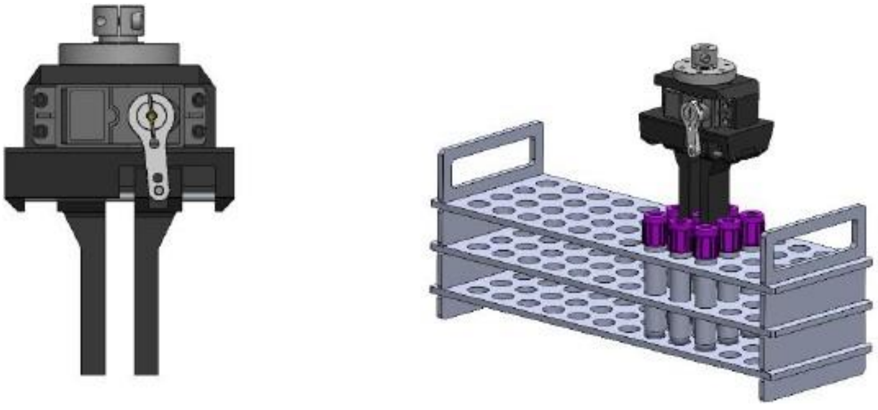

Figure 7 – Initial End Gripper

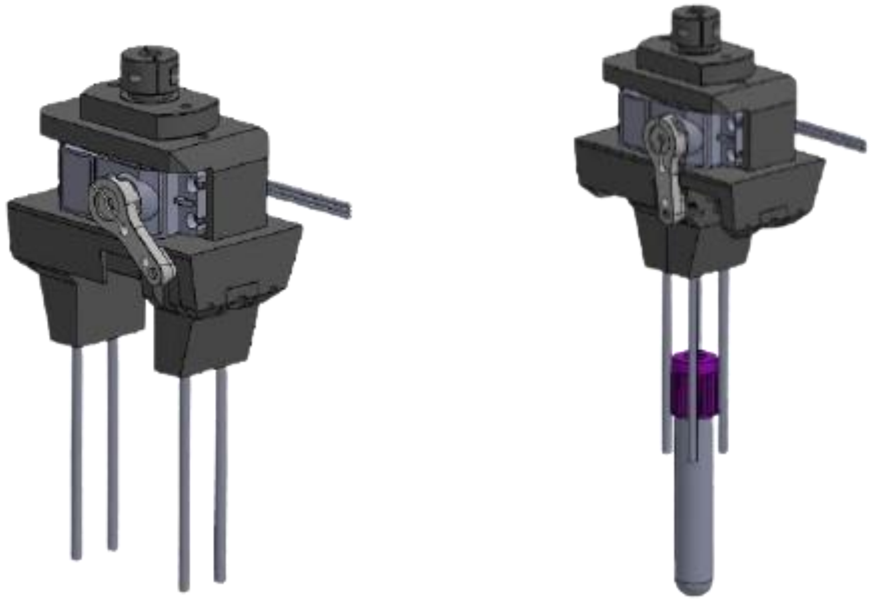

Figure 8 – Final End Gripper

Figure 9 – End Gripper

5. ROBOT FABRICATION EXPENSES

SL NO.	COMPONENTS	QUANTITY	TOTAL COST
1	Aluminium Extrusion	6.5m	2810
2	Angle brackets	30	850
3	Laser cutting	18	3300
4	NEMA 17 Stepper motors	4	5089
5	Servo motors	2	1440
6	Arduino Mega	1	1450
7	CNC Shield	1	150
8	Motor Drivers DRV8825	4	600
9	Limit Switches	3	150
10	Power Supply (SMPS)	1	900
11	Lead Screw	300mm	250
12	Belt	5m	330
13	Aluminium Spacer	3	54
14	Solid V Wheel Kit	20	2300
15	GT2 Idler Pulley	4	500
16	GT2 Pulley 30 teeth	4	620
17	Eccentric Spacer	12	350
18	Anti Vibration Feet	4	150
19	Spiral Wrapping Band	4m	42
20	Cable Carrier	4m	1000
21	AmazonBasics Camera	1	1100
22	Barcode Scanner	1	2890
23	3D Printed Slots	20	3100

24	End Effector	1	1040
25	Nuts	120	1200
26	Screws & Spanner	NA	2004
27	Plywood	600 x 400 mm	550
28	Wires	8m	500
29	Miscellaneous	NA	1000

TOTAL COST - 35,719

Table 1 - Cost Chart

6. SW TOOLS AND HW INFRASTRUCTURE

6.1. SW TOOLS

1. Python

Python is a vigorous and versatile programming language that is likewise exceptionally basic for novices to learn. There aren't numerous intricate ideas to stressover, and its punctuation is clear. Python is also used extensively in machine learning and artificial intelligence, which are becoming increasingly important in robotics.

2. Arduino IDE

The Arduino IDE (Integrated Development Environment) is a platform used to develop software for Arduino boards. It is an open source platform which provides an interface to integrate hardware and software to create efficient and innovative projects.Using Arduino IDE, we can write, edit, compile and even upload code to any Arduino microcontroller board which can be used with every model. The Arduino IDE is a C based language with an integrated version of C++ which uses simple syntax making it user friendly and thus provides a very simplified platform to handle projects and programs.

3. YOLO

YOLO (You Only Look Once) is a real time object detection algorithm that detects and identifies different objects in an image. The YOLOv5x gives us the class probability for the detected objects as it performs as a regression problem. The real time object detection in the YOLOv5x algorithm is based on Convolutional Neural Networks (CNN). Accordingly, the algorithm needs only one propagation through the neural network to detect objects. Thus the prediction of the whole image is finished by just one algorithm. Using this, the CNN is used to simultaneously determine the probabilities and bounding boxes for different classes.

6.2. MICROCONTROLLER, ACTUATORS AND SENSORS

1. Actuators

An actuator is a mechanical or electrical device that is responsible for converting energy into motion. Its purpose is to control or move a system or mechanism, such as a valve or a motor, in response to an input signal. The driven actuators system has various options in the field of linear motion due to the advancements in the Engineering field. Among them, the most used type of drive systems include the conversion of rotary motion to linear motion which uses lead screw and belt drive. The mentioned options play a significant role in the actuator system

1.1 Belt Drive Actuator

The rotation motion is transferred from one shaft to another with the help of a belt drive actuator provided the two shafts are running at the same or variable speed. The construction includes a belt at high tension connected between two or more pulleys. We have made use of a V belt which has a trapezoidal cross section which is used in a grooved pulley. This forms the X and Y axis of our gantry robot.

The following details are required for modelling a kinematics model of a belt linear actuator :

- Linear belt actuator length (L)
- Stepper motor steps per revolution (N)
- Pulley diameter (D)
- Micro-step resolution (μ): (e.g., 1/8, 1/16, 1/32, etc.)

The simple equations to find the displacement per micro-step and steps required to move the actuation per unit displacement respectively are:

$$d\_microstep = (L / (N * \pi * D)) / \mu$$
$$N\_microsteps = D\_desired / d\_microstep$$

1.2 Lead Screw Actuator

The rotation motion is converted into linear motion with the help of a mechanical linear actuator, i.e., lead screw actuator. It has no ball bearing between the nut threads while the working involves the sliding of the screw shaft. These are mostly used in vertical applications as they are found to be efficient in such scenarios. An important property of some lead screw actuators include no braking system as they are capable of self locking. We used this actuator for our Z axis on the gantry robot.

The following details are required for modelling a kinematics model of a lead screw linear actuator :

- Linear lead screw pitch (P) (distance travelled in one complete revolution)
- Linear actuator length (L)
- Stepper motor steps per revolution (N)

The simple equations to find the displacement per micro-step and steps required to move the actuation per unit displacement respectively are :

d_step = P / N
N_steps = D_desired / d_step

2. Stepper Motors

A stepper motor is a type of electric motor that is designed to rotate in precise increments or steps, rather than continuously. Each step corresponds to a fixed angular rotation, and the motor can be controlled to move forward or backward one step at a time.

The NEMA 17 stepper motor is a type of hybrid stepper motor which means it combines features of both permanent magnet and variable reluctance motors. It has two main components: a rotor, which is the rotating part of the motor, and a stator, which is the stationary part of the motor. The rotor of the NEMA 17 stepper motor typically has 50-200 teeth or poles, depending on the specific model. The stator has multiple coils of wire that are energised in sequence to create a rotating magnetic field,which causes the rotor to rotate in precise steps.

For our application of actuation, we are using 4 NEMA 17 motors. Two for the movement of the X axis, one for the movement of the Y axis, one for the movement of the Z axis.

Figure 10 – Stepper Motor

3. Servo Motors

Servo motors are rotary actuators which are capable of accurate angular or linear position and acceleration control in a mechanical system. It has an inbuilt sensor which provides feedback coupled to the motor. In our application, two servo motors are being used. One for the rotation of the end effector and another for the movement of the opening and the closing of the gripper.

The model we are using is OT5320M which has the following specifications:

- Torque = 16.5 kg cm
- Speed = 54 RPM
- Voltage rating = 6V
- Current rating = 2.3A

Figure 11 – Servo Motor

4. Arduino Mega

The Arduino Mega 2560 is based on a ATmega250 microcontroller. It consists of 16 analog inputs, 54 digital pins which can be used for input or output, 4 hardware serial ports (UARTs) and a 16 MHz crystal oscillator, power jack port with a reset button. We felt this was a suitable micro-controller due to its features that meet our requirements.

Figure 12 – Arduino Mega

5. CNC Shield

The CNC shield for Arduino has a compact design best suited for UNO or MEGA boards compatible with arduino. It features a 4-Axis support (X, Y, Z or A which can duplicate X, Y, Z or do a full 4th axis with custom firmware using pins D12 and D13). This CNC shield for arduino is most commonly used as a component in DIY 3D. This shield enables us to connect the arduino to the individual drivers and its functionalities help us control all the actuators. The Shield is placed on the Arduino microcontroller and the drivers are mounted on this shield. The motors are also connected through the connector pins provided by the CNC shield.

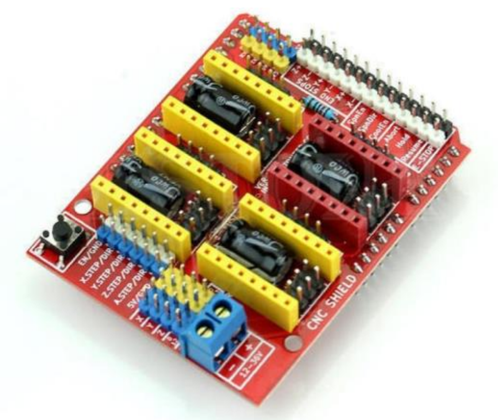

Figure 13 – CNC Shield

6. Motor Drivers

We use the stepper motor driver DRV8825. It can be mounted on the CNC Shield. It is a microstepping stepper motor driver that can control bipolar stepper motors. It supports up to 1/32 microstepping, allowing for smoother motion and finer control of the stepper motor. It allows you to set the motor current by adjusting a potentiometer on the driver board. This helps in optimising the motor performance and avoiding overheating.

It includes overcurrent and overtemperature protection to prevent damage to the motor and driver under certain conditions.The driver receives step and direction signals from a microcontroller or other control source to determine the motor movement. It is designed for use with bipolar stepper motors, which have two coils. These motors are commonly found in various applications like 3D printers, CNC machines, and robotics. It can operate in a voltage range suitable for the connected stepper motor.

The specifications are:

- Voltage setting = 0.6V
- Current setting = 1.2A
- Microstep Resolutions = full, 1/2, 1/4, 1/8, 1/16, and 1/32

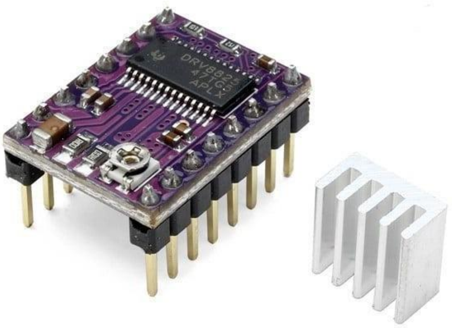

Figure 14 – DRV 8825 Driver

7. Limit Switches

Mechanical limit switch is a device that detects the physical position of an object. It typically consists of an actuator and contacts that open or close when the object reaches a specific point, triggering an electrical signal. A micro switch consists of dualswitches which operate together by sharing a common terminal. Among them, one of the switches is normally closed while the other is normally opened. This switch configuration is called Single Pole Double Throw (SPDT). The following working diagram shows a dotted line which represents that both the switches are mechanically connected. Hence, they operate at the same time.

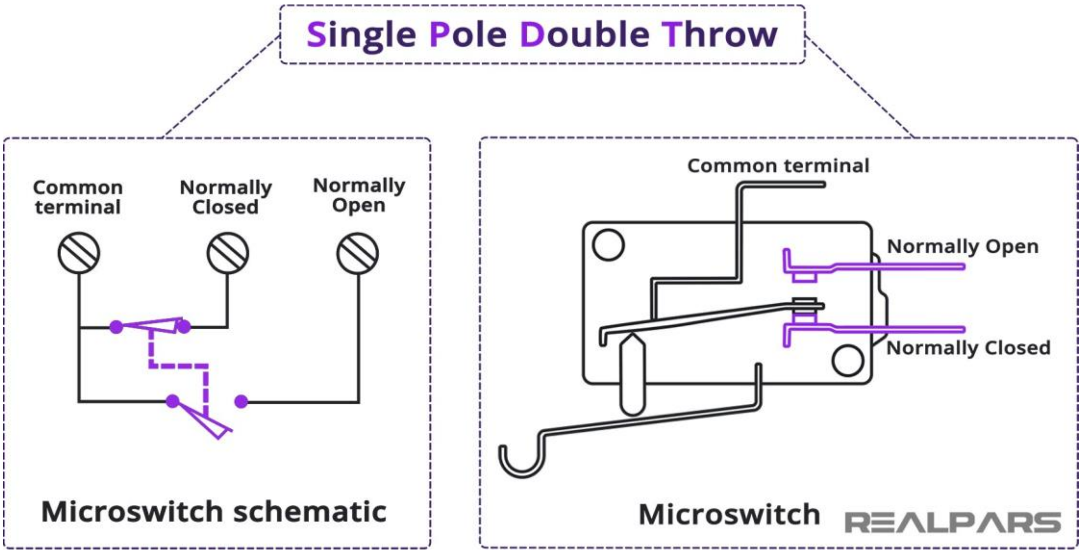

Figure 15 – Inside a Limit Switch

Figure 16 – Mechanical Limit Switch

8. Camera

A digital camera is a device that captures photographs in digital memory. Using a USB protocol, this photo is transferred to our system where it can be processed. It is mounted on the framework where it can be moved which allows us to take a clear image of the source racks. We tried this operation with various models but we found the best suitable model as the AmazonBasics camera.

Figure 17 – AmazonBasics Camera

9. Barcode Scanner Module

A barcode scanner module is an ocular scanner which is capable of reading barcodes which are printed on objects. The scanned data is transferred to a computer. It consists of a light source, a lens and a light sensor which converts optical impulses to electrical signals. We are using this as it has a lot of programmable features which are suitable for our application. This is mounted on the framework as it is easier to scan the picked up vacuum tube.

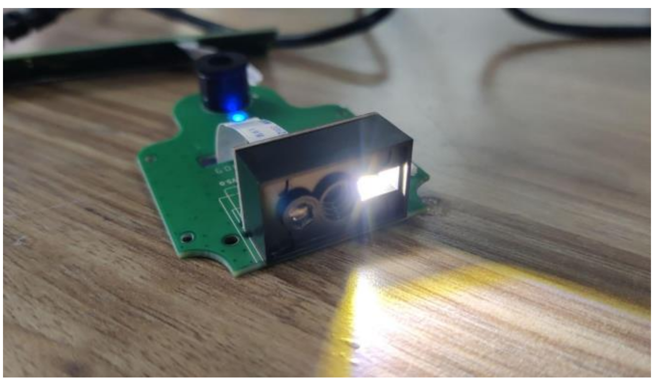

Figure 18 – Barcode Scanner

6.3. DESIGN PARAMETERS FOR AXES

To model a kinematics model and control system to control the Gantry System, to ensure seamless operation and synchronisation.

The kinematics model of a system describes the relationship between the inputs, the resulting position and orientation of the system's end effector or tool. It enables the prediction and calculation of the system's position, velocity, and acceleration based on the actuator inputs. This model is crucial for controlling and programming the gantry system's motion to achieve desired trajectories, positions, and orientations. The kinematics model of a system enables tasks such as trajectory planning, path generation, collision avoidance, and real-time control. It plays a crucial role in robotics, automation, and CNC machining applications where precise positioning and motion control are essential.

The Gantry System, just like any mechanical automated systems, needs a mathematical model that tells the system how much each actuator has to be actuated toreach the desired position. This ensures precise operation given the size of the object to be picked and placed. This helps in motion planning and control of the gantry robot’s movement, as the payload, the vacuum tubes, are to be handled with care as they contain biological masses and need to be transported carefully throughout the archiving process without breaking the vacuum tube or spilling the contents of the vacuum tube. The model also affects the runtime of the operation in-turn affecting the whole workflow of the lab.

X axis

- Diameter of the pulley = 12.8mm
- Circumference of the pulley = πd = 40.212mm
- Number of pulses for one rotation for NEMA 17 = 200 pulses/rotation
- Microstep Mode = ½
- Distance moved per pulse = 40.212/400 = 0.1005 mm/pulse
- Steps per second = 2000
- Distance moved in one rotation = 60mm
- RPM of X axis = 300

Y axis

- Diameter of the pulley = 10.3mm
- Circumference of the pulley = πd = 32.358mm
- Number of pulses for one rotation in NEMA 17 = 200 pulses/rotation
- Microstep Mode = ¼
- Distance moved per pulse = 32.358/800 = 0.0404mm/pulse
- Distance moved in one rotation = 60 mm
- RPM of Y axis = 150

Z axis

- Diameter of the lead screw = 8mm
- Pitch of the lead screw = 2mm
- Steps per second = 8000
- Number of steps for one rotation = 400
- RPM of the Z axis = 1200

7. DATASET GENERATION

The dataset generation process involves capturing a real time object using a camera. In our application, the objects are EDTA Vacuum Tubes placed in the test tube racks. The first step involved annotating the images by drawing bounding boxes around the tube caps. The annotated images were converted to a Class depending on the presence of the vacuum tubes using the RoboFlow software. This software is specifically used for annotating as well as augmenting the image dataset.

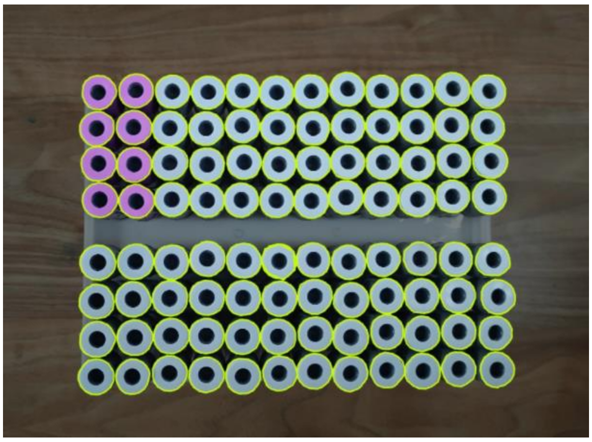

Figure 19 - Annotation by drawing bounding boxes

The second step involves the images being split into train, test and validation dataset in the RoboFlow software. About 120 images were sent for the training model. The resizing of the images and auto orientation was performed in the preprocessing method. Thus, the output image is resized to 400 x 400 pixels because the maximum size YOLOv5x can take up is 640 x 640 pixels.

Figure 20 - Preprocessing

Data Augmentation is a method where it applies different types of parameters on the image to increase the dataset for better processing. Such parameters are:

Rotation: Between -15° and +15°

Shear: ±7° Horizontal, ±3° Vertical

Grayscale: Apply to 9% of images

Brightness: Between -21% and +21%

Figure 21 - Augmentation

8. OBJECT DETECTION

The detection of the test tubes and localization of the captured image is done in YOLOv5x by using PyTorch. The YOLOv5x uses neural networks for the object identification process. It is specifically well known for its characteristics such as high accuracy, speed and training techniques. It makes the algorithm run faster as it is a one stage object detector. AS mentioned earlier, YOLO employs Convolution Neural Networks (CNN) which consists of 24 convolution layers and 2 fully connected layers that form the detection layer. It uses one neural network to process the whole image which later separates the processed image into small areas, further calculates the probabilities and the bounding boxes. The probability result depicts the weights of detected bounding boxes.

8.1. ONE STAGE OBJECT DETECTORS

The one stage object detectors deal with object detection as a regression problem. The output of this network includes the probability of classes and the coordinates of the bounding box from the captured image. This typical model omits the region proposal stage which is commonly referred as the region proposal network. This is found in the two stage object Detectors where these regions are marked as the region that contains the objects.

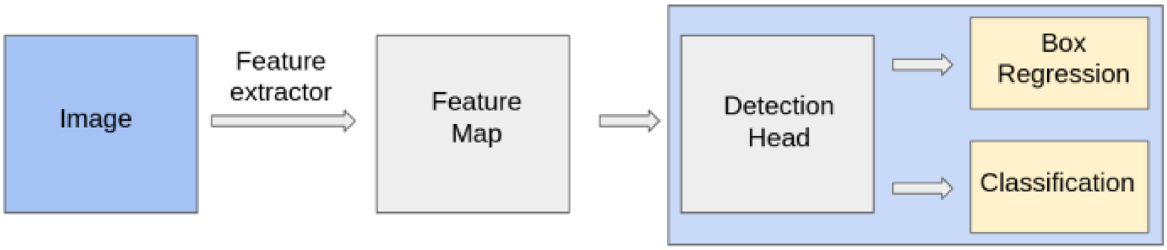

Figure 22 - One stage object detectors

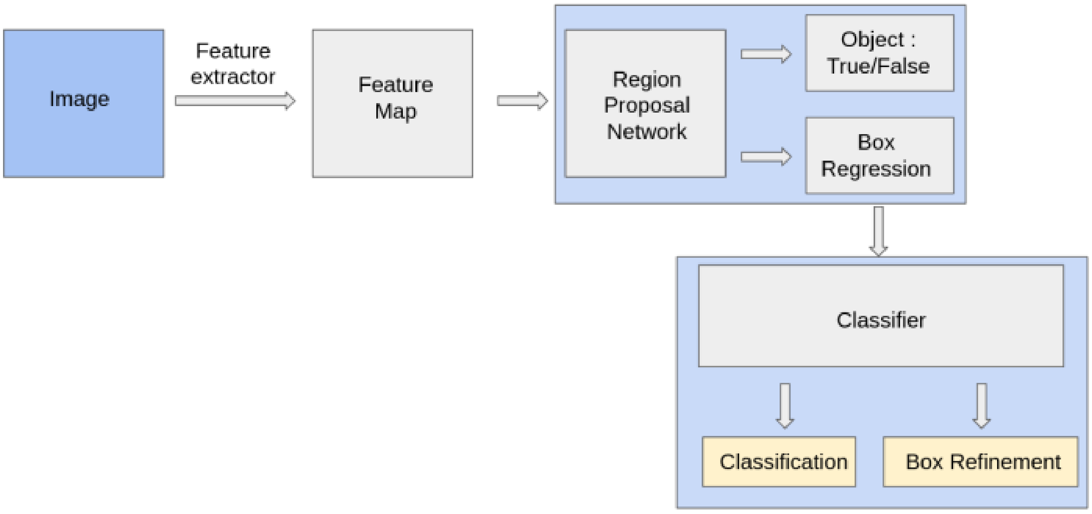

Figure 23 - Two stage object detector

8.2. WORKING OF YOLO

YOLO makes use of 3 main steps for object detection.

1) Residual Blocks
2) Bounding box regression or Non-Maximal Suppression (NMS)
3) Intersection of union

8.2.1. RESIDUAL BLOCKS

The real time captured image is fed as the input. The image is split into multiple boxes of equal dimensions. The detected grid cells contain objects present inside each grid cell.

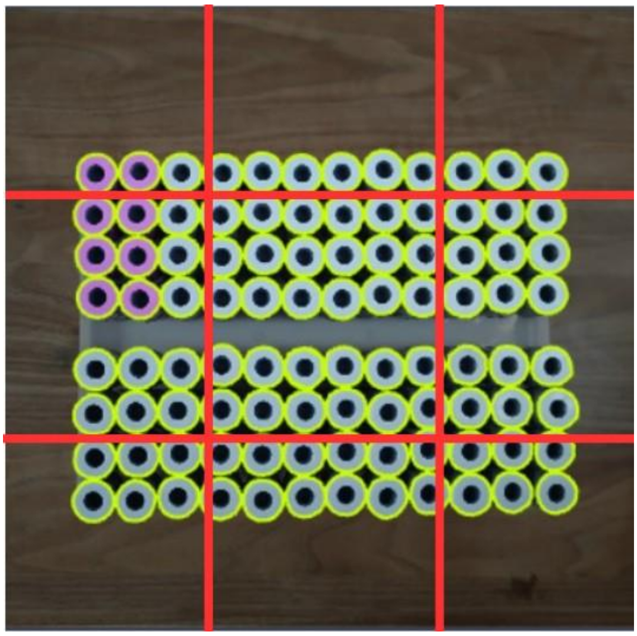

Figure 24 – Residual Blocks

8.2.2. BOUNDING BOX REGRESSION or NON-MAXIMAL SUPPRESSION (NMS)

Bounding boxes are drawn around the detected objects in the input image. The bounding boxes are characterised by different attributes such as height(bh), width(bw), class(c), probability of the object being in the box (pc) and x(bx), y(by) which forms the bounding box centre coordinates. YOLOv5x makes use of the regression technique on the bounded boxes to determine the values y=(pc,bx,by,bh,bw,c). It works on one condition, i.e if the probability value pc is less than the threshold, the bounding box is removed by the YOLO.

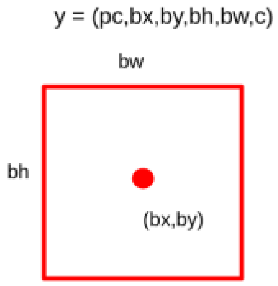

Figure 25 – Bounding Box

8.2.3. INTERSECTION OF UNION

Preceding the bounding box selection, YOLO uses IOU to draw an output bounding box which appears across the object. Each cell displays the bounding boxes and their confidence scores. The initial bounding boxes remain the same while the IOU turns one if predicted. The Intersection of Union discards the bounding boxes which are not of the same size as that of the actual box.

8.3. YOLO MODELS

Prominent improvements are seen through models ranging from v1 to v7. YOLO v1 is characterised for its object detection, confidence loss and division of grids. YOLO v2 model is employed with K-means, Two stage training model and a fully conventional network. YOLO v3 consists of multiscale detection integrated with Feature Pyramid Networks. MISH, a self-regulated non-monotonic activation function which performed better than Leaky ReLU, Spatial Pyramid Pooling, Generalised Intersectionover Union (GIOU) loss function as well as data enhancement Mosaic/Mixup was available in YOLO v4. We can enable flexible control of model size, application of Hardwish activation function, and data enhancement. The latest models of the YOLO family are the v6 and v7 which proved to be more precise and faster compared to the previous versions.

8.4. YOLOV5 MODEL VERSIONS

The YOLOv5 generates a range of pre-trained models. The comparison of the various YOLO models is a tradeoff between the times inferred to their model size. YOLO v5n is chosen to be the lightest version because of its small size of 4MB but has proven to be not very accurate. Compared to YOLOv5n, YOLOv5x is the most accurate of its family but with a large size of 168 MB.

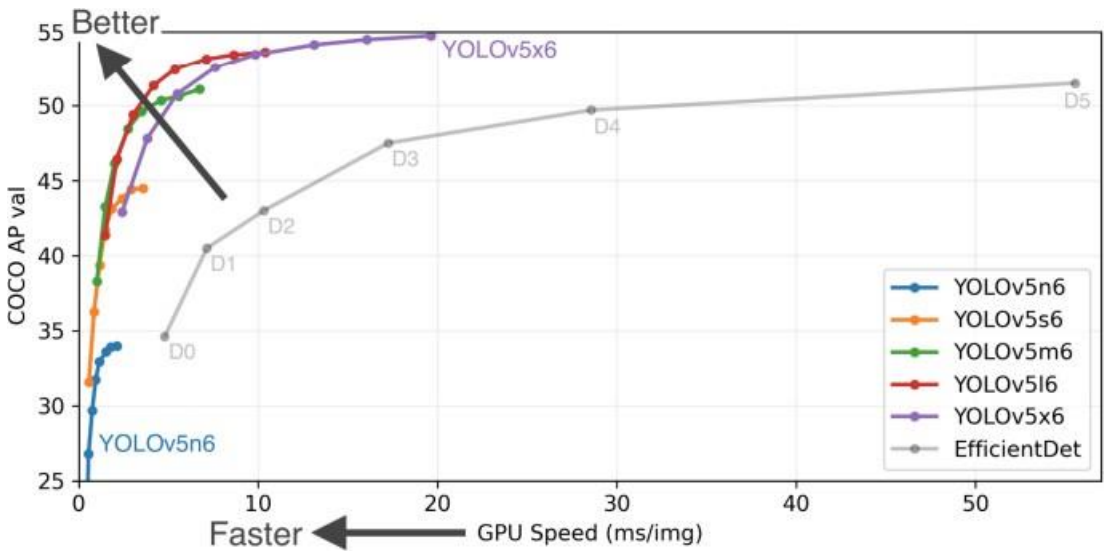

Figure 26 - Performance Comparison

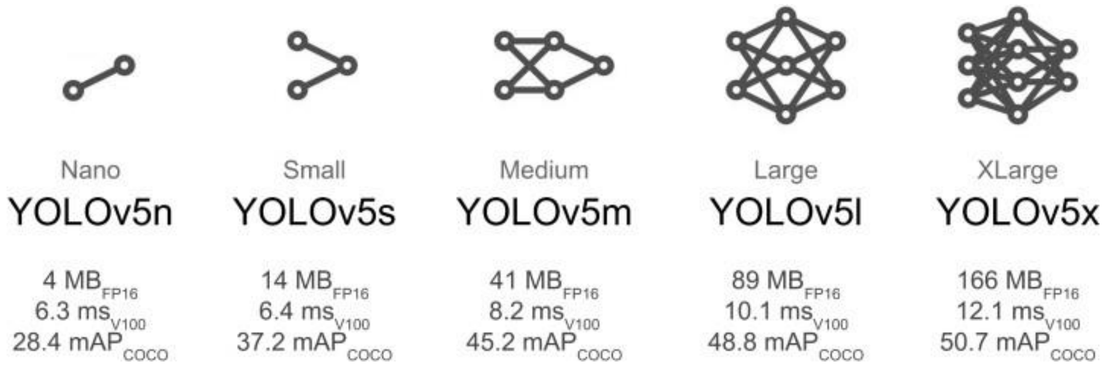

Figure 27 - YOLO Model Comparison

8.5. REAL TIME DETECTION OF VACUUM TUBES

The YOLOv5x model is used to help the process of disassembly by the vacuum tube detection as YOLOv5x is proved to be the most accurate versions of its family. This is 36 implemented by feeding a dataset which consists of about 120 images in various positions and parameters like lighting conditions. The input image size of 400x400 and 18 training batch size were used in detecting the tubes for 195 epochs. Following results were obtained for 195 epochs after being trained by the YOLOv5x model.

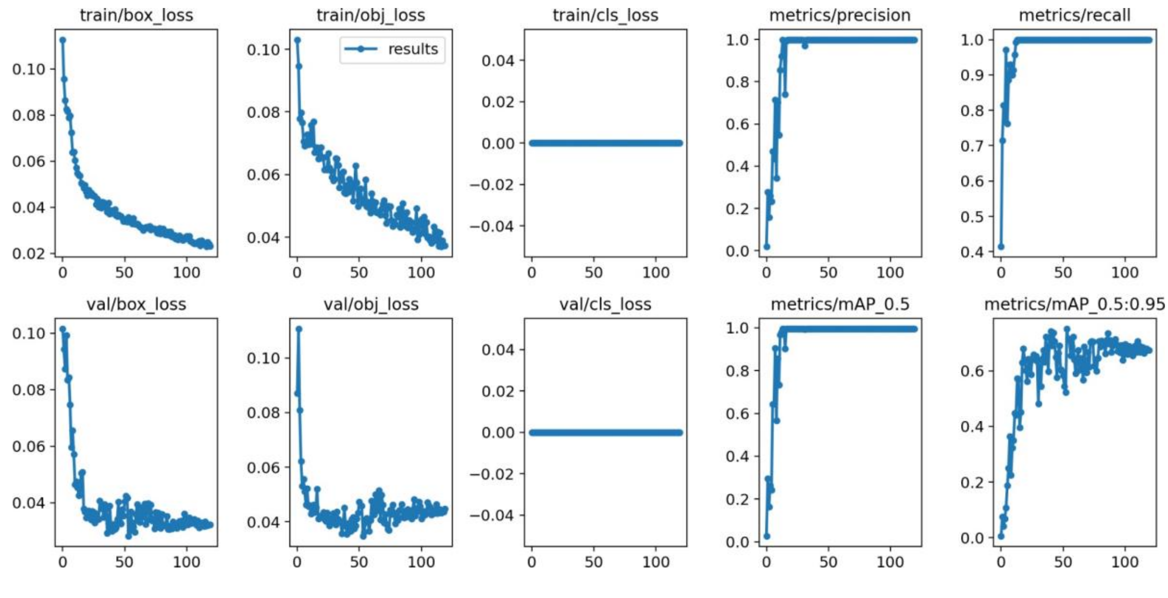

Figure 28 - Results obtained after training the YOLO v5x model for 195 epochs

The tube head is detected by using input image from the camera after being passed by the trained weights through torch.hub.load().

Figure 29 - Real time detection of tubes

8.6. GENERATION OF MATRIX USING PYTHON CODE

By providing pixel coordinates of the first slot, i.e., origin, we can approximately determine the positions of successive slots using slot interval distance also provided. By checking for centroids at these positions, a binary matrix is formed using 1 as a presence flag. Due to the video being dynamic, there are a few errors which are compensated for using carefully computed offset thresholds.

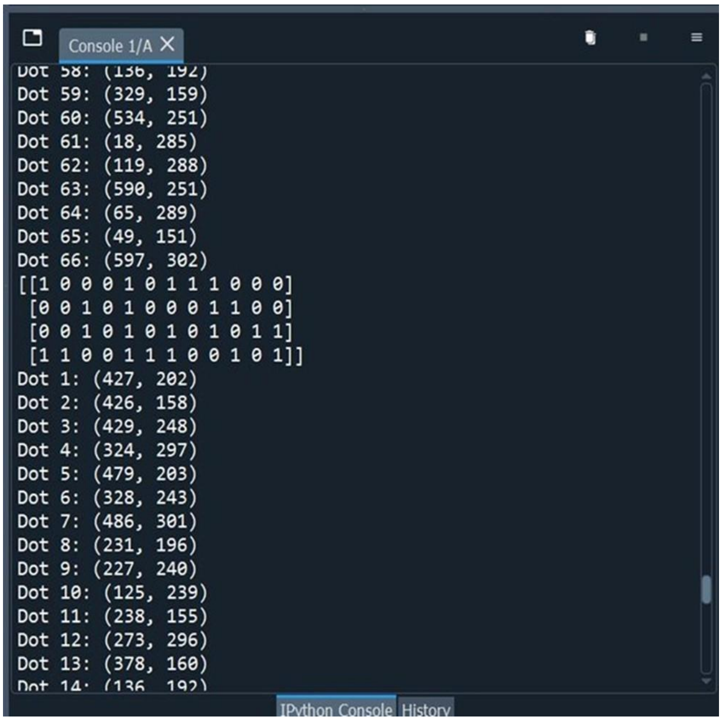

Figure 30 – Matrix Generated

9. SOFTWARE FLOWCHART

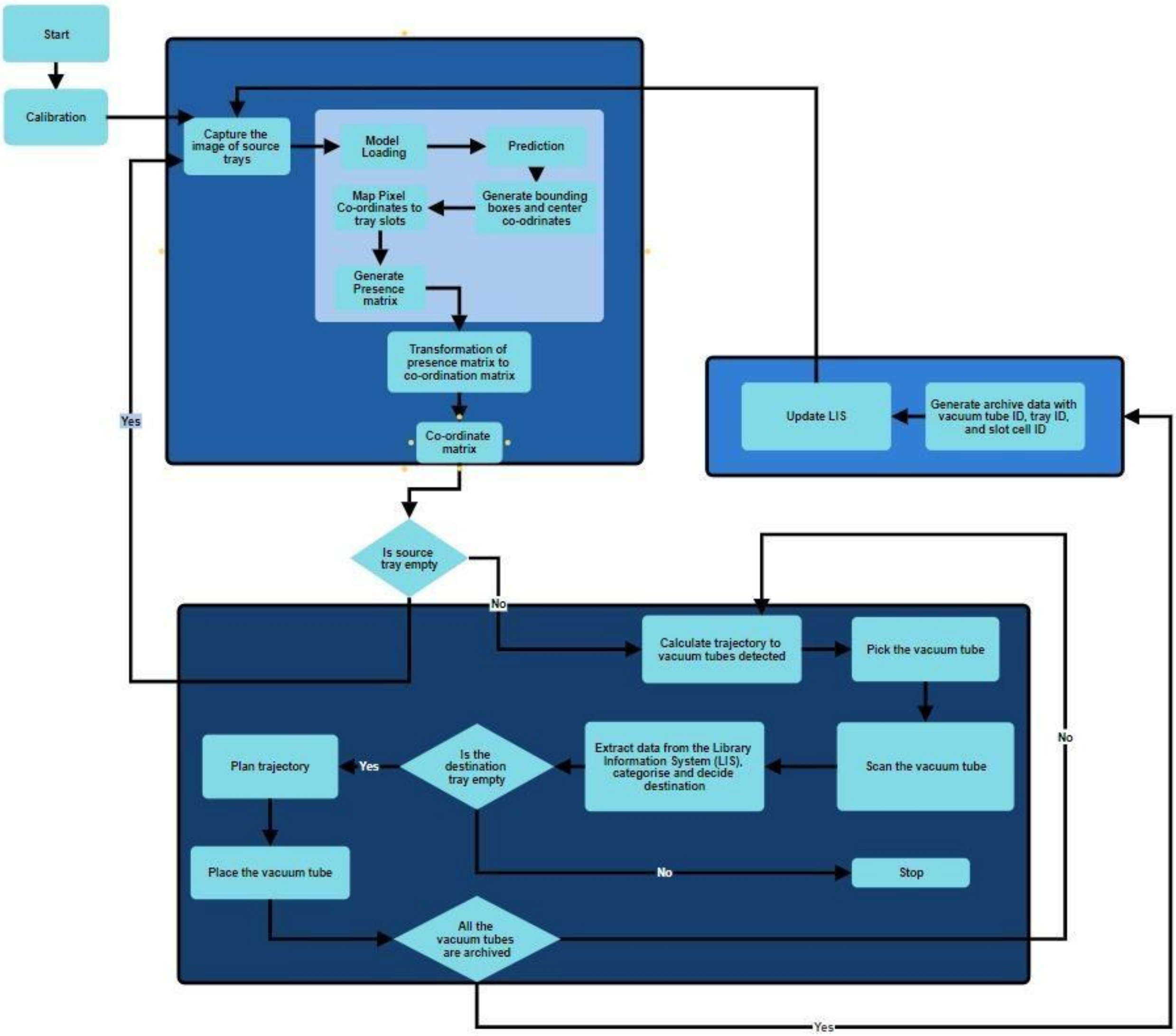

Figure 31 - Software Block diagram

10. RESULTS

10.1. GANTRY

An aluminium structure was used to create a gantry robot. For the movement, we used microcontrollers and actuators. By integrating kinematics and image processing, we developed a fully working gantry robot.

Figure 32 - Side view

Figure 33 - End Gripper

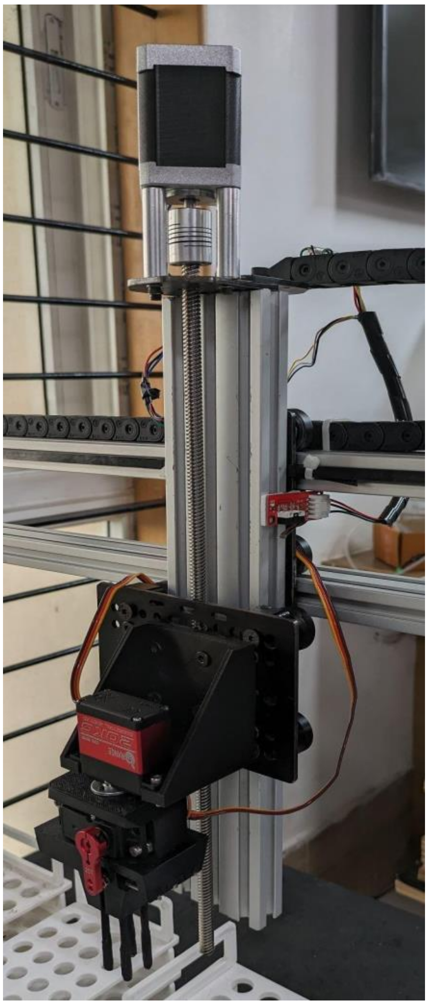

Figure 33 - Z axis

10.2. RECORDINGS

We have recorded the time required for the entire cycle and the table below shows the average time for each step:

	Start picking	Scanning	Placing	To initial position	Total
Src 1 to Dest 5	6.009999	2.40002	8.99999	8.774687	26.184696
Src 1 to Dest 4	6.209999	2.19999	5.20001	5.160713	18.770712
Src 1 to Dest 3	6.909999	2.89999	4.82002	4.73004	19.360049
Src 1 to Dest 2	6.619999	2.60001	5.73013	5.11014	20.060279
Src 1 to Dest 1	6.811111	2.40003	5.82007	5.62045	20.651661
Average (sec)	6.512221	2.500008	6.114044	5.879206	**21.0054794**

Table 2 - Cycle time recordings

In order to verify the precision of the test tube selection, we have additionally logged experiments:

Total no. of tubes	48	48	48	48
Picked	27	25	30	24
Missed	21	23	18	24

Table 3 - Trials

10.3. CONSTRAINTS OBSERVED

Some of the requirements that we faced while we carried out our project were:

- Object recognition under various lighting conditions and camera angles
- Deferral of the robot
- Spatial accuracy of the end effector
- Detection of the empty slots in the destination rack
- Maintaining a consistent power supply to all the actuators simultaneously
- Preserve the cycle time for pick and place operations consistently

11. CONCLUSION

In conclusion, the pick and place gantry robot used for archiving lab samples in a diagnostic lab is a highly versatile and efficient solution to develop an automated action, reducing the human workload. It offers numerous advantages in terms of accuracy, precision, efficiency, and safety. The use of computer vision significantly helps in identifying the location of the test tubes. Thus, increasing the overall speed and accuracy of the process. Additionally, the system can be feasibly scaled up for handling larger volumes of samples, with the potential to greatly improve the efficiency and throughput of the archiving process.

We have designed a gantry robot using Solid works and assembled the gantry primarily using aluminium extrusions. Also, an end effector was designed and 3D printed for gripping the vacuum tubes for pick and place application. We used YOLO for detecting tubes and NumPy to generate the matrix of the rack. In future, the incorporation of AI and machine learning algorithms will empower gantry robots to adapt to dynamic environments, optimise processes, and learn from experience.

Successful implementation of such a system requires careful consideration of factors such as camera placement, lighting conditions and image processing algorithms. However, the use of machine learning technology integration with the gantry system represents a highly promising solution for automating the archiving of lab samples, with the potential to greatly improve the accuracy of laboratory operations.

12. FUTURE SCOPE

- The system can be upgraded to perform various other functions in the laboratory such as segregation.
- Implementing a dynamic control for pick and place application.

13. REFERENCES

[1.] M. Karthi, V. Muthulakshmi, R. Priscilla, P. Praveen and K. Vanisri, "Evolution of YOLO-V5 Algorithm for Object Detection: Automated Detection of Library Books and Performance validation of Dataset," 2021 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES), Chennai, India, 2021, pp. 1-6, doi: 10.1109/ICSES52305.2021.9633834.

[2.] Song, Q.; Li, S.; Bai, Q.; Yang, J.; Zhang, X.; Li, Z.; Duan, Z. Object Detection Method for Grasping Robot Based on Improved YOLOv5. Micro Machines 2021, 12, 1273.

[3.] J. Černohorský and D. Lindr, "Laboratory gantry robot design and control," Proceedings of the 13th International Carpathian Control Conference (ICCC), High Tatras, Slovakia, 2012, pp. 86-90, doi: 10.1109/CarpathianCC.2012.6228621.

[4.] M. M. Rahman, S. Chakma, D. M. Raza, S. Akter and A. Sattar, "Real-Time Object Detection using Machine Learning," 2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT), Kharagpur, India, 2021, pp. 1-5

[5.] P. Andhare and S. Rawat, "Pick and place industrial robot controller with computer vision," 2016 International Conference on Computing Communication Control and automation (ICCUBEA), Pune, India, 2016, pp. 1-4, doi: 10.1109/ICCUBEA.2016.7860048.

[6.] C. M. Raj, W. Rajanbabu, T. M, R. M, Manjuladevi. and H. S, "Material Handling Using Pick and Place Robot," 2022 8th International Conference on Smart Structures and Systems (ICSSS), Chennai, India, 2022, pp. 1-6, doi: 10.1109/ICSSS54381.2022.9782275.

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