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Warehouse Handling utilizing Cartesian Robots

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Abstract—

There are numerous challenging parts in the production or manufacturing sector which needs attention and one of them is the maintenance of the inventory. The inventory can also be labeled as warehouses in certain sectors. The final products of the industry must be transported to fulfill the ultimate purpose of their own creation. Their main objective is obviously to be of use to the consumers. The segment between production and transportation is the handling of the final products in the warehouse. One of the principal problems faced during warehouse handling is the high labor cost and the dependence on the manual workforce for the lifting and positioning of the products in the appropriate spots. Basically, the heavy labor consumes a huge labor force thereby requesting the allocation of immense capital for this particular job. The formulated research work ensures the minimization of the fund allocation for heavy labor works in warehouse maintenance. The sensors are used to assist the precise and accurate maneuverability of the robot to deliver products to target locations. The current work motive is to design a manageable and convenient Warehouse Handling System. The criteria are fulfilled by incorporating a Cartesian robotic system in the design to aid in the flawless and easy positioning of the stocks in the warehouse thereby accomplishing the desired task.

Keywords— warehouse, inventory, cartesian robots, kinematics, sensors, stocks, open-source computer vision, path planning, end effector, electro-pneumatic system, computer aided design

I. Introduction

Warehouse handling is considered as a vital process in the manufacturing sector with no room for any doubts. The maintenance of the inventory is often mentioned as laborious. The process includes stocking of products and loading them to allow transportation of the goods [1]. Huge constructions are required to store the goods in a sorted way which enhances the uncomplicated way of stock handling. This task ultimately recommends an immense workforce to facilitate maneuverability of the stocks and to dock the necessary commodities in the heavy automobiles to advance to the next step of supplying them to the demanding customers [2]. The handling of the warehouse through the fabricated system boosts the profitability of the industrial or other related sectors. This is because the warehouse is an essential part of the logistics department of the industrial field and the supply chain [19]. Therefore, automating the maintenance of it can upgrade the manufacturing and delivery time and also totally cut off the non-profitable additional investments in the warehouse handling thereby raising the profits [3]. To tackle the necessary needs of the upgrading industrial environments and demands the engineering sector dealing with automation should take everything into consideration when it comes to automating the crucial sector of the stock handling in the inventory or warehouses [4].

In the automation process of any system, the use of sensor type becomes indispensable to identify and sort the stocks in a well distributed way to avoid complexity and ensure effective and efficient handling of the warehouse. Therefore, the cameras are to be employed to provide the system with the ability to distinguish the variations among the manufactured products and carry out the desirable task for each variation. The variation taken into account by the designed system as discussed in [5] is the color variation. The system perception is accelerated to target the distinguished objects (stocks with particular color codes) and perform tasks specified for the particular color variety of stocks by Open-source Computer Vision (Open CV). It's indispensable for the robotic system to possess real-time detection of color to identify and differentiate the divergence in the stocks. The fundamental colour variations that can be identified by the system are Red, Green and Blue (RGB). The computer vision fundamentality can be utilized for tracking these colours rather easily [9].

The objective of the current work is to design an intelligent warehouse handling system. The concept of Open CV is a crucial aspect to fulfill the automation part which limits the human intervention thereby avoiding the involvement of a massive workforce and reducing unnecessary additional investments. The differentiation algorithm is made possible through the Python code and the Open CV library is included to access the camera and determine the color discrepancies. It uses the Hue Saturation Value (HSV) colour space to identify the colours as perceived by the eyes of the humans. The advancements can be made with the use of Radio Frequency Identification (RFID) tags to boost accuracy. The position of the gripper can be calculated with the help of Computer vision technology. Python uses its multi-thread functionality to capture images from video streaming alongside the centroid of the packages to enable comfortable material handling free of errors. The WIFI connectivity module is employed to access robot control by addition of NodeMCU 8266 - 12E. A mobile application is created using MIT App Inventor to interface a control device with the handling system. With the use of block editor of the App inventor, the creation of user interface was achieved by consolidating the necessary logics. The NodeMCU 8266 - 12E directs the stepper motor at the joints to locomote the gripper toward the package which is meant to be picked. The design of the warehouse handling system accommodates the Cartesian robotic system. With the help of Computer Aided Design (CAD) software, the system's computer-aided design is drawn to express the better idea of the robotic system.

The Cartesian robot in the system which performs the maneuverability process which is also the pivotal job of the fabricated arrangement is static for each part of the aisle in the warehouse but the implementation of automated guided vehicles can further bolster the profits. The workspace of the robotic system is fixed and all maneuvers are focused within the space of the robot and the robot has three Degree of Freedom (DOF). The incorporation of Cartesian manipulator is justified because of its simplicity, easy predictability, reachability and collision free maneuverability [8]. The paths of the Three Prismatic (3P) manipulator are calculated with the aid of MATLAB software. The path to each target is precisely formulated so that the shortest route to the determined target point can be selected to reduce the inessential consumption of time. The path of the robot from a position to the target location is traced using path planning. The path planning of the labeled manipulator is carried out by usage of Kinematics to determine the posture of the end-effector. The utilization of Kinematic modelling is to develop a bridge between joint parameters of the manipulator and the position of the end-effector [11]. The Denavit–Hartenberg (DH) modelling was carried out for the 3P manipulator. The Kinematics of the manipulator is obtained by using the joint angles, lengths of links, twist angles and link offsets [18]. After finding these parameters the trajectory of the path can be made sure [7]. Additionally, MATLAB codes are employed to derive the desired dynamics of the robotic manipulator.

The designed automated system owns a separate mechanism for loading and unloading the stocks. The mechanism utilizes the Electro-pneumatic system for performing the loading and unloading tasks. Grippers are essential to every robotic system as they are the key components to bring off the operation of holding the stocks to the designated target location. The gripper used in the proposed system is Vacuum gripper which is mainly used in production sectors of industrial field as it possesses energy efficiency. As the end-effector of the Robotic system is a suction-type gripper its main purpose is gripping of light load articles [17]. And this system is installed in the end effector to facilitate the fetching actions. Many studies reveal that pneumatic systems hold tremendous advantages over other actuation systems. Moreover, electro-pneumatic systems which involve both pneumatic and electrical aspects are best suited for automated works [6]. Taking into account the warehouse handling system, the need for control of the system is mandatory in order to execute flawless and organized movements to achieve the desired objective. This is where the Electro-pneumatic system comes into play to fill the gap by aiding in the control of the robotic end-effector arrangement [6]. The logic to control the end effector arrangement was designed in an uncomplicated way and the switching mechanism of the electro-pneumatic system utilizes Direct Current (DC) voltage (an electrical power source) of an appropriate level and the pneumatic system carries out the gripping action. The rest of the sections are organized as follows. Section II presents modelling of 3P manipulator and section III comprises of methodology. Section IV completes the paper.

II. MODELLING

A. Kinematic Modelling of 3P manipulator

The Kinematic modelling has the main purpose of developing a connection between manipulator joint parameters and end-effector position. Both joint variables and end-effector position are essential in determining the posture and end-effector orientation in the workspace which is the warehouse here. These parameters help in deriving the trajectory of the path of the manipuator.

B. DH modeling of a 3P manipulator

The warehouse handling system which targets picking and placing. Modelled 3-DOF gantry with dimensions 120cm x 80cm. The gantry system consists of three stepper motors that control Cartesian movements using ball screw and pulley mechanism. Each ball screw and stepper motor assembly are considered as one prismatic joint, as there are three such assemblies so the manipulator is considered as a 3P gantry.

Table 1: DH parameter table

Joints	θ_{n+1}	l_{n+1}	a_{n+1}	α_{n+1}
1	0^o	l_1	0	-90^o
2	-90^o	l_2	0	90^o
3	0^o	l_3	0	0^o

Here in DH modelling we use DH-parameters for the warehouse handling system as indicated in Table1. The frames are represented as shown in Fig.1.

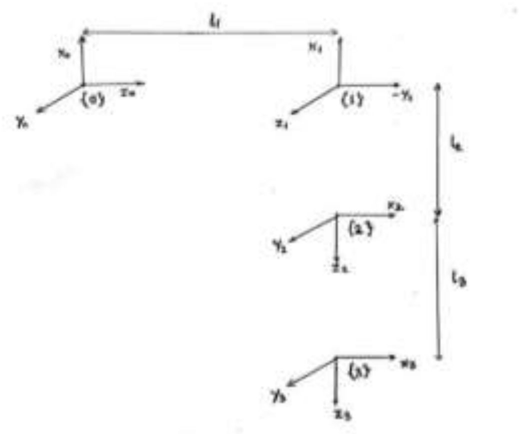

Fig. 1: Frame representation

The matrix of transformation of an end-effector with reference to the base frame obtained from the above DH-parameters is given in equation (1).

$$\begin{bmatrix} 0 & 0 & -1 & -l_3 \\ 0 & 1 & 0 & l_2 \\ 1 & 0 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Jacobian of the gantry system that is used in mapping of the variables of the joints and velocities of an end-effector with respect to the base frame is given in equation (2).

$$J = [J_1 \quad J_2 \quad J_3] = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (2)$$

The correspondence between end-effector and joint velocities are given in equation (3).

$$\begin{bmatrix} V_x \\ V_y \\ V_z \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{l}_1 \\ \dot{l}_2 \\ \dot{l}_3 \end{bmatrix} \quad (3)$$

C. Dynamic modeling of 3P manipulator

Dynamic modeling of a 3P manipulator is used to acquire the required force and torque of the actuators that are pulleys, stepper motors and belts in this case. Lagrangian method is used as in equation (4),

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} m_1 + m_2 + m_3 & 0 & 0 \\ 0 & m_2 + m_3 & 0 \\ 0 & 0 & m_3 \end{bmatrix} \begin{bmatrix} \ddot{l_1} \\ \ddot{l_2} \\ \ddot{l_3} \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ m_3 g \end{bmatrix} \quad (4)$$

l_1, l_2, l_3 are the joint variables and are considered as cubic spline functions equation (5).

$$\begin{aligned} l_1 &= p_{01} + p_{11}t + p_{21}t^2 + p_{31}t^3 \\ l_2 &= p_{02} + p_{12}t + p_{22}t^2 + p_{32}t^3 \\ l_3 &= p_{03} + p_{13}t + p_{23}t^2 + p_{33}t^3 \end{aligned} \quad (5)$$

Every joint has their initial and final velocities as zero. The end-effector can finish the mark from initial position to final position in four seconds. The joint1 and joint2 have a displacement of 376 mm and the joint3 has a displacement of 80 mm. The joint variables are obtained and are provided as equation (6).

$$\begin{aligned} l_1 &= 0.0705t^2 - 0.1175t^3 \\ l_2 &= 0.0705t^2 - 0.1175t^3 \\ l_3 &= 0.015t^2 - 0.0025t^3 \end{aligned} \quad (6)$$

And the joint parameters are revealed with the help of MATLAB software in Fig. 2 and Fig. 3. By determining the masses and specific payload, the forces can be calculated. With the help equation (6) the accelerations can be obtained by double differentiation process. Additionally, by obtaining the force equations for F_1, F_2 and F_3 respectively from equation (4) and substituting the accelerations in the obtained force equations, the forces of joints can be formulated.

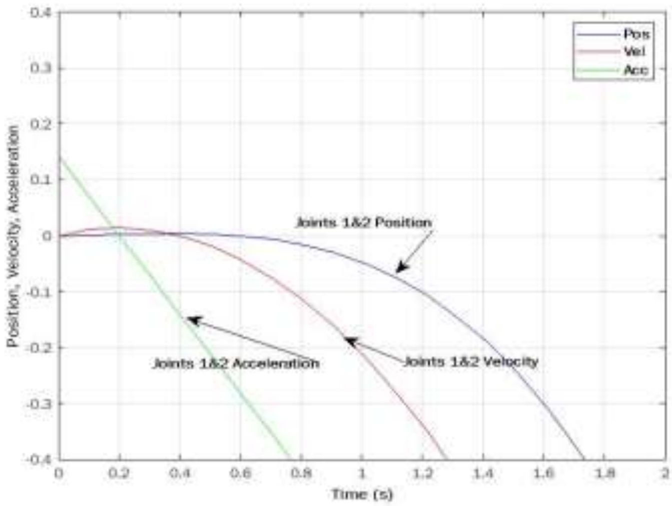

Fig. 2: Joints 1 and 2 parameters

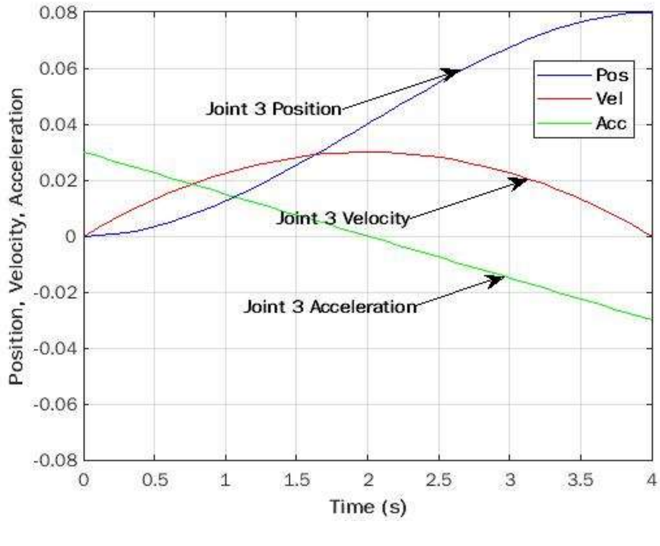

Fig. 3: Joint 3 parameters

D. Structural Analysis of 3P manipulator

The Fig. 4 provides us with the image of the CAD model of the 3P manipulator. Static analysis in Autodesk Fusion360 software was used to simulate the body. The four legs of the frame and sliders are fixed so that the effect at a particular point can be viewed clearly. The force given to the end-effector is 0.96N acting downwards at the joint that connects link 2 and link 3.

Fig 4: CAD of the 3P manipulator

Table 2: Material Properties

Property	Value
Density	7.85E-06 kg/ mm^3
Young's Modulus	210000 MPa
Poisson's Ratio	0.3
Yield Strength	207 MPa
Ultimate Tensile Strength	345 MPa
Thermal Conductivity	0.056 W/ (mm C)
Thermal Expansion Coefficient	1.2E-05/ C
Specific Heat	480 J/ (kg C)

Table 3: Parameters range after simulation

Name	Minimum	Maximum
Safety Factor		
Factor of safety (Per Body)	15	15
Stress		
Von Mises	0 MPa	0.03035 MPa
1st Principal	-0.007174 MPa	0.01929 MPa
3rd Principal	-0.03404 MPa	0.006397 MPa
Normal XX	-0.01097 MPa	0.006397 MPa
Normal YY	-0.01458 MPa	0.007535 MPa
Normal ZZ	-0.03077 MPa	0.01929 MPa
Shear XY	-0.003358 MPa	0.003316 MPa
Shear YZ	-0.004508 MPa	0.01272 MPa
Shear ZX	-0.002228 MPa	0.001365 MPa
Displacement		
Total	0 mm	3.411E-05 mm
X	-1.51E-06 mm	1.315E-06 mm
Y	-3.136E-05 mm	7.352E-07 mm
Z	-1.339E-05 mm	9.509E-06 mm
Reaction Force		
Total	0 N	125.2 N
X	-8.759 N	10.48 N
Y	-33.37 N	125 N
Z	-87.64 N	60.39 N
Strain		
Equivalent	0	1.845E-07
1st Principal	-1.728E-11	1.696E-07
3rd Principal	-2.023E-07	6.1E-11
Normal XX	-1.289E-08	1.56E-08
Normal YY	-5.923E-08	5.476E-08
Normal ZZ	-1.371E-07	8.831E-08
Shear XY	-4.157E-08	4.105E-08
Shear YZ	-5.582E-08	1.575E-07
Shear ZX	-2.758E-08	1.69E-08

Contact Pressure		
Total	0 MPa	0.01037 MPa
X	-0.00154 MPa	0.001318 MPa
Y	-0.001644 MPa	0.005476 MPa
Z	-0.01017 MPa	0.003959 MPa

The Table 2 and Table 3 gives details about properties of materials used taken from static-simulation of Fusion360 and parameter range after simulation respectively.

E. End – Effector Design

The gripper configurations can be altered as per industry requirements. The suction cups which perform the gripper tasks are operated in a controlled manner by using a solenoid-actuated Direction Control Valve (DCV). A type of positive displacement air compressor, the reciprocating compressor is used to generate the compressed air. This compressor possesses enough flexibility, elevated efficiency and is also known for its high-pressure generation. The incorporation of Filter, Regulator and Lubricator (FRL) unit is justified for its filtering, regulating and lubricating properties that are vital in ensuring the safety of the components of the system. The gripper system is displayed in Fig 5.

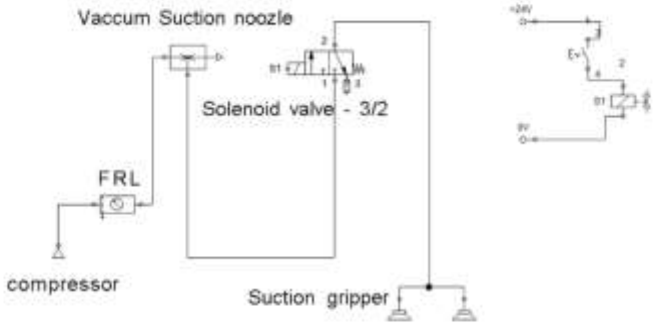

Fig. 5: Designed Electro-pneumatic system

The designed electro-pneumatic system of the end-effector utilizes an electrical circuit to activate the gripper operation directly controlling the flow of the compressed air in the pneumatic arrangement. The proposed electrical circuit incorporates a normally opened detent electronic switch, solenoid valve and direct current power sources to set off the pneumatic setup as shown in Fig 6.

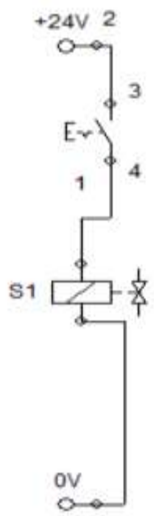

Fig. 6: Electrical circuit

F. Simulation and working of gripper

The simulation of the constructed electro-pneumatic system is done in Festo FluidSIM Pneumatics software. The Home position of the pneumatic circuit remains with the deactivated suction force of the suction cups because of the de-energization of the solenoid as shown in Fig 7.

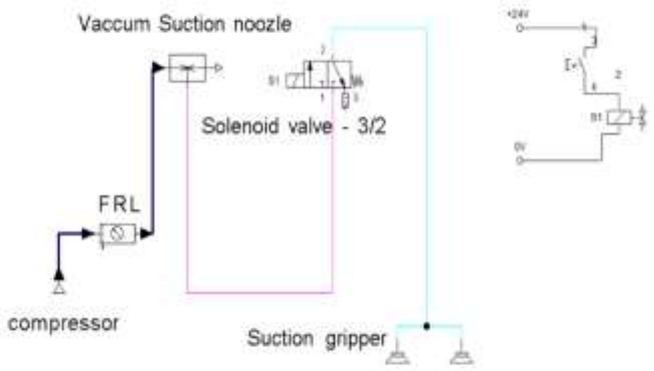

Fig. 7: Home position

In the event of pressing the electronic switch, the electrical circuit gets closed and activates the Solenoid valve. The activation of the solenoid valve allows the actuation of DCV to perform the suction process. The Vacuum suction nozzle is the part that works as a vacuum pump sucking the air creating a vacuum field at the suction caps to perform the gripping of the stocks. The Fig. 8 displays the activation of suction gripper.

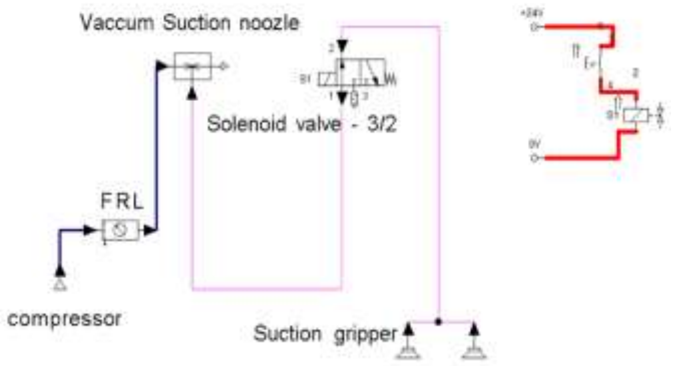

Fig. 8: Gripper activation

III. METHODOLOGY

A. Detection of coloured packages

The flowchart for the colour detection process is shown in Fig. 9. Object detection alone is not enough in the field of robotics, colour detection is also important in real-time. For example: detection of traffic lights in autonomous vehicles and colour detection is again used in industrial robotic manipulators to perform pick and place operations. To implement multiple colour detection functionality in the python program that we have developed, Numpy and OpenCV libraries are used. Workflow starts when the camera module captures video. The video is read in image frames. After reading it by each frame, the image frame is converted to HSV colour space from RGB format. After HSV, morphological transformation is done to reduce noises from the image frame. Masking is performed to detect a particular colour and neglect other colours. Contour is created for each colour to display the detected colour. Meanwhile, contoured packages are used to locate centroids. The detected colour and centroids can be visualized in Fig. 10.

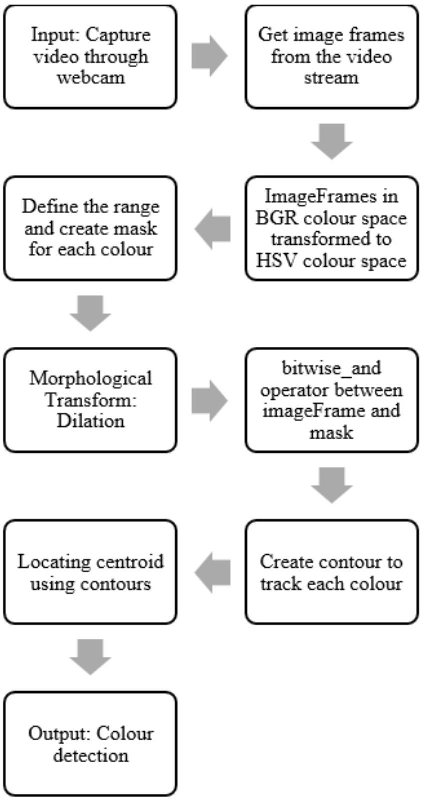

Fig 9: Flowchart for the colour detection

The camera mounted on the gripper captures the coloured boxes (red, blue, or green) continuously in an area. Python's multi-thread functionality can capture images as well as the centroid of the objects to be gripped from the streaming video. With the help of a recognized centroid, the end-effector can precisely suck the package and place it on the rack. As the camera captures undistorted images so firstly, it is converted to HSV images. Contours of the recognized package are used to locate the centroid. Masks are used in identifying colour patterns (RGB) as shown in Fig. 10. The colour green is used as a marker for the end-effector movement.

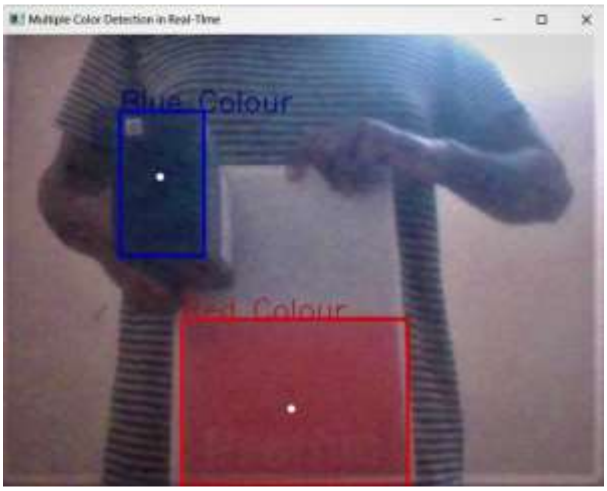

Fig. 10. Colour detection

B. Communication and Control System

NodeMCU is a cost efficient and easily available IoT platform. It is a system on chip (SoC) firmware which is used to connect the cartesian system and mobile through WIFI. Because WIFI is the basic feature that comes with NodeMCU whereas in other microcontrollers we need a separate connecting module. There are two types of variations available naming ESP - 12 and ESP – 12E shown in Fig. 11, here E stands for enhancement.

Fig 11: NodeMCU 8266 - 12E Developer Kit

The USB camera that is shown in Fig. 12 is attached to the suction gripper and helps in monitoring the loading and unloading of packages at appropriate places in the warehouse. A python program has been written for recognizing the coloured boxes. NodeMCU 8266 - 12E controls the stepper motor to direct the gripper toward the target stock. The gripper is pneumatically actuated and can be moved with the help of a ball screw using a stepper motor. Compressed air is passed through the suction gripper to generate the vacuum necessary to lift the package. A User Interface is created using the MIT app inventor. The app asks us to connect a WIFI device (android mobile) and after connecting, there will be two columns showing pick up and positions. Pick up option is colour-coded so that, it will be easier for the user to pick the desired package.

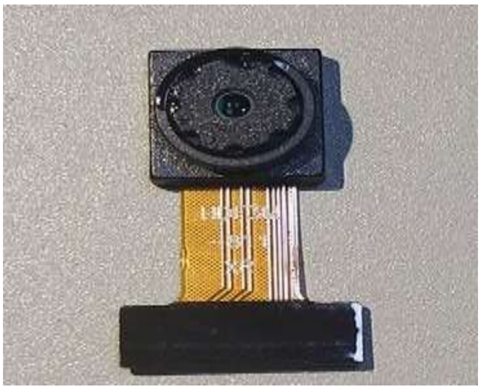

Fig. 12: USB Camera

C. Path Planning

The MATLAB code scripted creates a bridge between the joints and the stepper motor. But this simulation as shown in Fig. 13 is taken in all ideal conditions, however, could see some similarities in the physical model. And, it is possible to use this code as a building block and develop a prototype using microcontrollers such as Raspberry Pi, Arduino, NodeMCU 8266 - 12E. The matlab code is used to initialize the end-effector position as origin. Then by setting the limits of the 3D space, the 3-dimensional graph workspace is formed. Cartesian manipulator system design is used to obtain the length of the frames and link. Also, as ball screws are used in fabricating the gantry system, it is required to give in terms of steps per second. And, the movement of the stepper motor can be seen, provided the limits for the movement is set. Each position of the stepper motor is noted. There is always some maximum reach for every link which has to be given appropriately. The angular velocity for each stepper motor is given by $\omega = \left(\frac{steppermotor_{p_{curpos}}}{steppermotor_{p_{step}}}\right) * 2 * \pi$.

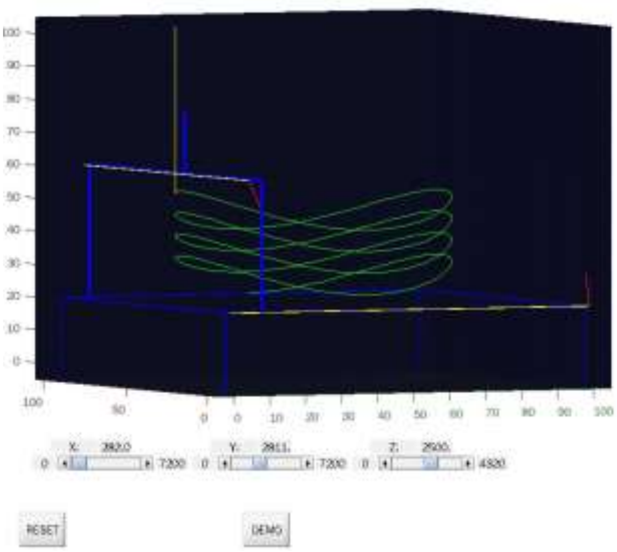

Fig 13: Path planning using MATLAB

D. User Interface

MIT App Inventor is used to create an app as shown in Fig. 14 to pick and place the package. On the first screen, the app asks us to connect a WIFI device (android mobile) after connecting, there will be two columns showing pick up and positions. Pick up option is colour-coded so that it will be easier for the user to pick the desired package.

Fig 14: Application created using MIT Inventor

IV. CONCLUSION

This paper provides exposure to the detailed description of the systematic design of the Automated Warehouse handling system. The management of inventory with the help of the proposed arrangement enhances comfortability and greatly decreases unimportant time consumption, reduces complexity and mitigates labor-intensive problems, and lessens high workforce investments. The initial investment in the fabricated Warehouse handling system proves to be cost-effective as the returns are favorable for the sectors which installed the proposed system. As the robotic system possesses incomparable speed in carrying out the programmed tasks as well as performs its job with great perfection devoid of unnecessarily short breaks unlike humans, the system can add constructive contributions to the sector which is a positive development because of the boost in sector profits. The use of Cameras as sensor components to perform computer vision offers plenty of advantages to sectors that manufacture or handle a variety of products because it provides the system with the sorting and specified loading and unloading performance. The computer vision is achieved by incorporating the algorithm needed to differentiate the stocks based on the color using the python library. The control of the system is also carried out with an application that provides easy remote access to the system. Thus, it is implied that the proposed system possesses great deal of capability and potential in easing the warehouse management involving light load items. In the proposed automated arrangement, the system identifies the differences in the stocks through variations in color, and no other aspects are taken into account. For improving this particular characteristic of the system machine learning technology can be integrated so that the system can identify even the minute differences and can sort out the stocks accordingly. Moreover, the system can be improved to analyze the product to differentiate between products to work on and unneeded articles that don't need attention by utilizing the concept of barcodes or RFID tags. This process of identifying the products to work on is crucial, in order to achieve maximum avoidance of human interference which is one of the ultimate objectives of the system. The proposed system can be further enhanced by incorporating the collaborative aspect to the robotic system to avoid mortal damage in the workspace. Additional development can be done in removing the system's static state by including automated motion technology such as automatic guided vehicles to increase the workspace of the system and perform maneuvers within it. This technology would further reduce the workforce and investment which in turn heighten the gains of the sectors.

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