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Design and Application of Plc Controlled Robotic Arm Choosing Objects According to Their Color

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Abstract: In this study, design and application of electro-pneumatic controlled color selector robot arm was performed. S7 1200 PLC, stepper motor and drives, screw shaft, conveyor belt, selenoid valves, vacuum apparatus and color sensors were used for this purpose. Red and green colored balls moving on belt are carried by worm shaft controlled by stepper motor and classified into separate boxes according to their color. Down, up, forward and backward movements of robot arm that we designed is provided with pneumatic drive, rotating around itself and axis back and forth movement is provided by stepper motor drive. The difference of this study from previous studies is that working area of the robot arm was extended by using a ball screw shaft while robot arm having cylindrical working area is generally used in other studies. For control of Pneumatic driven robot arm, which is an industrial and stable control device. Movable pneumatic system was used in robotic arm design for transportation. Aluminum profile was used to light the robot arm. Designed robot arm is capable of carrying objects up to 0.8 kg. Tiaportal V.2.1 program was used to program the PLC and Axis v1.0 version was used for axis control. Thanks to the worm screw shaft used in this study, the working area of the robot arm was increased.
Keywords: Electro Pneumatic, Color Sensor, Motion Control, PLC, Robotic Arm, Step Motor

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1. Introduction

Pneumatic systems are becoming increasingly popular due to their high speed and force capability [1]. Due to the highly nonlinear properties of pneumatic modeling and uncertainties of various parameters, the control problems become challenging for systems with high precision requirement on force and position [2]. Developed a robust controller using sliding mode techniques to drive the output tracking error to zero in finite time [3]. Robotic arms are mainly used to carry out highly repetitive, material handling and precision tasks such as spot welding, assembling, cutting, palletizing, spray painting etc. in manufacturing industries [4]. It is now possible to control pneumatic servo system just like electro servo system [5, 6, 7- 9]. Robotic arm is a programmable device with similar attributes to that of a human arm and is best suited to hazardous environments where human intervention is highly undesirable [10]. In recent years, major advancements in the field of robotics led its usage in numerous fields namely health care where it is used for executing complex surgical procedures, rehabilitation, prosthetics etc. [11]. Two control systems were

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designed for the robotic arm: Programmable Logic Controller (PLC) and Arduino UNO microcontroller [12]. Robots can be used in any situation and for any purpose, but today many are used in dangerous environments manufacturing processes, or where humans cannot survive [13]. At the end of 2007 there were around one million industrial robots in use, compared with an estimated 50,000 service robots for industrial use [14]. The robot arm is equipped with several servo motors which do links between arms and perform arm movements [15]. PLC is designed to be operated by engineers even by a limited knowledge of computers and computing languages [16]. The use of PLC in automation processes increases reliability, flexibility and reduction in production cost [17]. PLC sequence program consists of normally open and normally closed contacts connected in parallel or in series [18]. The term robotics is practically defined as the study, design and use of robot systems for manufacturing [19].

In this study, the robot arm was made of lightweight aluminum profiles. Pneumatic technology was used for forward-backward, up-down movement of the robot arm and vacuum processing. Stepper motors are widely used to control the robot arm [20]. Therefore, the driver circuit design of these motors can be designed easily. A stepper motor was used to increase working area of the robot arm with a ball screw and another stepper motor was used to rotate the robot arm around itself. Two color sensors were mounted next to conveyor belt to recognize colored objects and stop belt.

2. Connecting Robot Arm to PLC

Five input terminals and nine output terminals were used to connect robotic system to PLC. Three inputs were used for home operation of stepper motors and two inputs were color sensor inputs. Four of outputs were used for square wave and direction information required for operation of stepper motors.

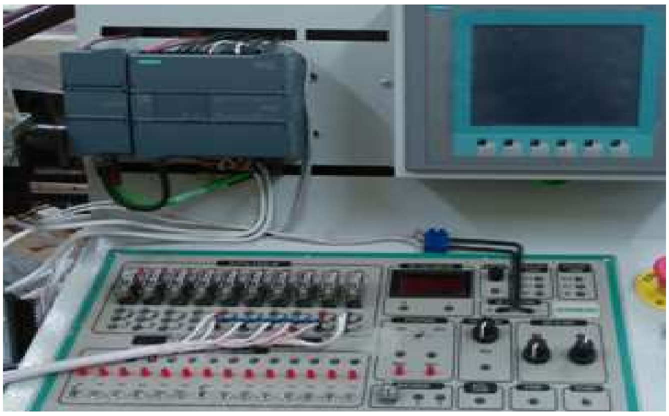

Figure 1. Connection of robot arm terminals to PLC

Table 1. Inputs and outputs of PLC

Input	Point of Contact	Output	Point of Contact	Output	Point of Contact
I 0.0	Axis home Switch	Q 0.0	Axis Step motor Pals terminal	Q 0.5	Arm down
I 0.1	Arm Home forward jog	Q 0.1	Axis Step motor direction terminal	Q 0.6	Arm forward valve
I 0.2	Arm home back jog	Q 0.2	Arm Step motor Pals Terminal	Q 0.7	Arm back valve
I 0.5	Red color censor	Q 0.3	Arm Step motor direction terminal	Q 1.0	Vacuum valve
I 0.6	Green color censor	Q 0.4	Arm up Valve	Q 1.1	Conveyor Bel

3. Axis Control Settings

Q 0.0 end of PLC was set for square wave output, and Q 0.1 end of PLC was set for direction information. Q 0.0 is able to output square wave thanks to fast counter 1.

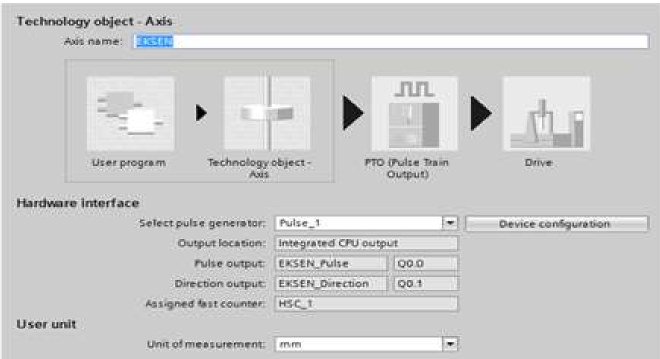

Figure 2. Axis technology PTO (Puls Train Output) settings

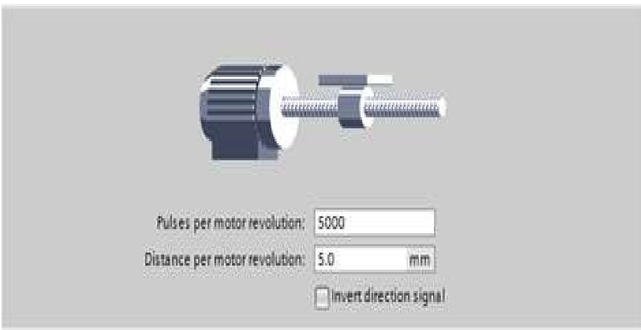

Figure 3. Performing engine mechanical settings

Number of pulses required for one turn of engine; Maximum engine speed: 1200 rpm…1200/60 = 20 rpm. CPU maximum output frequency: 100 KHz; Number of pulses = CPU frequency /

Engine maximum speed Number of pulses = 100000/20 = 5000. Spindle used in robot arm operation moves 5mm in one turn.

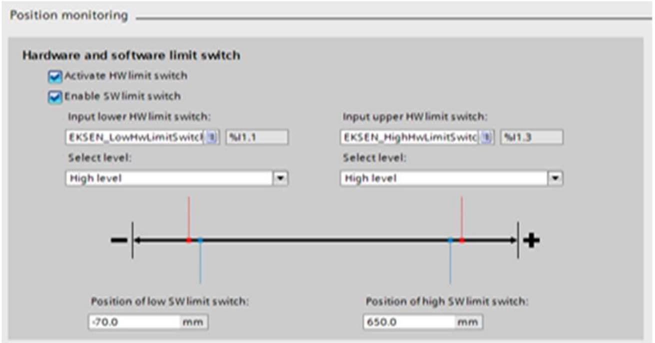

Figure 4. Determination of working limits of ball screw

Working range of axis arranged as 720 mm. The axis can move 650 mm in forward direction and 70 mm in reverse direction according to determined zero point (Figure 4). Limit switches are placed outside this working area. In this study, 1000 mm ball screw shaft was used.

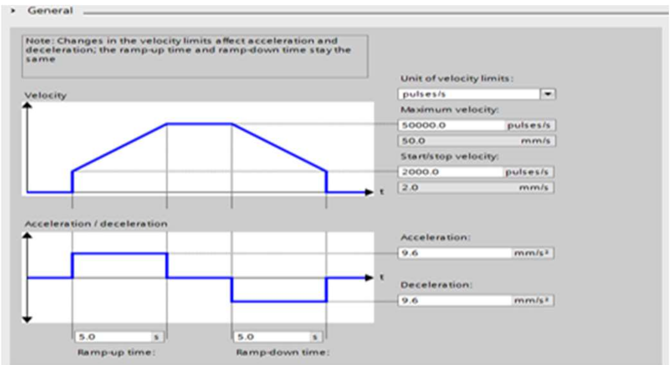

Figure 5. Adjusting speed and acceleration of stepper engine

Stepper engine should switch to its normal speed within a certain time so that it does not run jerky and does not draw excessive current at the moment of starting and stopping. Stepper engine connected to screw shaft starts at 2mm / s and reaches its normal speed after 5 seconds. Speed and acceleration of ball screw can be adjusted to desired conditions (Figure 5).

In order to set reference point without error, home operation must pass three times over switch according to axis V1.0 subprogram. Figure 6 shows home operation window. From this window, home switch search speed of engine and speed after finding home point can be adjusted. Step engine looks for home point in negative direction from window, and after finding home point, direction of movement will remain in positive direction and 10 mm away after home operation of table on ball screw.

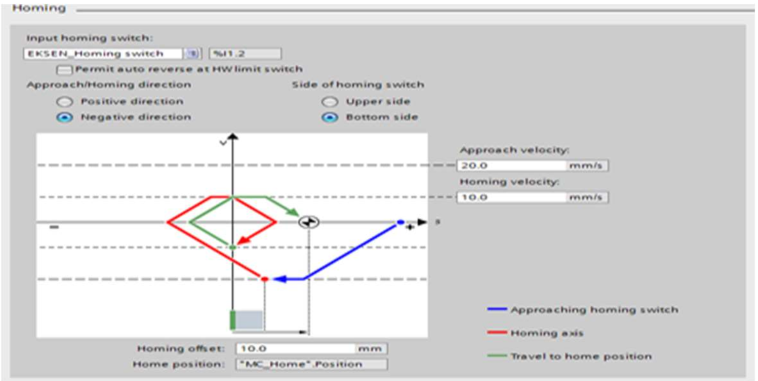

Figure 6. Home operation of axis stepper engine

3.1. Arm Axis Control Settings

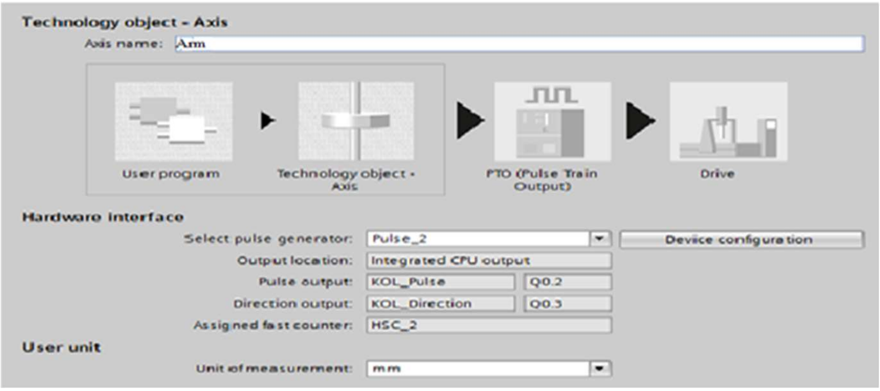

Figure 7. Arm stepper engine PTO settings

Arm stepper engine is the engine that allows robot arm to rotate around its axis at desired angle. PTO settings for motion control of this engine are shown in Figure 10. Pulse_2 fast counter 2 options were selected for square wave generator. Q 0.2 was determined as square wave output and Q 0.3 was determined as direction information output of engine. Ends of Q 0.0 and Q 0.1 were reserved for ball screw axis motor.

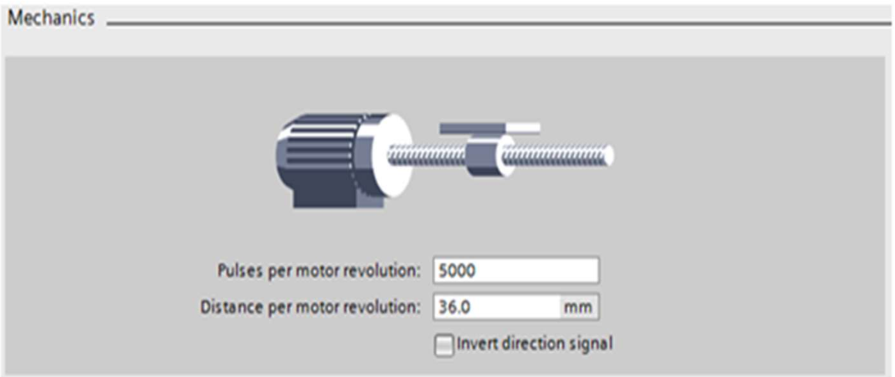

Figure 8. Arm stepper engine mechanical settings

Figure 8 shows arm step engine mechanical settings. Number of square waves required for one turn of stepper engine was determined as 5000 pulses. Arm stepper enginer is not connected to ball screw or belt system. It performs only one turn. Distance obtained by one turn of engine was calculated as follows. Since there is no angle adjustment system in mechanical adjustment section, 36 mm distance was entered, which corresponds to 360 angle. 18 mm corresponds to 90 degrees and 9 mm to 45 degrees.

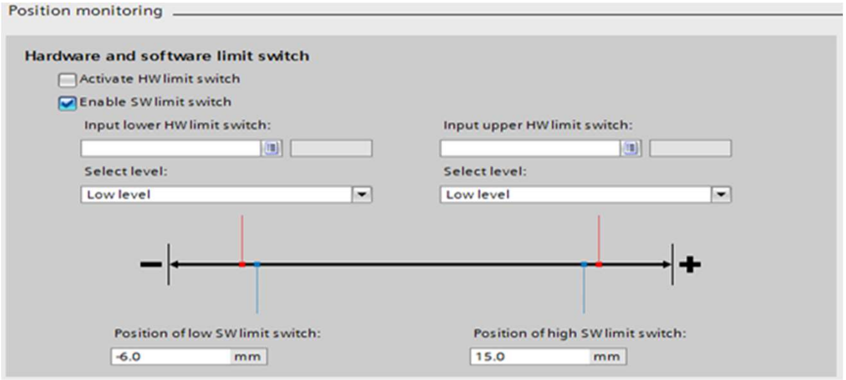

Figure 9. Determination of arm stepper engine operation limits

Figure 9 shows operating limits of arm stepper engine. Since stepper motor rotates about an axis, only software switches were preferred. 36 mm mechanical limit was determined for arm stepper engine. Since stepper engine cannot turn a full revolution, a total rotation limit of 21mm was determined, which ais 15mm on positive side and 6mm on negative side. Boxes that colored balls are collected were placed in positive working area.

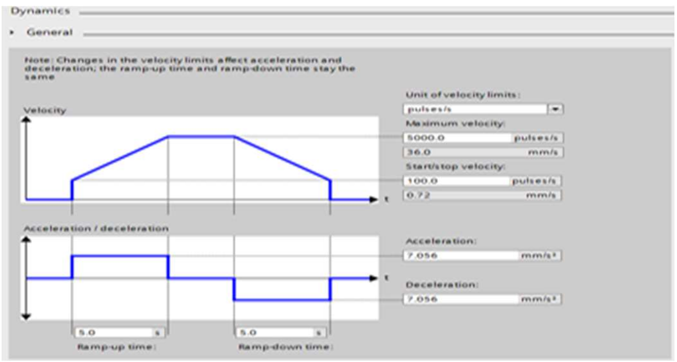

Figure 10. Performing arm stepper engine dynamic settings

Dynamic settings of arm stepper motor are shown in Figure 10. Since arm stepper engine moves less than one turn, the starting speed and maximum speed were kept low. This prevents jerky operation of engine and minimizes step error.

In this study, robot arm can rotate at most ¾ turn since pneumatic pipe connections are made. Therefore, instead of home operation switch, mode 0 was performed, which operation of accepting position is held as home. Mechanical point was used to keep home point constant. In order to prevent step shifts despite mechanical arrangement, two buttons were added to PLC program, which can turn engine forward and backward before home operation. The system is manually set to zero. Home command is then executed in mode 0. Axis V2.0 version was used for this problem.

4. Designed and Applied Circuit

4.1. Robot Arm Design

Aluminum profile was used in design of the robot arm. Stepper engine was placed on table that moves with screw shaft and stepper motor and pneumatic cylinder were placed in the box made of aluminum plate.

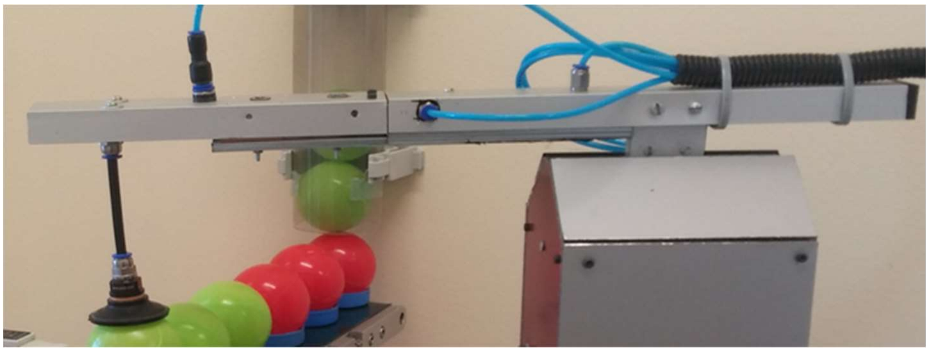

Figure 11. Image of robotic arm while pneumatic cylinders closed

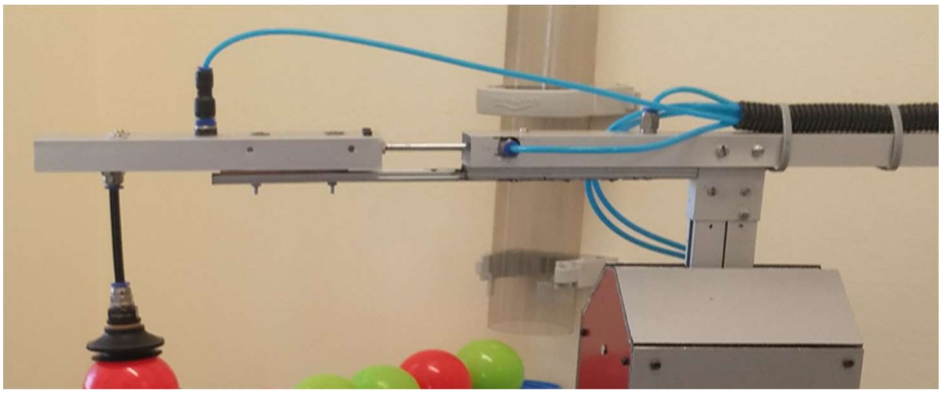

Figure 12. Image of robotic arm while pneumatic cylinders opened

Cylinder that moves the robot arm back and forth was placed inside aluminum profile. In this way, the robot arm can extend 5 cm and the robot arm can move 5cm up and down.

5. Results

In this study, motion control and electro-pneumatic system were combined to create an alternative for robotic arm applications. If detected object is red, the program remains in the red operation subprogram until the red ball is released, and the operation continues until the red ball is released. After the first object is detected, the program does not allow it, even if color sensors detect another color. If a green colored ball is detected after red ball is released, a flow diagram called green operation will be activated. This situation continues until there is no ball on conveyor belt. S7 1200 PLC equipment was programmed with TIA portal software. Axis V1.0 subprogram was used for motion control of stepper engines. MC_Move Absolute command was used in program software. Set, Reset commands, MC_Home MC_power command, and TON timer commands were preferred in program.

In this study, the robot arm with a cylindrical working area was used in other robotic studies, and the working area of the robot arm was expanded with a screw shaft. In this way, our robot arm has had the opportunity to work and transport materials in a very wide area. Operations that can be done by more than one robot arm in a wide working area can be done with a single robot arm.

5.1. Taking Red Balls from Belt and Placing in the Box

Pneumatic robot arm was positioned in home position, which is specified zero point. When red color sensor detects red ball, conveyor belt stops. The robot arm moves to position 607 mm from program, thanks to axis step engine, which rotates ball screw shaft. Arm step engine rotates 42.8 degrees set in program so that vacuum can take red ball. After the arm rotates at desired angle, robot arm extends in forward direction so that vacuum can take the ball. When the robot arm extends forward, arm goes down with piston and settles on red ball. When vacuum is pulled the ball, the robot arm lifts upwards. Extending arm moves in reverse direction to take its original position.

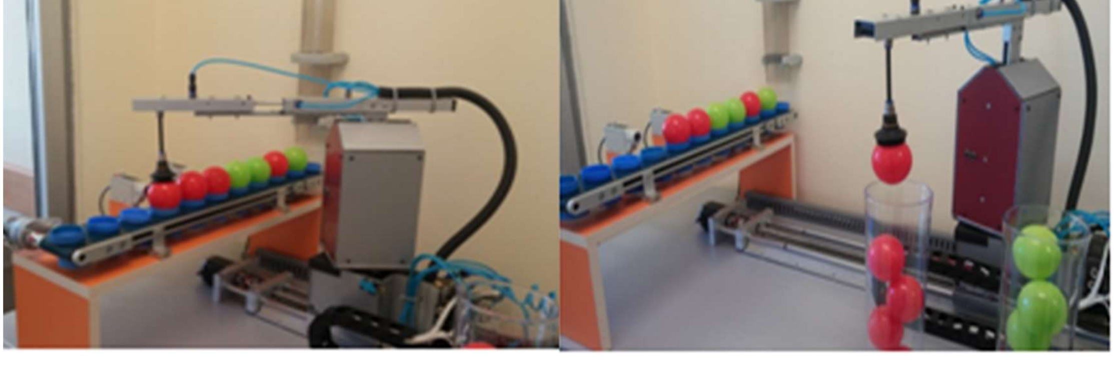

Figure 13. Placing red ball in the box

When vacuuming process takes place and extended arm is replaced, table on ball screw shaft returns 407 mm. Arm stepper engine on the table rotates 70 degrees and comes on red box. After two seconds, vacuum is de-energized and the ball falls into the red box. When red operation is completed, arm stepper engine returns to its zero position (Figure 13). As the red process is completed, conveyor belt will resume operation.

5.2. Taking Green Balls from Belt and Placing in the Box

The robotic arm is in standby position, ie in the home position. When green sensor detects green ball passing over rotating conveyor belt, belt stops. Table connected to ball screw moves to green ball. The robot arm rotates 23.8 degrees to the left ir order to take green ball. When vacuum holder comes on green ball, the robot arm comes down and vacuum is carried out at the same time. Once the robot arm is lifted up with a two-way piston, it reaches the point of 200 mm from the home position. Arm of the robotic arm rotates 1100 left according to home point and comes over green box.

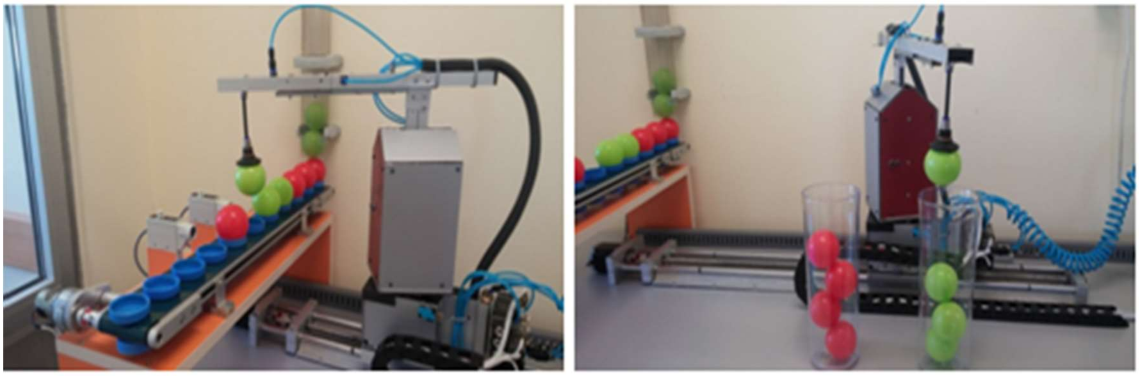

Figure 14. Falling green ball into box

Vacuum operation is reset when robotic arm is on green box of vacuum holder. Figure 14 shows the green ball falling into the box when vacuum valve controlling vacuum holder is de-energized.

Movable pneumatic system is used in the transportation process in the design of the robot arm. Although the pneumatic system is clean, it is not suitable for transporting large and heavy materials. Although the designed robot arm is capable of carrying objects up to 0.8 kg, a hydraulic system may be preferred for transporting larger materials. The forward-backward movement of the robot arm and its rotation around its own axis are realized by a step motor.

6. Suggestions

The robot arm can be developed using an artificial intelligence system based on image processing instead of a color sensor system. In this study, cylindrical and cartesian robot arm can be transformed into articulated robot arm to ensure efficient operation with less movement. For this purpose, number of stepper and servo engines must be increased. By replacing sensors and vacuum apparatus used in the system, many functions such as cutting, drilling, carrying operations can be added. This system can be used for industrial systems where we have to separate objects of different colors or same products labeled with different colors, as well as for packaging and separating faulty products. A hydraulic system must be used to transport larger materials. Since position control is very important in the robot arm, it would be more appropriate to use servo engine instead of stepper engine.

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