Design of a prototype of manipulator arm for implementing pick-and-place task in industrial robot system using TCS3200 color sensor and ATmega2560 microcontroller

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Abstract. It is widely known that the industrial robot system has supported an automation of production process in the industry. A robot provides consistent and predictable productivity that reduces management oversight. In manufacturing system, a manipulator arm is a type of robot that commonly used to pick and place the workpieces into a certain position. This paper describes a prototype of manipulator arm for implementing pick-and-place task in industrial robot system. Manipulator arm separates items based on the color detected by the TCS3200 color sensor and then processed by the ATmega2560 microcontroller. Furthermore, the output of the microcontroller will send a signal to four servomotor drivers to move the robot arm in the desired direction. The robot picks objects and places them in the designated place. The experiments are carried out to pick objects with certain colors and shapes and place into the provided container. The experimental result shows that manipulator arm works well according the design objective such as color accuracy and time response of robot movement from initial time until achieving the goal.

1. Introduction
Recently, the world is entering the fourth phase of the industrial revolution. The term Industry 4.0 is used to denote a level of industrial process which rely on controlling an entire chain of the life cycle of product [1]. The key point of this phase is automation that intensively employs the information and communication network. It is widely known that the industrial robot system has supported an automation of production process in the industry. Robots can easily replace human roles in a series of assembly processes, packaging, and quality control. A robot provides consistent and predictable productivity that reduces management oversight [2]. In the context of industry 4.0, some works has already been devoted to integrate the overall task of robot in industrial scale as reported in [3]. Borisov et al. designed the industrial cyber-physical system for workpieces production and processing using three articulated robots that are Mitsubishi MELFA RV-3SDB, KUKA youBot and Kawasaki FS06N [4]. While, Bonci et al. proposed a practical solution to the improvement of the performance of a manufacturing system that integrates robotics, mechatronics and automation systems at different level [5]. Grau et al. discussed a historical perspective on industrial robotics in factory automation from its early stage until industry 4.0 era [6].

In the academic environment, a prototype of robot equipped with control techniques is developed to provide a good understanding of how robots work to students. Due to unavailability of proper resources
and facilities in the laboratory, it is needed an innovative way to create such learning process in order to get the effective results. For a certain reason, one could realize a virtual laboratory platform of industrial robot [7], while other could build a prototype for academic purpose that integrate some aspect including hardware assembling skill, programming skill, and so on [8,9]. Generally, robot can be classified into three forms that are manipulator, mobile robot, and humanoid robot. A manipulator is constructed similar to a human arm. It is composed of links and joints with the gripper's tip resembling a hand or other form to hold a workpiece. Mobile robots are robots that move using wheels or legs, while humanoids are robots in the form of humans or animals. In manufacturing system, a manipulator arm is a type of robot that commonly used to pick and place the workpieces into a certain position. In a batch process, the manipulator arm picks, grasps, and moves the part from one place to certain place on a conveyor belt. Fig. 1 shows an example of the manipulator arm that realizes a pick-and-place process.

**Figure. 1.** A manipulator arm packs plastic parts into the boxes on the factory floor (left) and performing a bushing assembly task (right) [10].

This paper describes a prototype of manipulator arm for implementing pick-and-place task in industrial robot system. Manipulator arm separates items based on the color detected by the TCS3200 color sensor and then processed by the ATmega2560 microcontroller. Furthermore, the output of the microcontroller will send a signal to four servomotor drivers to move the robot arm in the desired direction. The robot picks objects and places them in the designated place. Recent works regarding a prototype of manipulator arm that performs pick-and-place task have been already reported in [11-14], for name a few. Mucchiani *et al.* proposed a method for picking objects of the manipulator with end-effectors that have no degrees of freedom [11]. Their technique can be applied to grasp a large variety of object shapes. Ropo *et al.* worked on design and implementation of a manipulator that used to pick and place ferromagnetic metals from one place to another [12], while Manjula & Karamagi realized a prototype of manipulator that was capable of picking objects and migrating them across a 10-inch horizontal with high accuracy and precision [13]. Shi & Koonjul presented a real time planning grasping algorithm for bin-picking and kitting application of a certain manipulator arm [14].

The rest of the paper is structured as follows. Section 2 describes on system design including block diagram and technical specification of the proposed manipulator arm. Hardware realization and experimental results is given in Section 3. It covers an interconnection between the components and the others as well as the mechanical structure of the prototype of manipulator arm. Last section provides the concluding remarks about the experimental results and further works to improve the performance of the constructed manipulator arm.

### 2. Method

Block diagram of the proposed prototype is depicted in Fig. 2. A manipulator arm is equipped by TCS3200 color sensor, ATmega2560 microcontroller, and SG90-type servomotor. The color sensor is used to detect the color of objects in the form of cubes that will be moved to a designated place. Microcontroller captures data from sensor, processes them, and sends to servomotor. It has 4 the
dedicated servomotor to render a movement of robot such as grasping the object, moving the robot arm forward behind and up-down, and putting the object into the specified place.

![Block diagram of the proposed manipulator arm](image)

Figure 2. Block diagram of the proposed manipulator arm.

The TCS3200 color sensor has an array of photo detectors, each with either a red, green, or blue filter, or no filter [15] as shown in Fig. 3. It works by reading the intensity value of the light emitted by the super bright LED (stands for light emitting diode) on the object. The reading of the light intensity value is done through an 8x8 photodiode matrix, where 64 photodiodes are divided into 4 groups of color readers. Each color illuminated by the LED will reflect the LED beam towards the photodiode. The reflected light has different wavelengths depending on the color of the detected object. This makes the TCS3200 color sensor is capable of reading several colors. Reflected wavelengths and LED beam of colored objects activate one of the photodiode groups on the color sensor. Whenever the photodiode group used is active, S2 and S3 pins will send a signal to the microcontroller to inform the detected color.

![TCS3200 color sensor and its pin out configuration](image)

Figure 3. TCS3200 color sensor (left) and its pin out configuration (right) [15].

In the proposed manipulator arm, ATmega2560 microcontroller is employed to process the data from the TCS3200 color sensor. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [16]. Such microcontroller has often been used for the purpose of robotics based implementation, see for instance [8][17][18]. Based on sensor data, the output of the microcontroller will send an actuating signal to four servomotor drivers to move the robot arm in the desired direction. Four servomotors are installed at gripper, joint, elbow, and base respectively as shown in Fig. 4. Gripper grasps the object that will be put at the specified place. In fact, a cube shaped object will be clamped with two finger-like forms of the manipulator arm. A servomotor supports the fingers to clamp the object. Other servomotor is dedicated to render the joint movement. It will rotate the object and move up and down as well during pick-and-place operation. Reaching the object at a certain position and shortening of the manipulator arm are possible by the servomotor installed on the elbow. While, the other servomotor is used to drive the base part such that the manipulator arm can rotate to put the object at a specified place.
3. Results and discussion

Interconnection TCS3200 color sensor, ATmega2560 microcontroller, and SG90 servomotor is given in Fig. 5. Each pin of TCS3200 color sensor denoted by S0, S1, S2, and S3 is paired to digital pins of ATmega2560 microcontroller which has the pin number 31, 33, 35, and 36 respectively. While, output of TCS3200 color sensor is connected to the pin number 39 of ATmega2560 microcontroller. Servomotor is driven via transmitting an actuating signal produced by microcontroller in the form of pulse width modulation. The pulse width of the actuating signal will determine the position of the rotation angle of the servo motor shaft. For example, the pulse width with a time of 1.5 ms will rotate the servo motor shaft to the 90° angle position. If the pulse is shorter than 1.5 ms, it will rotate in the direction of 0° or counter clockwise, whereas if the pulse is given longer than 1.5 ms, the servo motor shaft will rotate towards the position 180° or clockwise.

In addition to the hardware, the prototype of manipulator arm is formed with certain mechanical structures made of acrylic. Such material becomes the main body of the robot as well as a robot frame that forms a manipulator arm including the gripper. The robot parts prior to being assembled are given in Fig. 6. There are five grouped parts that build the mechanical structure of the proposed manipulator arm which denoted by the number 1 until 5 in Fig. 6. Parts grouped in number 1 will form the link and elbow which is useful for the manipulator arm moving the forward-backward and up-down. The parts grouped in number 2 become the place where the servomotor is installed as an actuator of the robot.
Gripper is realized by the parts grouped in number 3, whereas the body of robot is composed by the parts grouped in number 4. While, the part marked with number 5 are designated as the base of the proposed manipulator arm.

![Figure 6. Parts that forms a mechanical structure of the proposed manipulator arm.](image)

The constructed manipulator arm is shown in Fig. 7. It comprises of gripper, joint, elbow, and base. This prototype is designed to provide an understanding of students in terms of manipulator arm construction and pick-and-place tasks that must be done by robot. The gripper must be able to carry objects with a certain shape and color, then putting objects in a designated place. Prior to the constructed manipulator arm can move the object, the robot must recognize the color of the object. In practice, color recognition is done by storing a value of certain color in its RGB code. This RGB code is collected by bringing the TCS3200 color sensor closer to an object with a certain color then storing the respective data in the microcontroller. This step is shown in Fig. 8.

![Figure 7. The proposed manipulator arm when initial state (left), reaching the object (middle), grasping the cube shape object.](image)

![Figure 8. Storing RGB value of respective color; red (left), green (middle), blue (right).](image)
Experiments are carried out to pick a cube shape object with a certain color and then place into the provided container. In this experiment, the provided container means the designated place for putting the respective object with a certain color. Snapshot of experimental results is given in Fig. 9. Meanwhile, time response of the constructed manipulator arm to carry the object and placing in the specified location is tabulated in Table 1.

![Figure 9. Pick-and-place the object.]

| Object  | time (s) |
|---------|----------|
| red cube | 23.16    |
| green cube | 23.83  |
| blue cube | 25.05   |

4. Conclusion
Design and implementation of the manipulator arm that showing a pick-and-place task of the object has been presented. The proposed manipulator arm employs TCS3200 color sensor to recognize the objects color. From the experimental results, the color sensor can distinguish the colors of the object very well such that the manipulator arm is capable of putting the object into the specified place. Servomotors as actuators of the constructed manipulator arm could move according to the angle programmed through the ATmega2560 microcontroller by adjusting the actuating signal time of each motor so that the robot moves properly.

However, the improvement should be done to enhance the performance of the constructed manipulator arm in terms of smoothness in the robot movement, time response of the pick-and-place task, and robustness to light intensity around robots that can interfere with color recognition. Application of intelligent control in controller design as reported in Najmurrokhman and Amad is also interesting to be implemented for achieving pick-and-place task faced with uncertainty of the shape, the opacity of color, and so on [20,21]. Utilization of the camera as a sensor towards the vision based robot system is also interesting to work further in order to increase the capability of selective picking of the object [22].

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