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Design, Construction and Performance Test of an Autonomous Low-Cost Pick and Place Robot Based on Color Detection

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ABSTRACT
Pick and place robots are regularly utilized in assembling but at the same time are utilized in applications like packaging, receptacle picking, and inspection. The essential advantages of pick and place robots are speed and consistency. In this work, a low-cost pick and place robot based on color detection is designed and constructed which is small in size and lightweight, making them perfect for use in applications where space is restricted. This pick and place robot assists with increasing output, helping with the picking and packaging processes in warehouse settings based on color detection of the object. The robot aims to detect products or goods of different colors, pick those items of products and place them in different predefined places according to the color. The robot will follow a line to pick and place the products which makes the robot more efficient. TCS 3200 color sensor is used for detecting the color of the object and TCRT 5000 IR sensor Array8 is used for detecting lines. Micro metal gear DC motor and L298N motor driver is used for driving the main motors. For constructing the gripper to pick, hold and place the object MG 995 servo motor is used. Arduino Mega 2560 microcontroller is used for controlling the whole system. The robot is tested in the Heat Engine Laboratory, KUET and it performed satisfactorily. The robot picks the item utilizing its gripper and afterward puts it at a specified location based on color following the line. In this paper, the pick and place system based on color detection is depicted in detail while featuring the design principles for the warehouse settings, including the structure rule for the gripper and other electrical and mechanical parts. Also, various experiments to evaluate the performance of the robot are presented and shown that the robot is competent enough to accomplish the specific tasks in warehouse settings, for example, picking an objective thing from a location, grasping the objects, and performing pick and place tasks following the line. The limitation of this robot is that it is only capable of handling only cubic shape products of a limited weight and size range because of a very simple gripping mechanism.

Keywords: Microcontroller, Gripper, Robot, Color Sensor, Pick and Place.

1. Introduction

A robot that follows a line is called a line following robot. Usually, paths are denoted as a black line on a white surface or vice versa, where the path has a uniform width [1].

Pick and place means to pick an object from a specific location and place the object when the robot reaches the destination. In that case, a robot must follow a specific path. Pick and place robots are designed to hold an object of a specific dimension and weight. An autonomous robot can do its job by itself, as programmed [2].

The industries, where manufactured products are of identical size are produced, but the products have different color codes or bar codes. So, when the manufactured product just left the assembly line the product needs to be stored or delivered in different places, for example, storehouses. Similarly, in warehouse management, the regular pick and place of objects is a very common objective. In that case, an autonomous robot can do this job simply.

Mostly, the destination of different objects is not the same, in that case, the robot must follow different paths to reach the destination. Here, a robot must identify its destination. So, any distinguished information from the object which is to be carried can help the robot to find out its destination. The information can be a QR code, bar code, or color. But first of all, the robot should have the capability of collecting information from the object. Different types of sensors, camera vision, or laser rays can be used to identify the object and collect information about its destination.

In 2012, Jen, et. al. designed an autonomous line tracing car using a PID algorithm for various contest and academic purposes. Where writers showed that the minimum distance between sensors and an increasing number of sensors results in the fluent and fast movement of the robot. [3]. In 2018, Kader, et. al. presented a work describing the PID algorithm is more smooth and faster than the ON-OFF algorithm to constrain a robot within the track [4]. In 2012, Gosim et. al. designed a system where the IRB1410 ABB robot is synchronized with an LFR (Line Following Robot). Where pick and drop operation is conducted by a 6 DOF IRB1410 robot on or from the LFR and placing operation is done by an LFR through the line path [5].

The effectiveness of the PID algorithm has been verified by many previous researchers in LFR. In this paper, a robot is designed to pick and place any object having a specific size, shape, and color code. A color sensor in the robotic arm has been assembled to detect the color of the object. When the robot can detect the color of the object, the algorithm will help the robot to find out the destination. To move from starting point to destination, the PID controller algorithm is introduced in the robot. After

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placing the object at the respective destination, the robot will return to its starting point to pick and place another object. Thus it will work autonomously.

2. Methodology

The development of this robot can be divided into two major sections, i.e. hardware and software. The hardware part is all the physical components of the system and the software part is all the algorithms and programs run by the microcontroller.

2.1 Hardware

In this robot, there are several moving parts. So, apart from all the electronics, sophisticated mechanical design is also very important. For this reason, all the hardware components are attached and placed in such a way, so that the robot can move and do the job by maintaining its balance. The chassis is made of a PVC sheet of 5mm thickness. The arm is also made of the same PVC sheet with some reinforcement. A caster wheel is used as a front wheel, as it provides 360° rotation as the direction of the force drives it. The electronics components used in this robot are operated in 5VDC except for the motors. But the battery voltage is 11.1 VDC. So, a step-down voltage module is used which converts 11.1V to 5V to power the main circuit. The major hardware instruments used in this robot is labeled in Fig.1 and listed below-

i. Arduino Mega 2560
ii. Li-po battery (11.1 VDC)
iii. Color sensor (TCS 3200)
iv. IR sensor (TCRT 5000 Array8)
v. Servo motors (MG 995, SG 90)
vi. Gear motors (N 20)
vii. Motor driver(L298N)
viii. Step Down Voltage Module
ix. Grippers
x. Wheels
xi. Caster wheel
xii. Connecting wire

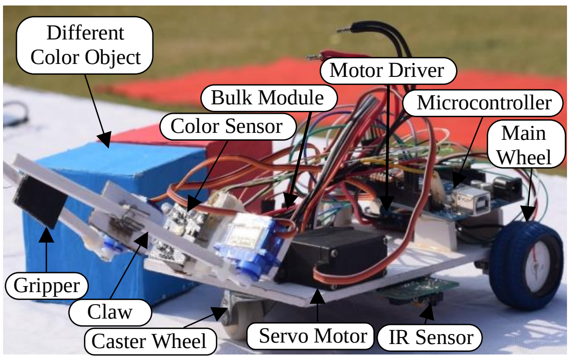


Fig.1 The hardware parts of the robot.

2.2 Software

The Arduino IDE (Integrated Development Environment) has been used to write the code and upload the code into the microcontroller. The programming language is called Arduino which is very much compatible with C and C++ language. The Arduino IDE is a cross-platform application developed by Java programming language [6].

2.3 Program Algorithm

An efficient algorithm is very important for a multi-tasking robot. As this is an autonomous robot, some decisions and work are done by the robot itself. Sensing the values from the input and to return the decision to output, all the commands are executed by the program installed in the microcontroller [7]. The algorithm tells the microcontroller what to do when it senses an input. The line following is a common operation for this robot. Apart from the line following, the pick and place operation by color detection algorithm is shown in a system flow chart in Fig.2.

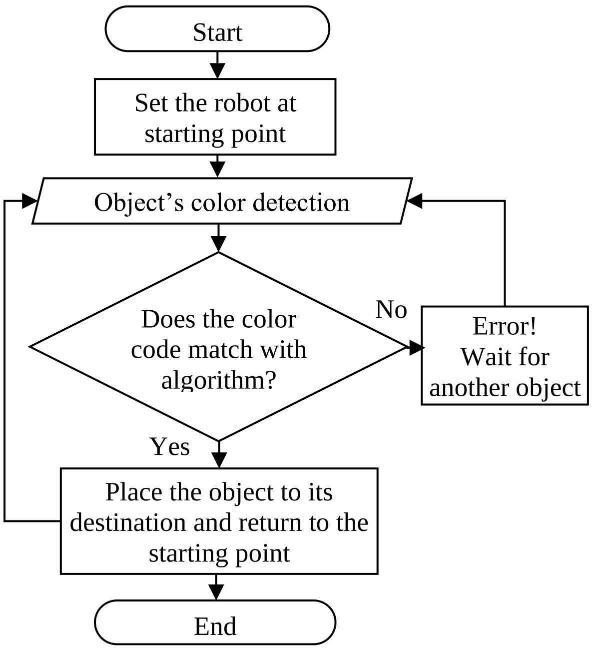


Fig.2 Flow chart of the program algorithm.

2.4 PID Controller Algorithm

Usually, a digital IR sensor provides output ‘0’ on the white surface and ‘1’ on the black surface. Based on the robot position, sensor to sensor distance, and line thickness, only some sensor output data combination is possible. For each sensor output data set, an ‘Error Value’ is set up in the program which is shown in Table 1.

Table 1 Possible sensor values and respective Error values.

Sensor Value	Error
10000000	-7
11000000	-6
11100000	-5
01100000	-4
01110000	-3
00110000	-2
00111000	-1
00011000	0

00011100	+1
00001100	+2
00001110	+3
00000110	+4
00000111	+5
00000011	+6
00000001	+7

After calculating the error, the program calculates the PID Value. To calculate the PID value, some constants Kp, Ki, Kd is used. The values are set up based on the performance of the robot using the trial and error method. A Base Speed is also provided, which represents the speed of the robot in ‘0’ error. To control the speed of the Left Motor, the PID Value is added with Base Speed, and in case of controlling the right motor speed, PID Value is subtracted from the Base Speed. Both speeds are constrained between 0 to 255. After controlling the motors using PID, the program seeks the new error value. The workflow is represented by a flow chart in Fig 3.

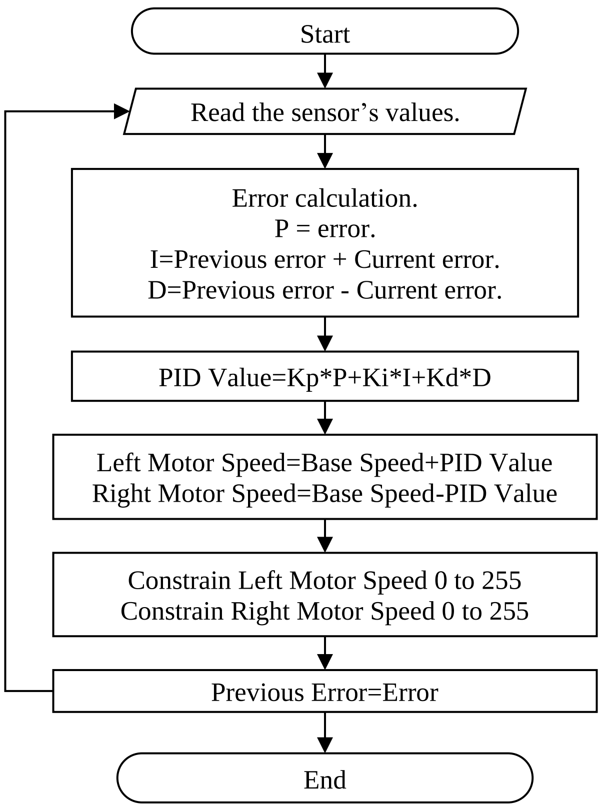


Fig.3 Workflow of PID controller algorithm.

2.5 Kinematics of the Arm

A single DOF (Degree of Freedom) arm is attached in the front section of the robot. The arm is controlled by a high torque servo motor. The rotation of the servo motor controls the movement of the arm as shown in Fig.4. In this robot, the value of θ is set between θ=0° to θ=45°.

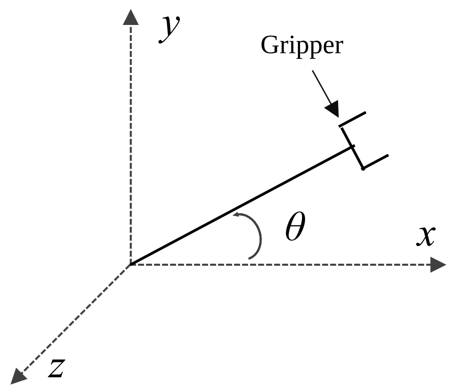


Fig.4 Arm kinematics.

3. Working Procedure

When the robot is set at the starting point, then it is all set up for its operations. The microcontroller receives all the data from the sensors and activates the output devices according to the program. In Fig.5, all the input and output devices are shown using a block diagram.

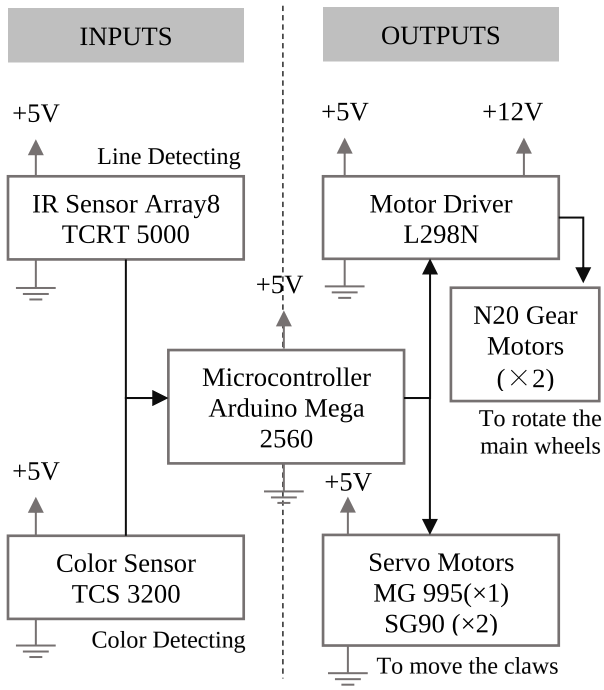


Fig.5 Block diagram of input and output devices.

The working principle is divided into two sections i.e. line following and pick and place.

3.1 Line Following

The IR sensors continuously provide information to the microcontroller so that the robot can detect it’s specific position with respect to given lines. The PID controller (Proportional Integral Derivative) algorithm is used to hold the robot on the line and propagate its motion smoothly [4].

In a simple straight line, the robot will just go straight, but at the junction point, as shown in Fig.6, the robot will decide whether it will go straight or left or right based on the pre-programmed path. At the end of each line, the robot will conduct its picking and placing operation. After picking or placing operation, the robot will follow the line with or without the object from the starting point to the destination to the starting point. Thus, this robot will follow this cycle of operation autonomously until the robot is in working condition.

3.2 Pick and Place

The pick and place operation is executed by only three servo motors, two servo motors in the claw, and one servo motor in the arm. The grippers are connected with claws and the movement of the claws is controlled by servo motors. The specific rotation of the servo motors produces enough pressure and friction to hold the object tight in between the claws for a specific size of the object. The SG 90 servo motor is used to hold the object and MG 995 is used to elevate and release the object.

3.3 Command Execution

The robot is run by its computer command. The computer code is written in such a way so that the operations should be done properly. In the computer code, some user-defined function has been used for programming simplicity. The different functions have different operations on the robot. Some prominent user-defined function and their response to the system is shown in Table 2.

Table 2 Major user-defined functions and their response to the system

Function	The response of the System
Straight()	Simply follow the line using PID.
TurnRight()	Right turn in the junction point.
TurntLeft()	Left turn in the junction point.
TurnAround()	Rotate the robot by 180°
Pick()	Pick the object by using the claw.
Place()	Place the object by releasing the claw
AllStop()	Stop all the movements of the robot.

To visualize the command execution, a site map can bring into consideration which is shown in Fig 6. This figure demonstrates several destinations and starting points. There are also some junction points shown in the figure. So, when the robot passes through the junction, the algorithm decides, where to go. For a complete operation, the command functions are executed in sequence.

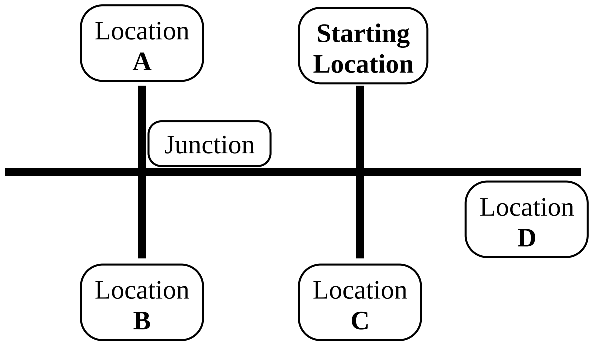


Fig.6 Simple location map.

When an object will come to the robot, firstly, the robot will detect the object's color. Suppose, the detected color is red. Then the program will find out the destination for this corresponding color, such as, 'Location A'. Now, to place an object at 'Location A', the object will follow the command respectively which is shown in Fig.7.

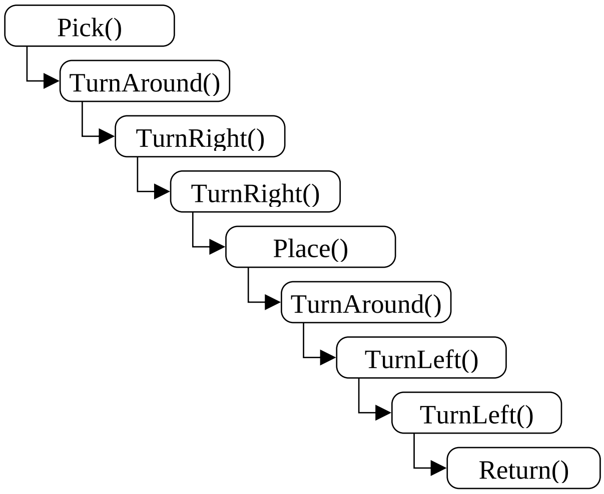
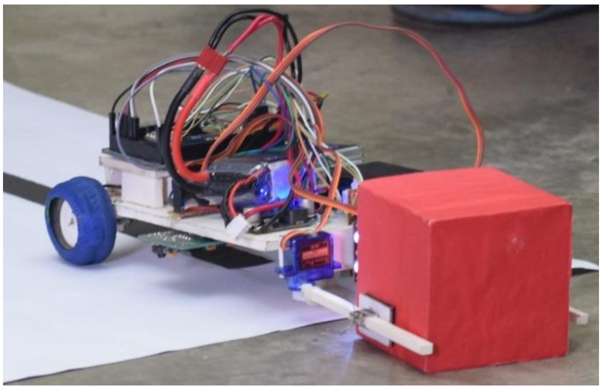


Fig.7 Command execution sequence for a single operation.

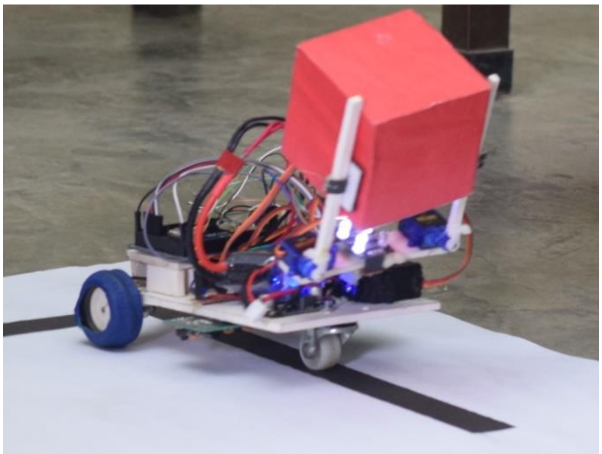
After any particular operation, the computer code will proceed to the main() function through the built-in return() function, this function lets the robot to wait at the starting point for another object.

4. Result and Discussion

The weight carrying capability, line following accuracy, and velocity was tested with and without load. The claw and gripping mechanism is very convenient to lift the cubic shape object shown in Fig.8.



(a)



(b)

Fig.8 The pick and place operation by the robot, (a) holding the object, (b) lifting the object.

The robot arm can elevate up to 100g easily with full safety. But a weight more than 110g sometimes slips out from the gripper.

As the line following is controlled by the PID algorithm, the robot hardly slips out from the center of the line. So, the line following and turning of the robot is very satisfactory. At the same time, the robot follows the line properly with the load shown in Fig.9.

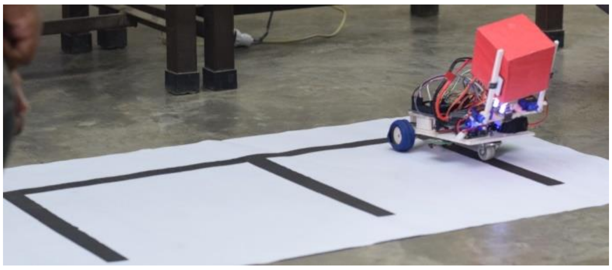


Fig.9 Object transportation to the destination by the robot.

The average velocities of the robot with and without load are approximately 0.28 ms^{-1} and 0.35 ms^{-1} respectively.

There are many limitations of this robot too. The object of unusual shape cannot be carried out with the available mechanism of the robot. Again, if the robot lost its way or misguided, it must be replaced at the starting point manually.

As regular IR sensors are used, if any dust or light flux from any source may disturb the robot to detect it's path. As the robot is battery powered, the robot must be recharged at regular intervals.

Overall, this is a low-cost autonomous pick and place robot, the total manufacturing cost is approximately 100 USD. With more budget, a more sophisticated robot can be built.

5. Conclusion and Future Aspects

The objective of building this robot was fulfilled and it works properly during performance testing. The weight carrying capacity can be increased if the frictional coefficient of the gripper can be increased and high torque servo motors are used. Objects having various sizes and shapes can be grabbed if more complex claw and gripper mechanisms are used.

The object sensing capability of the robot can be increased drastically by replacing the color sensor of this robot with a camera vision. The processed image of the QR code or bar code of the object can provide a vast amount of information about the object.

Overall, if this model of the robot can be made on a larger scale, and after some modification, the robot can be used for industrial purposes directly. A more sophisticated code can be written according to user demand.

In this modern age, sooner or later, industries will be more automated, the robot is started taking place of manpower. Heavy and risky jobs will be replaced by robots. So, usage of this type of robot in respective fields will advance the system towards industrial automation especially from the perspective of Bangladesh.

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