DESIGN AND IMPLEMENTATION OF METALLIC WASTE COLLECTION ROBOT

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Abstract

The accumulation of waste has become a major problem in urban city dumps. There are different kinds of waste that affect our environment, for example metallic and plastic waste. Developing a metallic waste collection robot system is a mighty challenge. There is very limited research related to robot systems that specialize in the collection and processing of waste. In this paper we propose a robotic system that can be used for metallic waste collection. This robot is equipped with a metal detector, ultrasonic sensor, control and power unit, and actuators. This autonomous robot can perform tasks such as obstacle avoidance and metal detection.

Keywords

Arduino; LYNX5 Robotic Arm, Metal Detector IR Distance Sensor; Ultrasonic Sensor.

Introduction

As a result of the accumulation of metallic waste in recent times, researchers are working to find possible solutions to reduce environmental pollution caused by these waste dumps. Some of those solutions are related to robotics, such as Zen Robotic Recycling, which has multiple sensors for accurate analysis. Based on these analyses, the robot can make independent decisions to pick up objects from the waste stream [1]. Zen Robotic Recycling can be used only in recycling factories and some commercial establishments, but it has high-cost and it is non-usable in different environments. We decided to design and implement our own metallic waste collection robot. In this work, some factors have been considered such as cost, size, flexibility, weight, and autonomy. The purpose of this work is to detect metallic objects in a specific area and pick them up by using a robot arm.

There are different kinds of microcontrollers that can be used as a platform. These include Arduino, LilyPad, SparkFun and Seeed Studio. To meet the objective of this work, several sensors, such as Ultrasonic sensor, and Infrared (IR) sensor have to be used. In order for a metallic object to be picked up, the detector also plays a significant role. There is an IR distance sensor mounted on top of the contraption which is used in this work. It also has servomotors that control the movement of the robotic arm.

DC motors are also used in this work. The Arduino Motor Shield allows the microcontroller to drive the two- channel DC motor. Speed control is accomplished through conventional pulse width modulation (PWM), which can be obtained from the Arduino PWM output pins. This paper has two main sections, which are methodology and experimental results. Methodology describes hardware and software modules used in this work. Experimental Results shows an experimental result of collecting metallic objects using this robot.

Methodology

This work consists of four modules locomotion, detection, pickup, and control. The locomotion module is equipped with a transport platform for transporting the robotic vehicle from a start location to a target location. The locomotion module depends on the detection module for moving and stopping. The pickup module depends on the control module to determine and define target location by the data which the control module receives from detection module.

This work is divided into two important sections, hardware and software. The hardware section contains four main subsections, which are arm, locomotion, metal detector, and control unit. While the software section contains three subsections, which are obstacle avoidance, detection, and arm movement. During the design and development of this work, we considered cost, weight, flexibility and autonomy. Overall budget in building this work was $1350. In the Lynx5 robotic arm subsection, we explain the inverse and forward kinematics to obtain joint angles for smooth movement of the arm. In the locomotion subsection, we explain the working of the DC motors and ultrasonic sensor and how the robot utilizes them to accomplish the obstacle avoidance task. In the metal detector subsection we describe general information about the kind of metal detector and its working principles. In the control unit subsection we describe what kind of microcontroller we use. In the software section, we briefly explain the algorithms that we use in the obstacle avoidance, detection, and arm movement tasks. Figure 1 shows a simple block diagram of hardware and software modules. Figure 2 shows an overview of the hardware architecture design.

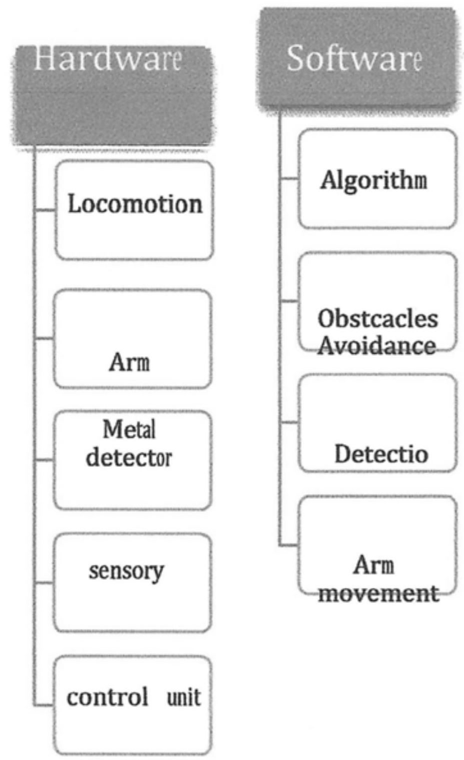


Figure 1. Hardware and software modules.

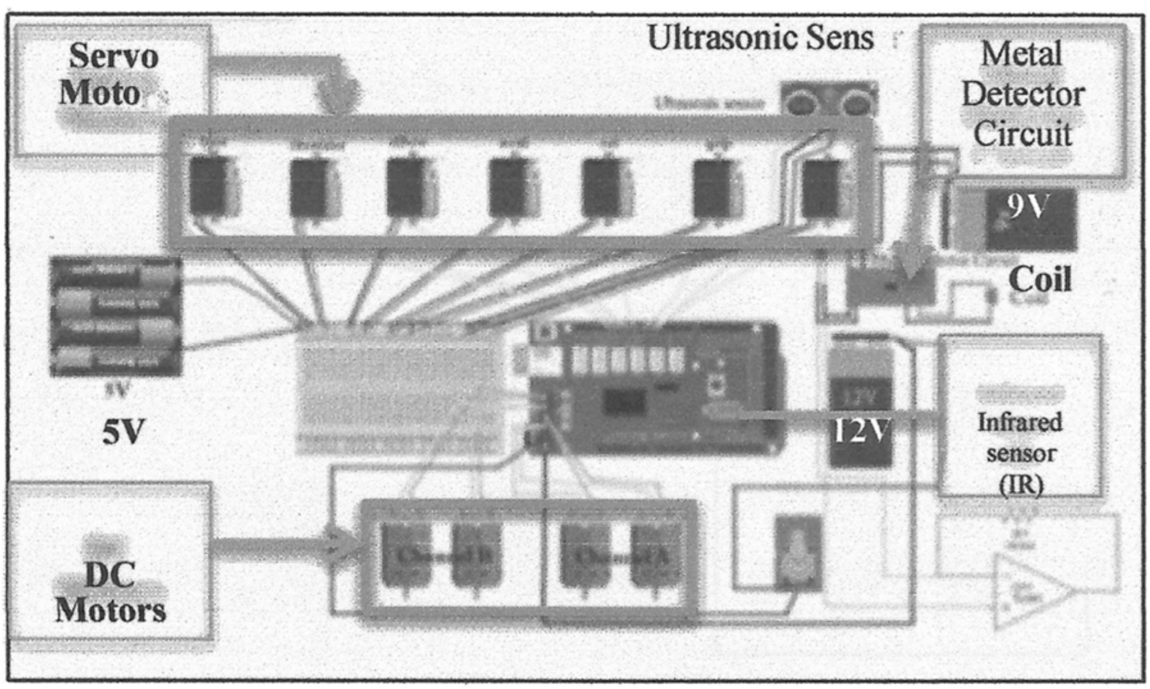


Figure 2. Hardware architecture Design.

A. Hardware Design

The hardware design for metallic or non-metallic waste collection robots consist of five components: Lynx5 robotic arm, IR distance sensor, Arduino Mega 2500 Microcontroller with Arduino Motor Shield, Metal detector, and *4WD1* robot rover kit. In this work, we utilized the above components and built a re-configurable robot. In addition, we designed a contraption and installed it on the front of the rover to give the robot enough support in the object collection task. Furthermore, we added two boxes on the robot. Box 1 was placed on the right side of robot to collect non-metallic objects. Box 2 was placed on the left side of the robot to collect metallic objects. In this section, we describe the hardware components in more details.

1) Locomotion

We selected the Lynxotion Aluminum 4WD1 rover kit in our work, because it is robust, modifiable and has an expandable chassis see Figure 3. In addition, the robot uses RC truck tires for motion that depend on the gear head motor and small Ni-MH battery packet.

Figure 3. 4WD1 Robot [2].

There are mounting holes for sensors, Arduino board, and AL5 Series Robotic Arm. The underside of the robot has space for the gear head motors and a 12 V 2800 mA Ni-MH battery to power the drive motors and servos. The robot is capable of carrying up to a 51b payload [2]. The chassis is 8" wide, 9" 9.75" long and 4" high (approximately) [2].

2) Lynx5 Robotic Arm

The Lynx5 Robotic Arm has six motors that control the position of the arm and gripper. Inverse and forward kinematics are used with the Arduino Mega to determine the angle of each servomotor in order to move the arm in coordinate space (X,Y,Z). The Lynx5 arm rests in the XY-plane and the z-axis is perpendicular to the XY-plane. The origin of the three dimensional coordinate space located at (X,Y,Z) = (0,0,0), is at the base of the arm.

Figure 4 shows the distribution of servomotors on the arm and, Figure 5, shows the definition of the coordinate space for Lynx5 arm.

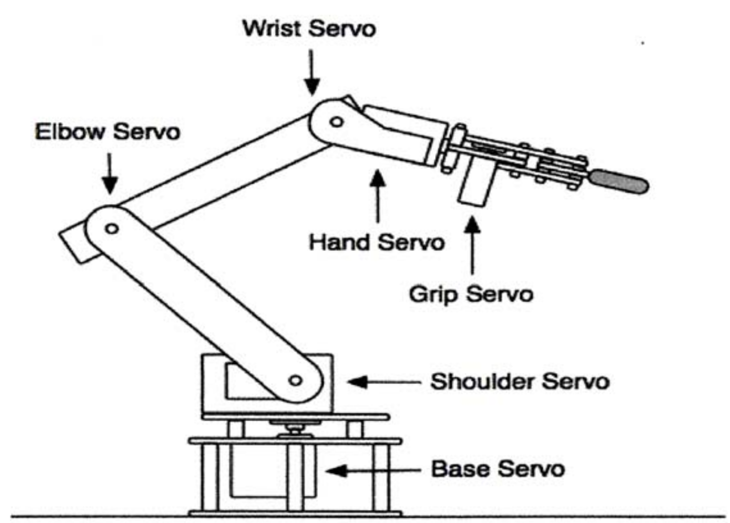


Figure 4. Distribution of Servos.

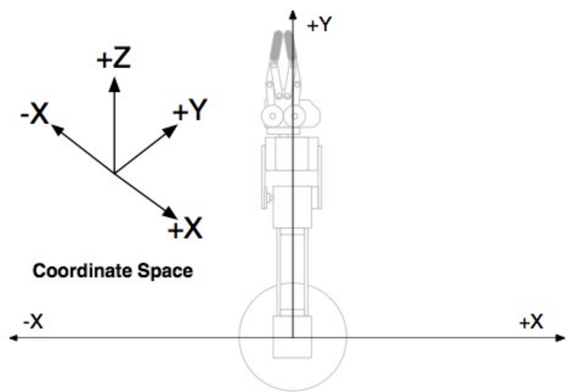


Figure 5. Definition of coordinate space for Lynx5 arm.

Pulse-width modulated signals allow the servomotors to reach a specific position. The servo pulse-width was ranged between 500 to 2500 microseconds which corresponds to a servo rotation angle 0 to 180 degrees. For example, 1500 pulse- width put a servo at 90 degrees.

The base servo controls rotation of the arm in the horizontal (X, Y) plane. On the other hand, elbow, shoulder, and wrist servos control the rotation of the arm in the vertical (Z) direction.

Also, the range for the base servo angle is from 15 to 165 degrees. When the angle of the base servo is at 90 degrees, the arm will be in the positive y-axis. This is the same with the other servos. The shoulder servo rotation is ranged from 15 to 165 degrees. When the angle of the shoulder servo is at 90 degrees, the upper section of the arm, shoulder to elbow, will be in the positive z-axis. The elbow servo rotation is ranged from 0 to 160 degrees. When the angle of elbow servo is at 90 degrees, the lower section of the arm, elbow to wrist, will be at right angles to the upper section of the arm (shoulder to elbow). In the case where the elbow and shoulder servo are at 90 degrees, the upper section of the arm will be parallel with horizontal (X, Y) plane as well as parallel with the wrist servo, which is ranged from 0 to 180 degrees. The lower section of the arm, elbow and wrist, are collinear with the gripper when the angle of the wrist servo is at 90 degrees. Finally, the range of motion for the gripper servo is from 0 to 2 inches. The gripper servo will be fully open at 2.0 inches and closed at 0 inches.

The forward kinematic helps us to position the arm in a 3-D space. However all angles for each joint should be known. The position of any point in the arm can be calculated by starting the calculation from the base and going through each joint successively until the (X, Y, Z) coordinates are determined. On the other hand, inverse kinematic is defined as calculating the required joint angles for each joint. [3]

This work performs the inverse kinematic calculation with the Arduino Mega chip. First, some inputs should be specified. These include the (X, Y, Z) coordinates for gripper point, the angle of gripper from horizontal, and the width of gripper. Secondly, there are some values that should be known. These are the base location, located at coordinate (0, 0,0), and the height of the shoulder which is 3.0 inches in Lynx5 robotic arm, the height of the upper section of arm and the height of lower section of arm both of which are 4.75 inches each and the grip width. In this work, the 3-D inverse kinematic calculation is reduced to 2-D inverse kinematic clcluation by making two planes, z-plane and XY-plane.

The z-plane is a vertical plane, which is also the centerline of all arm's section. The (X,Y) planes are horizontal planes that the base of the arm rested on. The Z-plane is perpendicular to (X,Y) plane. Figure 6 shows how to calculate the base angle by using (X,Y) coordinates.

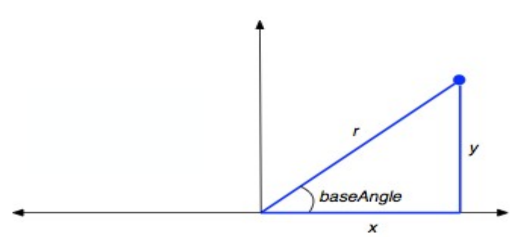


Figure 6. Angle's calculation.

r, radical distance is the distance between the points (0,0,0) to (X,Y,0). The base angle and r is calculated as follows:

$$\alpha = \text{Atan}\ (y/x)$$

$$r = \text{sqrt}\ (x^2 + y^2)$$

Figure 7 shows how to calculate the angle of the elbow, shoulder, and wrist.

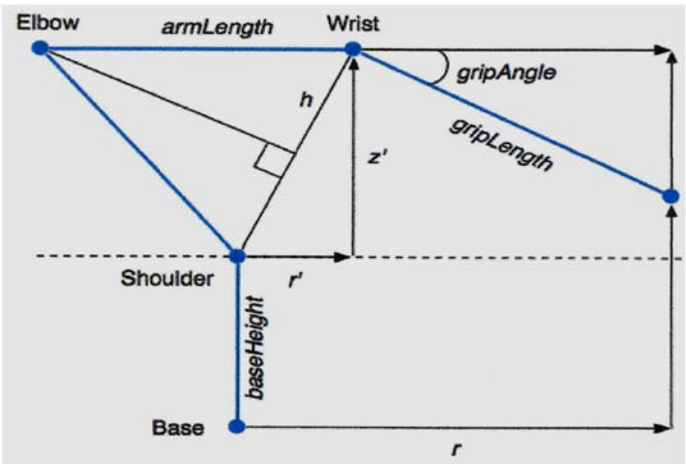


Figure 7. Calculate the angle of elbow, shoulder and wrist.

Before calculating the angles of the arm, Z-plane side, two values must be known: r' and z'. These values are given by using the equations below:

*r' = r – (sin(Grip Angle)*Grip Length)*

*z' = z – Base Height + (cos(Grip Angle)*Grip Length)*

Once r' and z' are given, the Elbow angle ca be calculated as follows:

$$h = sqrt\ (z'^2 * r'^2)/2$$

$$Elbow\ Angle = Asin(h/arm\ Length)*2$$

Once elbow angle is given, the shoulder angle can be calculated as follows:

ShoulderAngle = Atan($z'^2 * r'^2$) + ((pi-ElbowAngle)/2)

Once the shoulder angle is given, the wrist angle can be determined as follows:

WritstAngle = pi + GripAngle-Shoulder-ElbowAngle

3) Metal Detector

In this work, we depend on metal detector, because we need to decide object if the is metallic or non-metallic.

A metal detector is a device which takes advantage of the electric and magnetic properties of metals (Eddy currents) to detect metals. Eddy currents are electric currents induced within conductors by a changing magnetic field in the conductor, see Figure 8. The metal detector generates electromagnetic fields by passing an electrical current through the coil. The magnetic field surrounds the coil. If the object has a magnetic field, the magnetic field will create the current (Figure 6). As a result, the metal generates a magnetic field of its own, and the detector senses this field and detects metal (Figure 9). Metal detectors are used for security and industrial purposes. They are also used for the detection of treasurers.

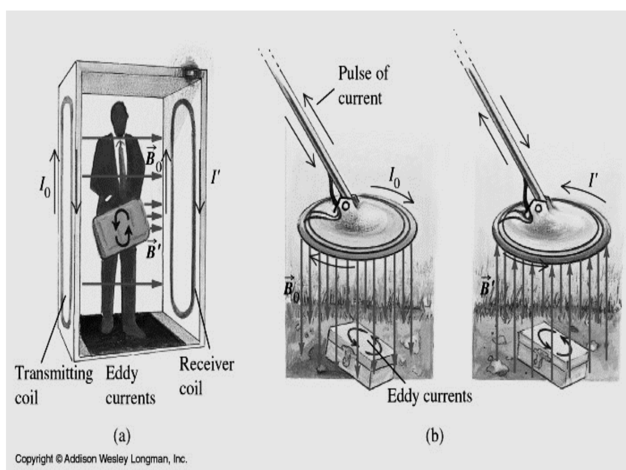
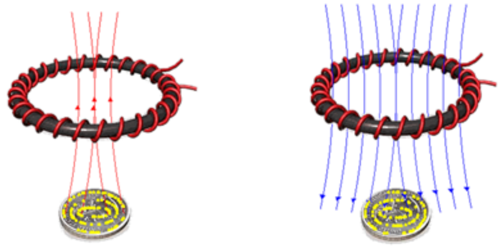


Figure 8. Eddy Currents [4].



(a) (b)

Figure 9. Metal Detector Working [5].

A metal detector consists of simple parts, which are as follows:

a) Search coil, which is the main section of the device. It is used in the metal detector and is sometimes called the detection head.
b) LED indicators light up when the detection detects metallic objects.

The metal detector is placed in front of the vehicle. When the vehicle moves, the metal detector is turned on to detect a metallic object. If the metal detector detects a metallic object, the vehicle will stop. This is because there are two wires taken from the LED, which exist in the metal detector's circuit, and they are connected to the amplifier's circuit to receive a signal from the metal detector. The amplifier's circuit is responsible for sending a signal to the Arduino Mega, which controls the movement of the vehicle. Figure 10 shows the metal detector placement.

4) Sensory

In this work, there are two kinds of sensors: the ultrasonic sensor and the infrared sensor (IR). Next, we briefly describe the two kinds and explain their job.

Ultrasonic Sensor

There is an ultrasonic sensor in front of the chassis, which is responsible for changing the path of the vehicle if there is an obstacle. The Ultrasonic sensor works by transmitting calculates the distance between the target and sensor. Figure 11 shows the working principle of the ultrasonic sensor. In addition, there are three pins, which are specified as: one for voltage, one for ground, and the last one for signal. The ultrasonic sensor takes +5 VDC. It is easy to connect using a servo extension cable [6]. It has a range of 2cm to 3 m[6].

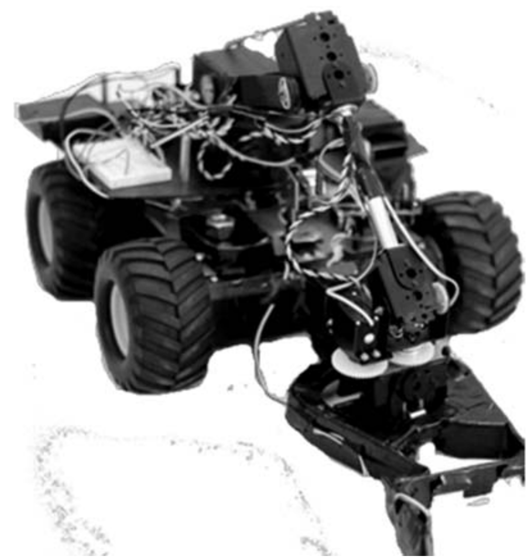


Figure 10. Metal Detecor.

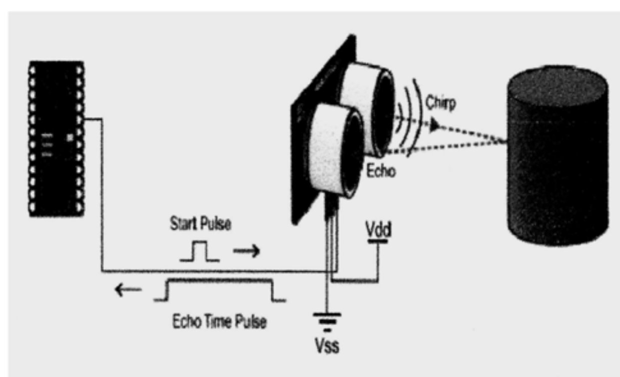


Figure 11. Ultrasonic Sensor [6].

IR Sensor

In this work, the contraption, which is installed in front of a metal detector, was enhanced with an IR distance sensor mounted at the front of the contraption. The reason for using an IR sensor is for measuring the distance to the closest object and supporting the metal detector to check on the object. An IR sensor is used to scan the working field in an arc 35 to 125 degrees in 5 cm.

5) Control Unit (Arduino Mega 2500 Microcontroller and Arduino Motor Shield)

Arduino microcontroller on board can be programmed using Arduino programming language. Arduino Mega is based on ATmega 1280 and has 54 pins distributed as 14 PWM outputs, 16 analog inputs, 4 serial port and 16-crystal oscillator. Arduino Mega obtains power in a range of 7 – 12 V from USB cable or an external power supply. Arduino Mega is also connected to the Arduino motor shield as well as all sensors are connected to Arduino Mega [7].

B. Software Design

In this section, we describe briefly software architecture of this work, such as obstacle avoidance, detection, and arm movement. All these tasks come under general algorithm that controls the robot.

1) Algorithm

The general algorithm has main steps to accomplish the general tasks, which are start, travel, stop, drop, pickup, and end. The program will begin with start step; through this step the Arduino Mega will run and check for pins and then go to the next step, which is travel. During this step, the robot moves and utilizes both the metal detector and IR sensor to check for any passing object. In case the detector or IR sensor finds an object, the robot will go to stop step and then pickup step to pick the object up. After that, the robot will check if the object is metallic object or not by passing it over the metal detector. In case the object is metallic the robot will go to drop step and drop it in box 2 and increment the metallic counter then check for the limit of metallic object counter. If metallic counter equal to the limit of metallic object counter, the robot will go to the end step. Otherwise, the robot will return to the travel step till it finds another object. On the other hand, if object is not metallic, the robot will go to drop step and drop it in box 1 and increment the non-metallic object counter then check for the limit of non-metallic counter. If non-metallic counter equal to the limit of non-metallic object counter, the robot will go to end step. Otherwise, the robot will return to the travel step. Figure 12 shows an overview of operating algorithm.

a) Obstacle Avoidance

This task depends on ultrasonic sensor. First of all, the robot starts with reading and determining the path free of obstacles. In the case of the readings being less than or equal to the allowable distance limit, the robot will stop and go back to find another path. In the other case, if reading is greater than distance limit the robot will continue to move.

b) Detection

This task depends on metal detector and IR sensor. The robot obtains a signal from both metal detector and IR sensor when it finds any metallic or non-metallic object, the robot will stop and pick it up. In case, the metal detector does not detect a metallic object the robot will still depend on IR sensor to check if there is any non-metallic object stuck in Contraption.

c) Arm Movement

As we mentioned in Lynx5 robotic arm subsection, the robot's arm has six servomotors and each of them can move from 0 to 180 degree. In this work, we depend on inverse and forward kinematics to calculate angles for all these servomotors. This challenge is to operate the arm smoothly.

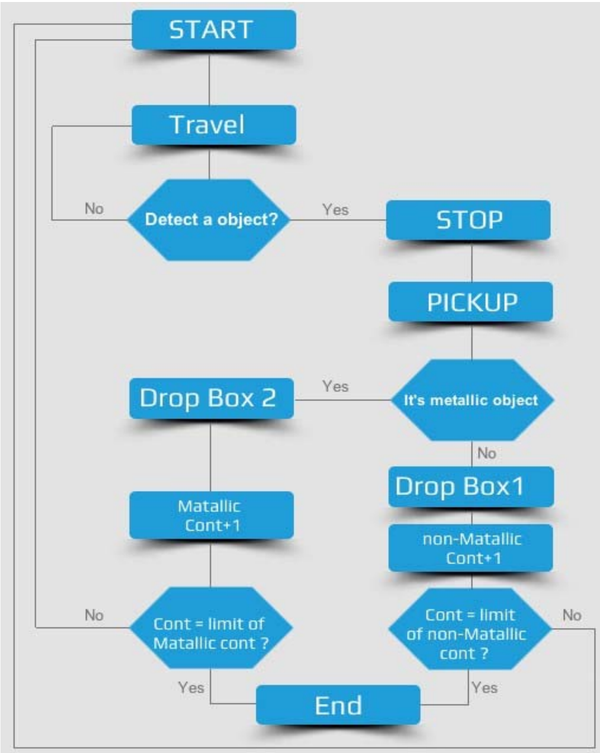


Figure 12. Operating Algorithm.

Experimental Results

We have designed and implemented metallic waste collection robot. We have performed different experiments to explain system's ability and its accuracy in doing the task. Figure 13 shows the photos of metallic waste collection robot during doing the main task. We have built a re-configurable and flexible hardware, which can be developed in the future. We tested the robot in different environments and experiments, such as metallic or non-metallic object detection.

First we started with obstacle avoidance task. To conduct this experiment, we randomly placed the robot in area and monitored the robot's movement. The robot stopped on moving when it faced any close object and changed its path. Second experiment was object detection task, we tested metal detector with metallic or non-metallic object, and we succeed to obtain a signal from metal detector when we passed metallic object over it. Third experiment was arm movement task, in this task; we put a metallic object in front of robot. We noticed the robot moved forward and then stopped and started moving the arm smoothly to pick it up then passed it over metal detector to check if the object is metallic or not. After that, the robot dropped the object in metallic object box. The result of these experiments showed that the robot has succeeded in object detection, obstacle avoidance, and arm movement task. According to the results, the robot preformed the desired task efficiently.

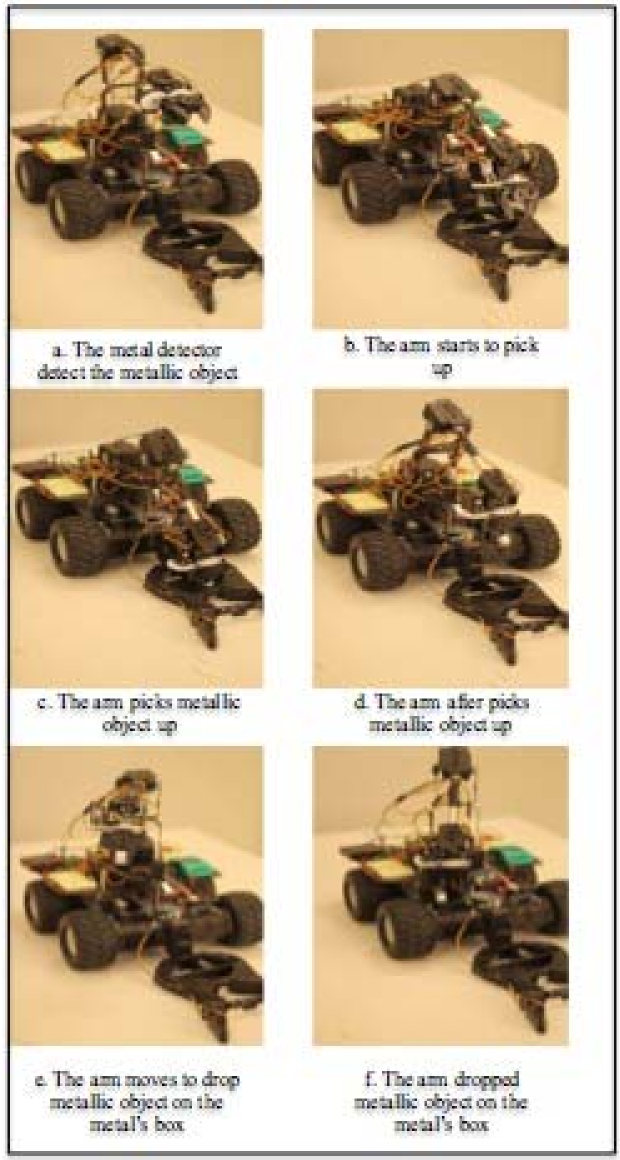


Figure 13. Drop Metallic Object on the Metallica's Box.

In comparison, the Zen Robotic Recycling only works in specific environments that require a waste stream and it has a high installing and operating cost. Our robot can work in different environments that have flat and rough terrain like garbage dumps and it has a low operating cost. This system can also be modified with additional sensors and actuators to sample other different kinds of waste.

Conclusion

Our goal was to build a robot that can identify and collect metallic or non-metallic object in a specific area. We used Arduino mega microcontroller with motor shield to control this robot. We demonstrated the working of this robotic system using a set of experiments that are monitor to the actual environment. In addition, there were some issues we faced during the testing of this robot. One of those issues was obtaining a signal from the metal detector; we bought a metal detector and re-design it to fit our work. We connected its circuit directly to Arduino Microcontroller. Figure 14 shows the signal that we succeed to obtain from metal detector circuit. The issue was dealing with that signal via Arduino Microcontroller. In order to deal with that signal, we wrote a small method to limit voltage value in 0 or 1. Zero means voltage off and one means voltage on. The method that we wrote has worked well and gave us a reliable reading. Other issue was with collection of small metallic object. We solved that issue with building a contraption to collect a small object. Finally, this modular system can be extended to handle different type of waste.

For more information about this work including working videos, pictures, and code, please visit: www.robotcomes.com

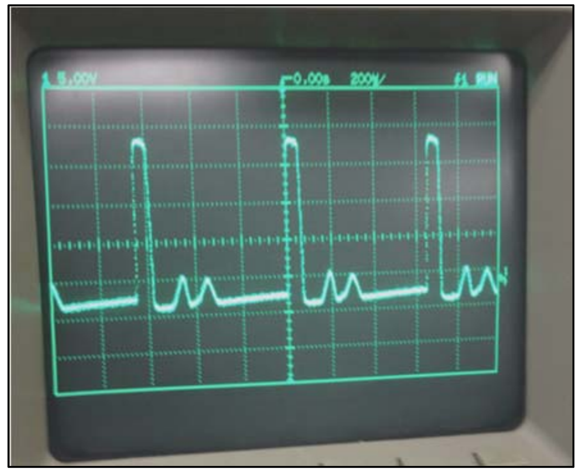


Figure 14. Detecting a Signal from the Metal Detector.

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Editor Note

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