Plastic Waste Segregation Using Robotic Arm

PLASTIC WASTE SEGREGATION USING ROBOTIC ARM

A DISSERTATION SUBMITTED TO

GOA UNIVERSITY

FOR THE DEGREE OF

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IN

ELECTRONICS

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<u>CERTIFICATE</u>

This is to certify that the project entitled

“PLASTIC WASTE SEGREGATION USING ROBOTIC ARM”

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M.Sc. Part II (Electronics)

2019-2020

The candidates themselves have worked on the project during the period of study under my guidance and to the best of my knowledge it has not previously formed the basis of award of any previous degree or diploma at Goa University.

HOD (Electronics)	**Examiner**	**Project Guide**

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<u>DECLARATION</u>

I hereby declare that, the thesis entitled "**PLASTIC WASTE SEGREGATION USING ROBOTIC ARM"** submitted by us for the award of Degree of Master of Science in the faculty of Science of Goa University, Goa – India has been completed and written by us, has not previously formed the basis for the award of any Degree or Diploma or other similar title of this or any other University in India or any other country or examining body to the best of my knowledge.

M.Sc. (Electronics)

2019-2020

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Date: - - 2020

Place: Goa

ABSTRACT

Waste management is one of the primary problems in the world. As tonnes of waste is produced across the world therefore its proper disposal is a must. Improper disposal of waste can cause numerus problems to environment as well as to human beings.

In most of the waste management plants waste collected is already separated as dry waste & wet waste. The wet waste is converted into bio gas through different processes while dry waste is manually segregated by the workers. Manual segregation can be harmful and toxic.

Hence, we propose a system to segregate plastic waste using robotic arm with image processing. The sensor used is a CMOS camera which detects the object under it and image processing algorithms like CNN, SVM will take place. The plastic waste detected is compared with the pre-defined database to distinguish its type. Once its type is distinguished by the algorithm a signal from an Arduino board is sent to the robotic arm to pick-up the waste and place into a container. Similarly, the mechanism works for more than one plastic type like plastic bottles, plastic bags. After the waste being placed in the container the arm returns to its original position.

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CHAPTER 1

INTRODUCTION

Introduction

Waste is any substance which is discarded after its use, or is defective, worthless etc. Once a substance (edible/ nonedible) is used it needs to be discarded.

Figure1. 1 Dry Waste

According to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal of 1989, Art. 2(1), "'Wastes' are substance or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law".

Types of waste:

There are many waste types defined by modern systems of waste management, including:

- Municipal waste which includes household waste, commercial waste, and demolition waste
- Hazardous waste that includes industrial waste
- Biomedical waste like clinical waste

- Special hazardous waste like radioactive waste, explosive waste, and electronic waste (e-waste)

Household waste, is waste that consists of everyday items that are discarded by the public. "Garbage" can also refer specifically to food waste.

Commercial waste consists of waste from places used mainly for the purposes of a trade or business or sport, recreation, education or entertainment,

Demolition waste is waste debris from destruction of rroads, bridges, buildings, or other structures. Debris varies in composition, but the major components include concrete, brick and clay tile, asphalt shingles, steel, wood products and drywall. Many of these wastes can recycled.

Industrial waste it is produced by industrial activity which includes any material that becomes useless during a manufacturing process such as that of mills, industries, factories and mining operations. It includes gravel and dirt, scrap metal, masonry and concrete, chemicals, oil, solvents, scrap lumber, even vegetable matter from restaurants and hotels. Industrial waste may be liguid, solid or gaseous. It may be hazardous or non-hazardous waste. Hazardous waste may be corrosive, ignitable, toxic, reactive, or radioactive. Industrial waste may pollute the soil, the air, or nearby water sources, eventually ending up in the sea.

Biomedical waste it contains infectious materials, waste associated with the generation of biomedical waste that appears to be of medical or laboratory origin (e.g infusion kits, unused bandages, packaging etc.), as well research laboratory waste containing biomolecules or organisms which are restricted from environmental release.

It may be liquid or solid. Examples of infectious waste like sharps, unwanted microbiological cultures and stocks, discarded blood, identifiable body parts, used bandages and dressings, other human or animal tissue, discarded gloves, other medical supplies that may have been in contact with blood and body fluids, and laboratory waste that exhibits the characteristics described above. Waste sharps include potentially contaminated used (and unused discarded) needles, scalpels, lancets and other devices capable of penetrating skin.

Hazardous waste it has any potential or substantial threats to public health or the environment.

- Characteristic hazardous wastes are materials that are known or tested to exhibit one or more of the following hazardous traits:
  - Ignitability
  - Reactivity
  - Corrosivity
  - Toxicity
- Listed hazardous wastes are materials specifically listed by regulatory authorities as hazardous wastes which are from discarded chemical products, specific sources or non-specific sources,

Radioactive waste is a type of hazardous waste that contains radioactive material. Radioactive waste is a by-product of various nuclear technology processes. Industries generating radioactive that waste include nuclear medicine, nuclear power, nuclear research, manufacturing, construction, coal and rare-earth mining and nuclear weapons reprocessing.[1] Radioactive waste is regulated by government agencies in order to protect human health and the environment.

In modern nuclear plants over 96% of spent fuel is recycled back into uranium-based and MOX fuel. Radioactivity of the remaining 4% fission products naturally decreases over time, so it has to be isolated and confined in appropriate disposal facilities for a sufficient period until it no longer poses a threat.[2] The time radioactive waste must be stored for depends on the type of waste and radioactive isotopes. Current approaches to radioactive waste storage have been segregation and storage for short-lived waste, nearsurface disposal for low and some intermediate-level waste, and burial in a deep geological repository or transmutation for the high-level waste.

Electronic waste or **e-waste** describes discarded electrical or electronic devices. Used electronics which are destined for refurbishment, reuse, resale, salvage recycling through material recovery, or disposal are also considered e-waste. Informal processing of e-waste in developing countries can lead to adverse human health effects and environmental pollution. Electronic scrap components, such as CPUs, contain potentially harmful materials such as lead, beryllium, or brominated flame retardants. Recycling and deposite od e-waste may involve significant risk to health of workers and their communities.

The waste generated is in abandance therefore, improper disposal of waste can cause numerous problems to environment as well as to human beings. Improper disposal of dry waste can have an effect on soil, air, water etc. Some wastes that end up in landfills excrete hazardous chemicals that leak into the soil and affects plant growth. For example, if a plastic bottle is thrown, it eventually breaks down, releases DEHA, a carcinogen that affects our reproduction systems, causes liver dysfunction, and weight loss. It is also unhealthy to humans and animals feeding on those plants. Even the marine life is endangered. Hence, waste management is one of the primary problems. Since improper waste disposal has such a negative effect proper waste management is a must!

Waste sorting is the process by which waste is separated into different elements. Waste sorting can occur manually at the household and collected through curbside collection schemes, or automatically separated in materials recovery facilities or mechanical biological treatment systems. Hand sorting was the first method used in the history of waste sorting. "Waste segregation" means dividing waste into dry and wet. Dry waste includes wood and related products, metals and glass. Wet waste typically refers to organic waste usually generated by eating establishments and are heavy in weight due to dampness. Waste can also be segregeconomic concern. Waste Segregation is different from Waste Sorting. Waste Segregation means to group Waste into different Categories. Each waste goes into its category at the point of dumping or collection. Sorting comes after collection or dumping. According to the Cambridge Dictionary, sorting involves separating items into groups and cites sorting of wastes as an example. Segregation of waste ensures pure, quality material. Sorting on the other hand will end up producing impure materials with less quality.

In most of the waste management plants waste collected is already separated as dry waste and wet waste. The wet waste is converted into bio gas through different processes while dry waste needs to be segregated so that it can be recycled. Dry waste contains all the waste which is not wet. It can contain waste like metals, glass materials, plastic materials, wooden pieces, wraps etc. Much of the waste can segregated with respect to its weight. Metals can be segregated by employing an electromagnet. Light weight wastes like plastic bags, bottles, tins, cup, cans etc needs to be segregated manually.

Figure1. 2 Manual Segregation

Manual segregation can be harmful and toxic. It can also be very hectic and mentally challenging to the workers involved. It is also be very time consuming and with the health problems encountered can deteriorate workers performance. The harmful and toxic can be life threatening as well.

To overcome this problem of harmful manaul segregation, in this project we have tried to build a robotic arm which will segregate the plastic bottles automatically without having any need of human involvement. There are different kinds of robots that can be used.

Types of Robots

Mechanical bots come in all shapes and sizes to efficiently carry out the task for which they are designed. From the 0.2 millimeter-long “RoboBee” to the 200-meter-long robotic shipping vessel “Vindskip,” robots are emerging to carry out tasks that humans simply can’t. Generally, there are five types of robots:

Pre-Programmed Robots

Pre-programmed robots operate in a controlled environment where they do simple, monotonous tasks. An example of a pre-programmed robot would be a mechanical arm on an automotive assembly line. The arm serves one function — to weld a door on, to insert a certain part into the engine, etc. — and it's job is to perform that task longer, faster and more efficiently than a human.

Humanoid Robots

Humanoid robots are robots that look like and/or mimic human behavior. These robots usually perform human-like activities (like running, jumping and carrying objects), and are sometimes designed to look like us, even having human faces and expressions. Two of the most prominent examples of humanoid robots are Hanson Robotics’ Sophia (in the video above) and Boston Dynamics’ Atlas.

Autonomous Robots

Autonomous robots operate independently of human operators. These robots are usually designed to carry out tasks in open environments that do not require human supervision. An example of an autonomous robot would be the Roomba vacuum cleaner, which uses sensors to roam throughout a home freely.

Teleoperated Robots

Teleoperated robots are mechanical bots controlled by humans. These robots usually work in extreme geographical conditions, weather, circumstances, etc. Examples of teleoperated robots are the human-controlled submarines used to fix underwater pipe leaks during the BP oil spill or drones used to detect landmines on a battlefield.

Augmenting Robots

Augmenting robots either enhance current human capabilities or replace the capabilities a human may have lost. Some examples of augmenting robots are robotic prosthetic limbs or exoskeletons used to lift hefty weights.

APPLICATIONS OF ROBOTICS

- Helping fight forest fires
- Working alongside humans in manufacturing plants (known as co-bots)
- Robots that offer companionship to elderly individuals
- Surgical assistants
- Last-mile package and food order delivery
- Autonomous household robots that carry out tasks like vacuuming and mowing the grass
- Assisting with finding items and carrying them throughout warehouses

- Used during search-and-rescue missions after natural disasters
- Landmine detectors in war zones

The Robotic ARM required for this project is “industrial type”. There are around six main types of industrial robots: cartesian, SCARA, cylindrical, delta, polar and vertically articulated. However, there are several additional types of robot configurations. Each of these types offers a different joint configuration. The joints in the arm are referred to as axes.

Figure 1.3 Diffferent types of robotic arms

Articulated

This robot design features rotary joints and can range from simple two joint structures to 10 or more joints. The arm is connected to the base with a twisting joint. The links in the arm are connected by rotary joints. Each joint is called an axis and provides an additional degree of freedom, or range of motion. Industrial robots commonly have four or six axes.

Cartesian

These are also called rectilinear or gantry robots. Cartesian robots have three linear joints that use the Cartesian coordinate system (X, Y, and Z). They also may have an attached wrist to allow for rotational movement. The three prismatic joints deliver a linear motion along the axis.

Cylindrical

The robot has at least one rotary joint at the base and at least one prismatic joint to connect the links. The rotary joint uses a rotational motion along the joint axis, while the prismatic joint moves in a linear motion. Cylindrical robots operate within a cylindrical-shaped work envelope.

Polar

Also called spherical robots, in this configuration the arm is connected to the base with a twisting joint and a combination of two rotary joints and one linear joint. The axes form a polar coordinate system and create a spherical-shaped work envelope.

SCARA

Commonly used in assembly applications, this selectively compliant arm for robotic assembly is primarily cylindrical in design. It features two parallel joints that provide compliance in one selected plane.

Delta

These spider-like robots are built from jointed parallelograms connected to a common base. The parallelograms move a single EOAT in a dome-shaped work area. Heavily used in the food, pharmaceutical, and electronic industries, this robot configuration is capable of delicate, precise movement.

Further more this system uses a CMOS camera to detect and capture an image of the plastic waste under it among the other wastes. The detection is done with the help of image processing. Algorithm like CNN is used for the same. In deep learning, a convolutional neural network (CNN, or ConvNet) is a class of deep neural networks, most commonly applied to analyzing visual imagery. They are also known as shift invariant or space invariant artificial neural networks (SIANN), based on their shared-weights architecture and translation invariance characteristics. Image classification began in the late 1950s and has been widely used in various engineering fields, human-car tracking, fingerprints, geology, resources, climate detection, disaster monitoring, medical testing, agricultural automation, communications, military, and other fields. A large number of image classification methods have also been proposed in these applications, which are generally divided into the following four categories. Image classification methods based on statistics: it is a method based on the least error, and it is also a popular image statistical model with the Bayesian model and Markov model. Image classification methods based on traditional colors, textures, and local features: the typical feature of local features is scale-invariant feature transform (SIFT). This method was first proposed by David in 1999, and it was perfected in 2005. SIFT looks for the position, scale, and rotation invariants of extreme points on different spatial scales. It is widely used in object recognition, panoramic image stitching, and modeling and recognition of 3D scenes and tracking. However, this type of method has problems such as dimensionality disaster and low computational efficiency. Image classification method based on shallow learning: in 1986, Smolensky proposed the Restricted Boltzmann Machine (RBM), which is widely used in feature extraction, feature selection, and image classification. In 2017, Sankaran et al. proposed a Sparse Restricted

Boltzmann Machine (SRBM) method. Its sparse coefficient is determined by the normalized input data mean. It defines a data set whose sparse coefficient exceeds the threshold as a dense data set. It achieves good results on the MNIST data set. However, the characteristics of shallow learning are not satisfactory in some application scenarios. Image classification method based on deep learning: in view of the shortcomings of shallow learning, in 2006, Hinton proposed deep learning technology. For the first time in the journal science, he put forward the concept of deep learning and also unveiled the curtain of feature learning. In view of this, many scholars have introduced it into image classification. Krizhevsky et al. presented the AlexNet model at the 2012 ILSVRC conference, which was optimized over the traditional Convolutional Neural Networks (CNN). It mainly includes building a deeper model structure, sampling under overlap, ReLU activation function, and adopting the Dropout method. It is applied to image classification, which reduces the image classification Top-5 error rate from 25.8% to 16.4%. Therefore, this method became the champion of image classification in the conference, and it also laid the foundation for deep learning technology in the field of image classification. Since then, in 2014, the Visual Geometry Group of Oxford University proposed the VGG model and achieved the second place in the ILSVRC image classification competition. It reduces the Top-5 error rate for image classification to 7.3%. Its structure is similar to the AlexNet model, but uses more convolutional layers. In 2015, Girshick proposed the Fast Region-based Convolutional Network (Fast R-CNN) for image classification and achieved good results. Compared with the previous work, it uses a number of new ideas to improve training and testing speed, while improving classification accuracy. In 2017, Lee and Kwon proposed a new deep convolutional neural network that is deeper and wider than other existing deep networks for hyperspectral image classification. In 2018, Zhang et al. proposed an image classification method combining a convolutional neural network and a multilayer perceptron of pixels. It consistently outperforms pixel-based MLP, spectral and texture-based MLP, and context-based CNN in terms of classification accuracy. This study provides an idea for effectively solving VFSR image classification. Some scholars have proposed image classification methods based on sparse coding. For example, Zhang et al. embedded label consistency into sparse coding and dictionary learning methods and proposed a classification framework based on sparse coding automatic extraction. Jing et al. applied label consistency to image multilabel annotation tasks to achieve image classification. Zhang et al. proposed a valid implicit label consistency dictionary learning model to classify mechanical faults. However, this type of method still cannot perform adaptive classification based on information features.

The detected image of plastic waste is then compared with the pre-defined database to distinguish its type. Once its type is distinguished by the algorithm a signal from an Arduino board(microcontroller) is sent to the robotic arm to pick and place the waste into a container. Similarly, the mechanism works for more than one plastic type like plastic bottles, plastic bags. After the waste being placed in the container the arm returns to its original position.

The main goal of this project is to develop a robotic arm which will automatically detect the waste, pick it and place it in the respective container and hence reducing risk to the human life.

CHAPTER 2

LITERATURE SURVEY

Automation of Object Sorting System Using Pick & Place Robotic Arm & Image Processing paper presents a smart approach for a real time inspection and selection of objects in continuous flow. This paper presents a mechatronics colour sorting system solution with the application of image processing. Image processing procedure senses the objects in an image captured in real-time by a webcam and then identifies colour and information out of it. This information is processed by image processing for pick-and-place mechanism. The Project deals with an automated material handling system. It aims in classifying the coloured objects by colour, size, character which are coming on the conveyor by picking and placing the objects in its respective pre-programmed place. Thereby eliminating the monotonous work done by humans, achieving accuracy and speed in the work. The project involves sensors that senses the object's colour, size and sends the signal to the microcontroller. The microcontroller sends signal to circuit which drives the various motors of the robotic arm to grip the object and place it in the specified location. Based upon the detection, the robotic arm moves to the specified location, releases the object and comes back to the original position.

Automatic Waste Segregation using Image Processing and Machine Learning paper provides a solution that can detect, identify and segregate waste items into biodegradable and non-biodegradable categories without any human assistance. The waste segregator is a centrally partitioned movable bin that travels in the area of interest and picks up any waste item in its path. This work is an integration of machine learning concept, Image processing and embedded application using Raspberry Pi. The robotic arm places the object on a rotating flap attached over the two compartments. Machine Learning is used to identify the category of the waste item. The proposed system does not use any sensors and is totally based on training hardware using artificial intelligence. The waste item is then dropped into its respective compartment by the rotating flap. The system continues to travel in its path until the end of the area is reached. The designed segregation of bio-degradable and non-biodegradable items is carried out with 92% accuracy in short time.

Smart Garbage Separation Robot with Image Processing Technique project states that rising garbage of the world poses serious threats to human being because escalating amount of waste generated each minute by an individual. Approximate 0.2 million tones' garbage generated per day only in India. Maximum garbage cannot be fixed to proper solution because separation mechanism is not present widely in India. Only rage picker does separation of garbage in some cities but it cannot complete the whole separation. As only 30-40% garbage is separated daily. Some garbage cannot be separated by hand as they are hazardous like chemical waste, medical waste, floating waste etc. so the separation of the garbage is needed which is safe, lenient and automatic. The aim of the paper is to present a smart robot which is capable of separating degradable and non- degradable waste using image processing techniques. The proposed robot is in random motion whenever it senses any object it stops and camera takes image of the object, after processing and segmentation is done, it separates waste into degradable and non-degradable waste.

Object Sorting Robot Using Image Processing paper presents a system in which a robotic arm sorts objects according to their colour and shape. Objects are categorized into three colours which are red blue and green. The objects are also differentiated based on their shape into two categories, one with edges and other without edges. The image of the object to be sorted is captured using a webcam and image processing is done using MATLAB. The robotic arm is controlled by an ARM 7 based system. Geared DC motors are used for operating the robotic arm.

Object Detection using Image Processing for an industrial Robot paper talks about the increasing need of automation, machine vision is supposed to be pioneer future technology. Industrial automation and robotics are at high demand in the industry as both of them directly affect the growth of industry. Vision sensors are used for providing visual information to assist robot controllers. The robot controller uses the extracted object information and the simulation program to control the robot arm for approaching, grasping and relocating the object. One picture is worth more than 10,000 words. Image processing has become the most common and powerful emerging technology. Machine vision gives flexibility to identify and manipulate any surrounding object. Ensuring reliability and reducing per unit cost are two fundamental objectives of process automation in manufacturing industry. The focus is on the technical details of pick and place robot. For a pick and place application accurate positioning is essential in assuring product quality and also fast and stable operating speed enables high product rate to be achieved. Also, colour is the most common feature to distinguish between objects, sorting, recognizing and tracking.

Object Sorting Robot Using Image Processing paper object sorting is done based on colour criteria. Object Sorting Robot using image processing is operating using ARM 7. For the detection of colour, it uses image processing technique. This robot has robotic arm which is used for the function of pick and place, and its arm can move in a vertical direction. This paper presents an object sorting system solution based on colour with the application of image processing. Image is captured in real-time by a webcam and then image processing is used for identification of colour and information out of it. This information is processed for picking the object on the basis of colour and place at particular position. The Project deals with an automated material handling system. The aim of the project is classifying the objects based on its colour.

Waste Segregation using Convolutional Neural Network paper works with a system based on Convolutional Neural Networks. The basic idea is that when the waste is to be dumped in the garbage bin, the system will identify the type of waste and will open the dustbin of that category accordingly. Using this system, it becomes easier the segregate waste at the basic level. The system has four categories in which waste will be segregated namely, glass, paper, plastic, metal. Four distinct dustbins along with servo motors will be used for the same.

Literature Review of Automated Waste Segregation System using Machine Learning: A Comprehensive Analysis presents that waste management is a pervasive problem in today's world and is rising continuously with a rise in urbanization. Waste management has a vibrant part to have an ecological environment. Proper waste disposal at the dumping sites has an essential part in sorting at the base level. Increases in time and more manpower is needed in order to sort waste using the traditional process. Sorting waste can be done in various methods and forms. Analysing and classifying the garbage using image processing can be a very productive way to process waste materials. This paper aims to analyse existing research presented studies around the globe. This will enable to determine the problems, an algorithm used and method of those cited studies. It can also assess the correct algorithm to be used in a future study. These paper talk about the different methods and proposed systems in which waste segregation took place. These also talk about the drawbacks faced by the already existing systems and algorithms they used. With it, this paper gives a lot of opportunities to produce new knowledge in creating a new system. Keywords - Convolution Neural Networks, Deep Learning, Image Processing, Segregation, Support Vector Machine, Waste Classification.

Artificial Neural Network based Intelligent Waste Segregator presents that in today's fast-paced world, we are facing an escalating problem in ensuring efficacious and sustainable management of waste. This is a result of rapid increase in urbanization and industrialization. India ranks second in the world after China, in terms of population and this rising population has given way to an increase in the use of resources and ultimately resulting in a proportional increase in waste generation. Waste management has gained popularity as an issue that requires immediate attention and action. Waste segregation is the most important step in this process. The objective of this project is to capture images of a single waste material and effectively identify and segregate it into six classes viz. Metal, Cardboard, Glass, paper, plastic and miscellaneous. The proposed system exploits Deep learning and is mechanized using a robotic manipulator to ensure effective automated waste management and will speed up the process of segregation without any human intervention. Index Terms - Deep learning, Artificial Neural Networks, Robotic Manipulator, and Waste Segregation

Sensory-Based Colour Sorting Automated Robotic Cell presents that robotics application in colour recognition using fiber optic cabled sensors interfaced with robot controller and Programmable Logic Controller (PLC) is discussed in this paper. The sensors send input signals to the robot controller and the specified program will be executed with respect to the triggered input. The aim of this research work is to recognize colour by pin point detection and sorting of object specimens with respect to their colour attributes, which includes hue, saturation and luminance level. The controller programs were designed to control the robot and the conveyor belt independently parallel to each other via relays, to be synchronized during operation. Finally, the calculative results were verified experimentally and the real time implementation was carried out. It can be observed how controllers are integrated and synchronized in a system to perform a desired operation without conflict using real time applications such as chemical, pharmaceutical, agricultural, food industries and even recycling.

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sensors, PLC, automation.

A project states that a software framework for the robotic arm of 3 DOF with motion and path planning is developed using Robotic Operating System (ROS). Gazebo software and Moveit RVIZ is used for designing and motion planning of robotic arm. They have developed a geometric approach to compute inverse kinematics for 3 DOF robotic arm. Inverse kinematics deals with its motion with respect to coordinate frame and also involves complex matrix operation to find solution.

Another project involves image processing which has been the most common and powerful emergency technology. A camera is used for providing visual information to assist robot controller. The waste is dumped on the conveyer belt. The image is captured by the camera placed at fix position. Captured image is then compared with the training set using machine learning. If the captured image matches then the signal is given to the microcontroller to instruct the robotic arm. Robotic arm is trained to move in a predefined path. Robotic arm picks the material and places it into the respective bin and comes back to the original position and waits for the next signal.

PET waste clasi_cation method and Plastic Waste DataBase WaDaBa presents that recycling is one of the most important methods of environmental protection, the purpose of which is to reduce the amount of waste stored in landfills and conservation of natural resources. The recycling should be more widely applied and promoted. However, in order to apply the recycling a sorting of waste is necessary on the ones being recyclable and on remaining. Mixed waste in sorting plants is segregated manual and mechanical. The need for manual sorting selectively collected fractions of municipal waste due to the lack of the corresponding transmission of information related to the rules of the system of selective collection of recyclable materials with low environmental consciousness of society. In addition, manual sorting is time consuming and expensive, so it is advisable to establish and develop methods for automatic sorting of plastic waste. the sorting of the waste is a complex process, and difficult to implement, due to the mechanical deformations and contaminants of delivered waste. Most modern waste collection trucks use a compaction mechanism and waste carried by such vehicles have been affected by mechanical stress and blending, which leads to considerable difficulties in distinguishing individual objects during sorting process.

Waste segregation system using artificial neural networks presents that the waste segregator system aims at automating the segregation using recent tools of Machine Learning. With the help of a powerful deep layered network called Convolutional Neural Network, a Machine Learning tool, high accuracy of segregation results can be achieved. The network is trained for the various waste categories using the appropriate datasets. This trained network is integrated with a mechanical system that performs the physical segregation of waste, thereby avoiding human intervention.

The waste items that are fed into this system are classified to their respective types by three fundamental stages: Acquiring the images of the waste material. Classification done by the Convolutional Neural Network. The physical segregation of the waste conducted by the means of a control mechanism. The waste is segregated into six categories: Recyclable 1, Recyclable 2, Non-Recyclable items (food), Non-Recyclable plastic, Recyclable- paper, Organic. An average of 500 images for each item in every category were collected and compiled to achieve an extensive data set of about 15,000 images in total. The data base created consists of images that were rotated in different angles to increase diversity to suit real time testing conditions.

STAGE 1: Initially, the categories were based on the type of the material. The four categories we considered were – plastic, paper, metal and organic. The Alex Net which is a pre-trained model on ImageNet, was used as a feature extractor. The extracted features served as inputs to a multiclass SVM classifier, which we trained on our new dataset.

STAGE 2: More research on recyclable and non-recyclable materials showed that classification based on materials was less efficient. Since each material varies vastly in grade depending on the usage for which it is manufactured, it made more sense to categorize each material itself into recyclable and non-recyclable categories. This leads to new classification categories- R-paper, R-plastic, Non-recyclable plastic, Non-recyclable paper and Organic and hence, creation of new data base.

STAGE3: Real time testing for the mentioned categories was done using a webcam. Results obtained were satisfactory. Hence, the number of categories and the items under each category were increased for expansion.

STAGE 4: Increase in the number of items lead to modification of existing categories. The new categories were R-plastic, R-paper, R-metal, Organic, N-items (food) and N-Plastic. Real time testing using a webcam was done for the new categories. Results obtained were analysed for misclassifications.

STAGE 5: Transfer learning was used to train the convolutional neural network by adding 2 drop out layers and changing the last fully connected layer to suit our application. Results were compared with the outputs of the previous stage.

STAGE 6: To enhance the performance of the network, we modified the categories further to Recyclable-1, Recyclable-2, R-paper, Organic, N-items (food) and N-Plastic, leading to further changes in the dataset.

Waste segregation using programmable logic controller paper describes an Automated Waste Segregation; we are developing a prototype for separating out metals from waste materials using Programmable Logic Controller. A higher level of automation demands more and more programmable logic controllers (PLC). The advantage of PLC is the automation with a relatively small amount of cabling and a low error rate. Productivity, flexibility and efficiency with only a few contactors (heavy duty relay) specify the controller. The system is completed by modifications and extensions of functions (without mechanical intervention) as well as by communication with other devices via analog, digital and serial interfaces. With programmable logic controllers, processes can be monitored and operated via a PC. In this system the waste will be fed to the conveyor belt through an automatic feed system which will comprise of a hopper and other mechanism. Sensors will detect the waste material on the conveyor belt and start the rotation of conveyor belt. After this, metal Sensors which are clamped below the conveyor belt, will sense the metal particles and in turn stop the conveyor belt. A robotic arm to which an electromagnet is attached will extract the metal from the waste and will deposit it into a bin. The waste material will be carried on further once the metal is extracted and dumped into a waste bin.

Automatic Waste Segregator and Monitoring System paper says rapid increase in population has led to improper waste management in metro cities and urban areas which has resulted in spreading of diseases. It is estimated that 2.02 billion tones of municipal solid waste were generated universally in 2006. The segregation, transport, handling and disposal of waste must be managed properly to minimize the risks to the public, and the environment. An efficient method to dispose the waste has been designed in our project, “automatic waste segregator and monitoring system”. This paper proposes an automatic waste segregator (AWS) which is a cheap, easy to use solution for a segregation system at households, so that the wastes can be sent directly for processing. Automatic waste segregator is designed to sort the waste into three main categories namely; metallic, organic and plastic, thereby making the waste management more effective. Ultrasonic sensors are added for monitoring waste collection process. The sensors would be placed in all the garbage bins. When the garbage reaches the level of the sensor, then the indication will be given to a microcontroller. The microcontroller will give indication to the driver of garbage collection truck by sending SMS using GSM technology.

Waste Separation Smart Dustbin research proposes the use of technology to tackle the issues being faced in terms of waste management. Nowadays poor waste management has caused an increase in landfilling and dumping sites that instigated pollution and a waste of recyclable materials that can be used for recycling or remanufacturing. The method approached to solve this issue wasto construct a waste separation smart dustbin by integrating proximity sensors and a moisture sensor into a microcontroller to detect metal, moist and recyclable waste while using a conveyor belt to segregate it. The constructed prototype provided sufficient results to justify the method attempted. With this research attempted, waste management system is taking its first steps into a successful system to achieve a sustainable environment for the present and the years to come.

Waste Classification System Using Image Processing and Convolutional Neural Networks states that image segmentation and classification is more and more being of interest for computer vision and machine learning researchers. Many systems on the rise need accurate and efficient segmentation and recognition mechanisms. This demand coincides with the increase of computational capabilities of modern computer architectures and more effective algorithms for image recognition. The use of convolutional neural networks for the image classification and recognition allows building systems that enable automation in many industries. This article presents a system for classifying plastic waste, using convolutional neural networks. The problem of segregation of renewable waste is a big challenge for many countries around the world. Apart from segregating waste using human hands, there are several methods for automatic segregation. The article proposes a system for classifying waste with the following classes: polyethylene terephthalate, high-density polyethylene, polypropylene and polystyrene. The obtained results show that automatic waste classification, using image processing and artificial intelligence methods, allows building effective systems that operate in the real world.

The robot, called RoCycle, uses pincers to pick through garbage and identify what materials each bit contains. It could help reduce how much waste gets sent to landfill. Computer Science and Artificial Intelligence Lab at MIT have developed a robot arm with soft grippers that picks up objects from a conveyor belt and identifies what they are made from by touch. The robot, called RoCycle, uses capacitive sensors in its two pincers to sense the size and stiffness of the materials it handles. This allows it to distinguish between different metal, plastic, and paper objects. In a mock recycling-plant setup, with objects passing on a conveyor, RoCycle correctly classifies 27 objects with 85% accuracy. Such robots could be used in places like apartment blocks or on university campuses to carry out first-pass sorting of people's recycling, cutting down on contamination. The drawback is that picking up items one by one takes time. This makes RoCycle too slow for industrial recycling plants, which are expensive to run and need to process waste quickly to cover costs. Some ZenRobotics robots can sort 4,000 objects an hour, for example. The team is working on combining its touch-based robot with a visual system to speed things up. This robot would scan objects passing by and pick up only those it wasn't sure about. RoCycle could also be good at identifying electrical items that have plastic cases, such as video game controllers or electronic toys. A vision-based system would only see the plastic, but RoCycle's capacitive sensors can detect the hidden treasure underneath.

Developing an Intelligent Waste Sorting System with Robotic Arm: A Step towards Green Environment states that waste management as well as sorting is a very crucial task to make the environment green and to ensure better (re)use of the resources. Bangladesh, because of its high-density population, is facing enormous challenges to manage huge amount of wastes produced every day. So, the purpose of this paper is to use the advancement of Information and Communication technology (ICT) to improve the waste management system and make lives better by providing a smarter way for waste sorting and management. In this paper, an intelligent system was proposed and developed for automatically sorting the waste to be used in context of Bangladesh. A light weighted experiment was carried out to evaluate the system performance. The experiment replicated with 11 objects (waste) of different size and types. The experimental results showed that the proposed system was reliable and achieved about 82% accuracy for the categorization of different kinds of waste.

An Approach for Real Time Plastic Waste Segregation Plastic has found an irreplaceable part in human life. Human produces plastic wastes continually which results in pollution. In this paper GLCM (Gray Level Co-occurrence Matrix) technique is used for plastic segregation. Plastic segregation is necessary for recycling; hence they have to be segregated from other wastes. Manufacturing plastics from recycled plastic products uses only two-third of the energy used to make plastics from virgin materials. By the variation in intensity levels of reflected light from the plastic wastes it is segregated. This type of waste management gains attention in recent days due to enormous increase in the wastes generated. Robotic arm controlled using vision system that uses GLCM technique is used for segregation. The GLCM property of contrast is calculated for the given sample and it is compared with the stored pre-defined value. On successful comparison with the given condition a signal is sent through the serial port to the 8051-microcontroller using USART (Universal Synchronous/Asynchronous Receiver/Transmitter) feature. On receipt of this signal, the microcontroller provides movement of the robotic arm by controlling the servo motors.

Robotic Arm for Trash Collecting and Separating Robot presents that the rising population of India poses serious threats with regard to the availability of living space, utilization of natural resources and raw materials, education and employment. The serious peril that follows is the escalating amount of waste generated each minute by an individual.Developing a mechanized system to help save the lives of many and making the world a cleaner and a greener place is the noble objective of the project.A proposed system where the collection of some database of garbage images where it is necessary to train those images and to get some features of all the images and then by using the Pi-camera real time images are captured and then it should detect the features of that particularimage whether it is a garbage image or not, if yes then it will checks for the segregation either dry or wet waste by using kNN algorithm. If there is no garbage on the road then raspberry pi will inform the robot to move forward, if there is any waste present on the road then accordingly to the segregated it will pick and place the garbage in specific direction. That is if it finds out the waste is dry, then the dry waste will be placed on right side else wet waste is placed on left side.

Plastic-plucking robots are the future of recycling - Working in collaboration with the Carton Council and Denver-based municipal waste facility Alpine Waste & Recycling, AMP has taken a two-decade old mechanical trash-sorting system and given it something not even the Great and Powerful Oz could: robotic eyes and an AI brain. The robot has been installed in the Alpine facility for about a year. It uses a visible-light camera to spot milk, juice and food cartons amid a conveyor belt of recyclable waste, plucking them from the line using a robotic arm and twin suction cups. It can pick a steady rate of 60 items per minute, 20 more than the average human worker does, with 90 percent accuracy. That leads to a 50 percent reduction in sorting costs, according to the company.

CHAPTER 3

HARDWARE AND SYSTEM OVERVIEW

HARDWARE COMPONENTS

ARDUINO MEGA 2560

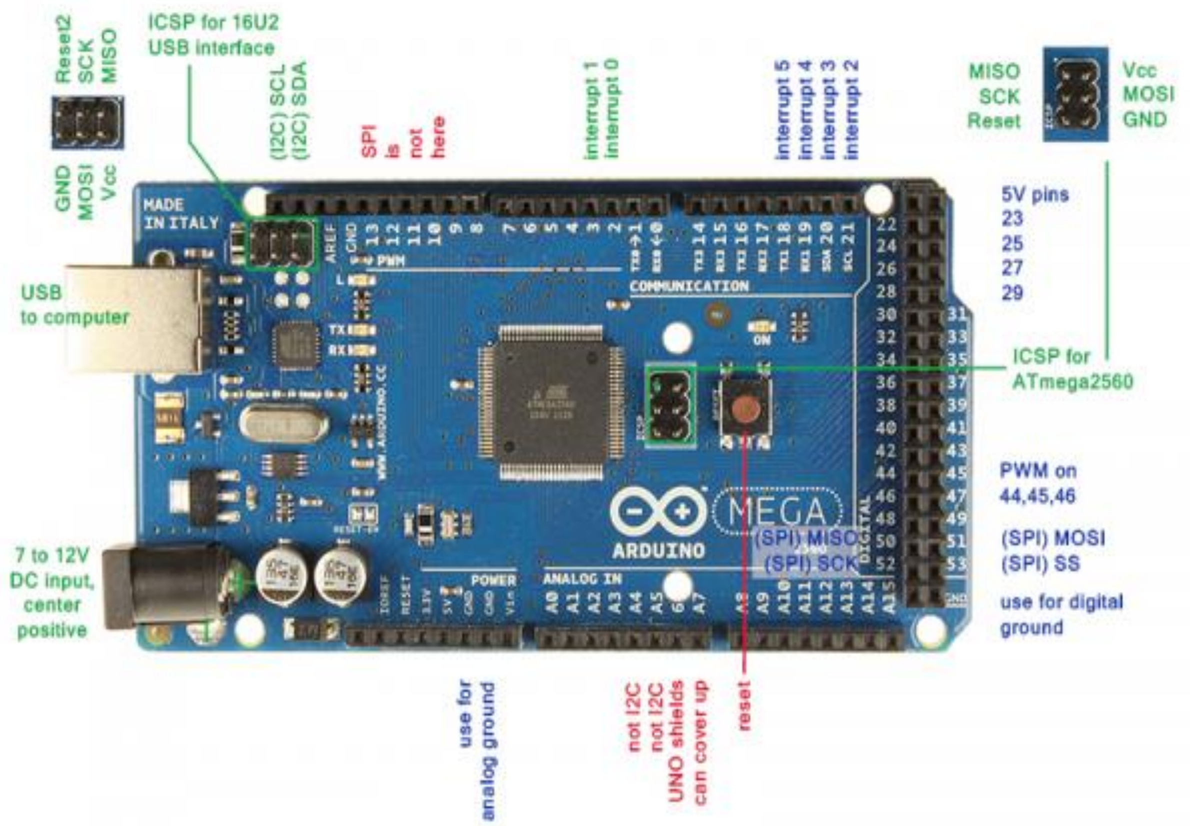


Figure3.1 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 with 54 digital input/output pins, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It is the recommended board for 3D printers and robotics projects. It contains everything needed to run the microcontroller; to get started just connect it to a computer via a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino.

Carbon Brush DC Motors - PG45775123000-516K

Figure3.2 Carbon Brush DC Motors

In this project two carbon brush DC motors are used in the robotic arm. The geared motors PG45775123000-516K are carbon brushed 12V DC motors. These motors help in the movement of the robotic arm and are operated by interfacing with the L293D motor driver IC. The L293D is interfaced with I/O pins of Arduino 2560 board.

Technical Specifications:

Voltage	12V
Number of stages	4
Reduction Ratio	516
Gearbox length	65.7mm
Max. Running Torque	120Kgf.cm
Max. Gear Braking Torque	360Kgf.cm
Gearing Efficiency	65%

Schematic Diagram of Motor:

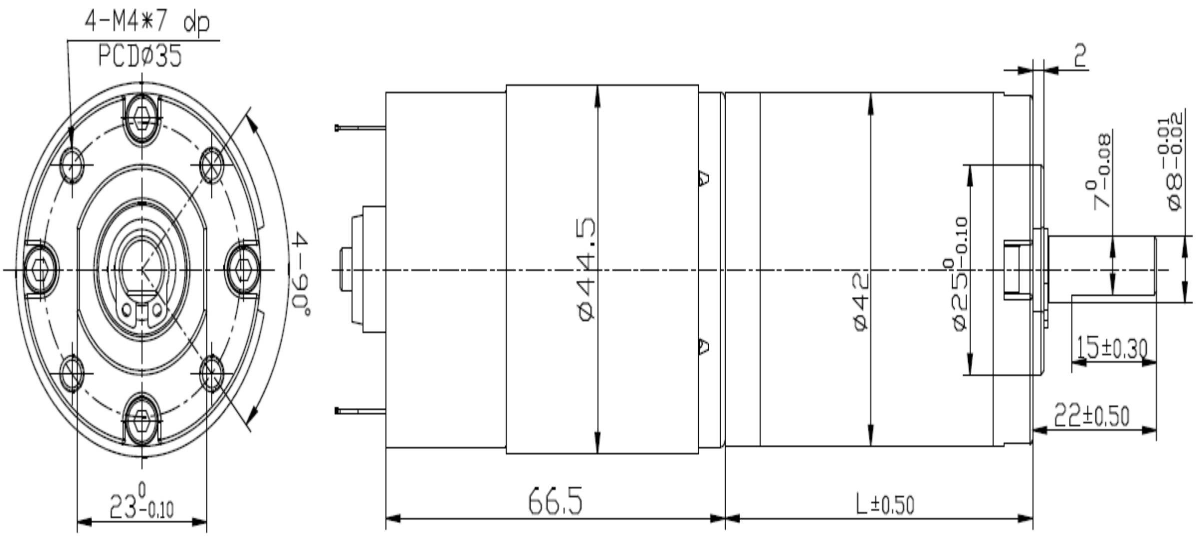


Figure3.3 Schematic Diagram of motor

12V DC WORM GEAR MOTOR

A 12V DC worm gear motor is used in this project along with the two carbon brush DC motors for locking the robotic arm at certain desired positions. Worm gear motor is a combination by worm gearbox plus DC motor, the worm gearbox is assembled of two main structures: worm meshes with a worm gear, it uses the screw drive principle in a simple machine, this structure is similar to other gear reducers (worm gearboxes), it can reduce the speed or generate a large torque to fit the different use.

Figure3.4 12V DC Worm Gear Motor

Specifications:

Voltage	12V
Rated Power	60W
No Load Speed	136 ± 10% rpm
Rated Torque	5.27N.m
Current	20A
Weight	1.1Kg

Schematic Diagram of Motor:

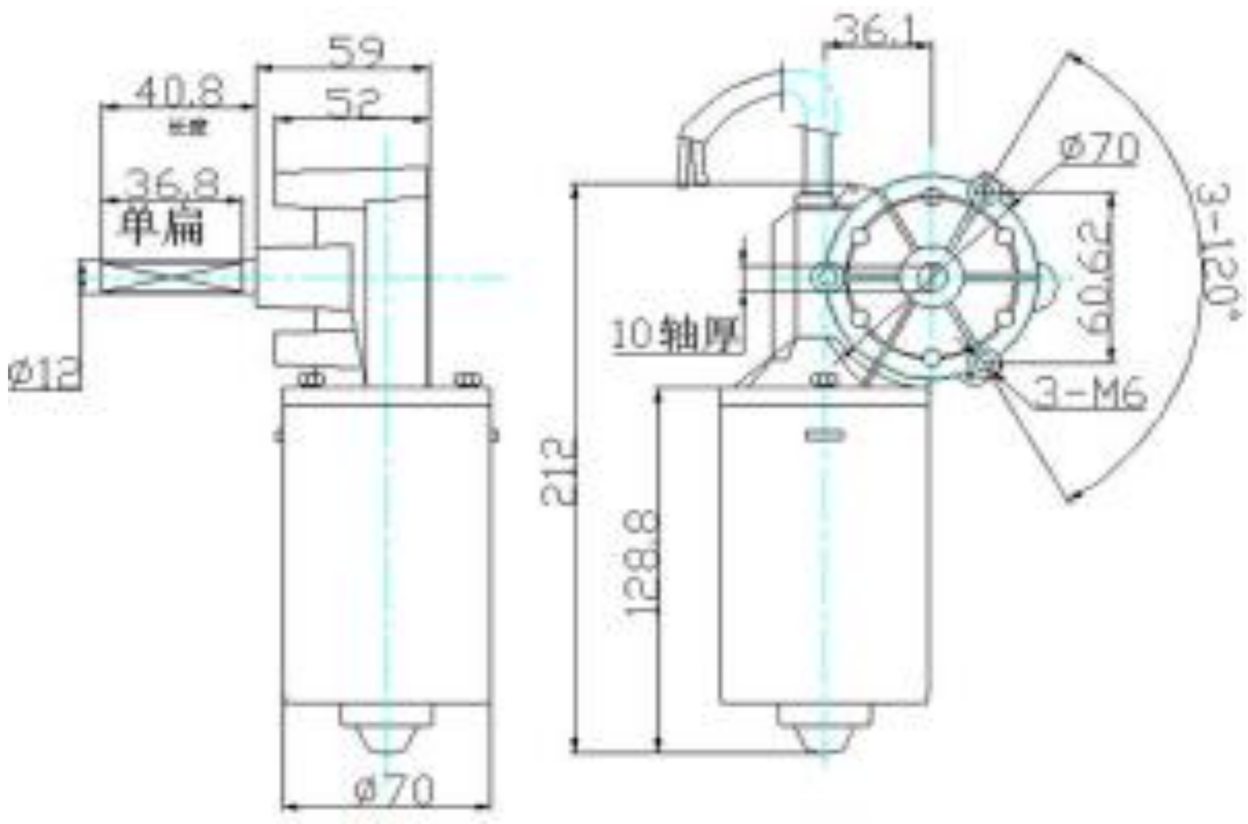


Figure3.5 Schematic Diagram of motor

L293D Motor Driver

A motor driver is an integrated circuit which is usually used to control motors in autonomous robots. Motor driver act as an interface between Arduino and the motors.

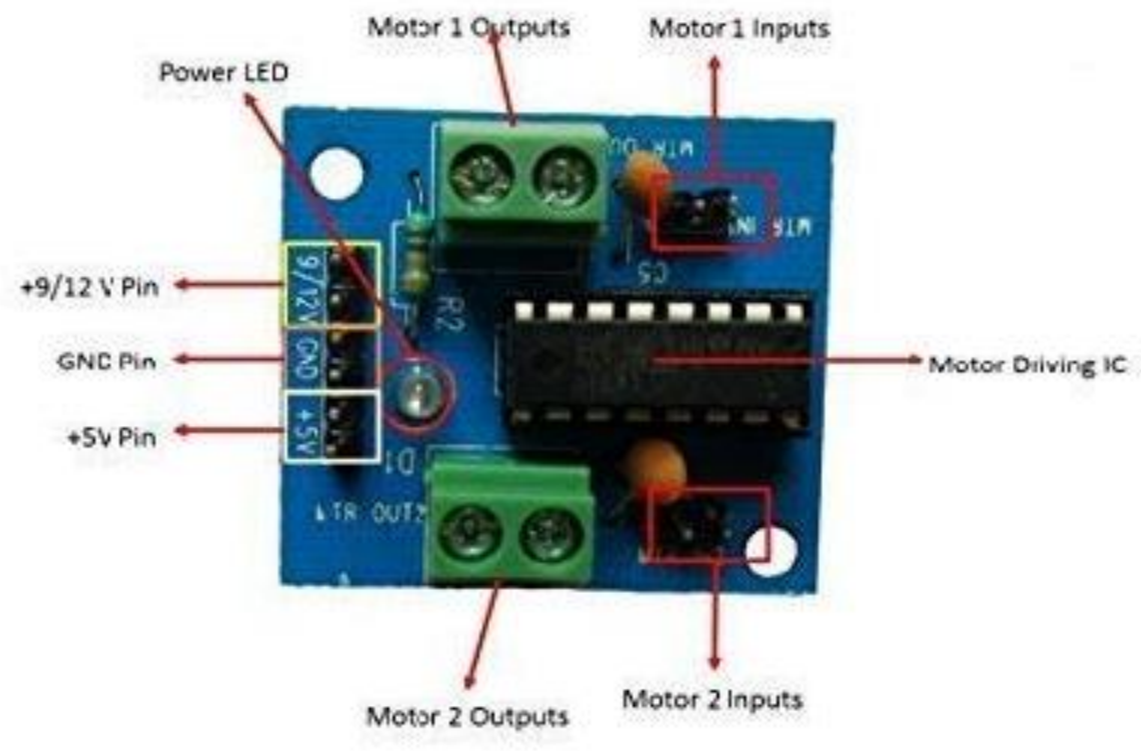


Figure3.6 L293D Motor Driver

L293D is a dual H-bridge motor driver integrated circuit. H-bridge is the simplest circuit for controlling a low current rated motor. It is an electronic circuit that enables a voltage to be applied across a load in opposite direction. Motor drivers act as a current amplifier since they take low-current control signal and provide a higher-current signal. This higher current is used to drive the motors.

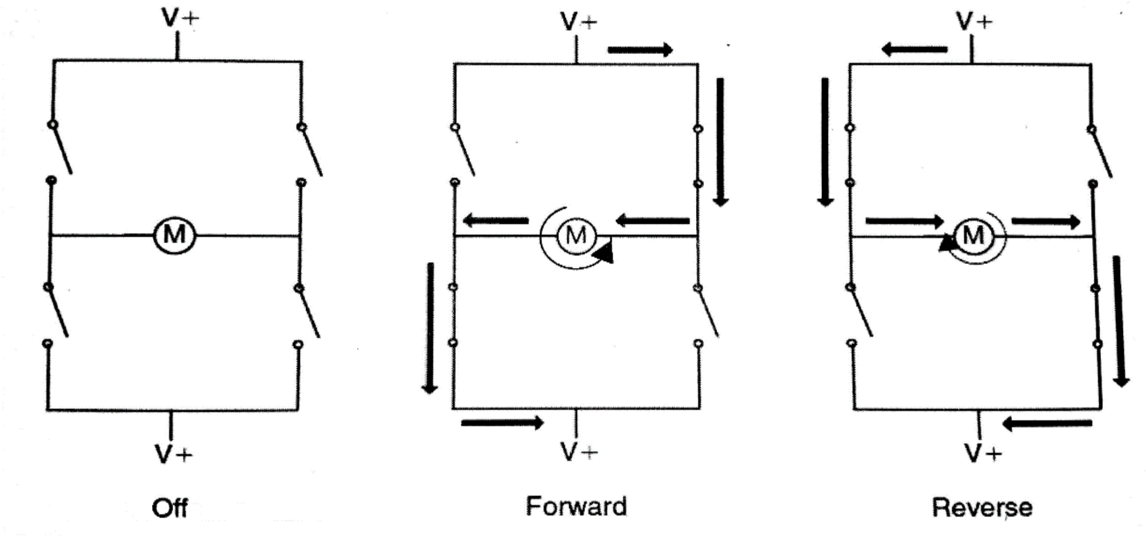


Figure3.7 H-bridge driver circuits of L293D driver

L293D contains two inbuilt H-bridge driver circuits. In its common mode of operation, two DC motors can be driven simultaneously, both in forward and reverse direction. The motor operations of two motors can be controlled by input pins. Input logic 00 or 11 will stop the corresponding motor. Logic 01 and 10 will rotate it in clockwise and anticlockwise directions, respectively.

Enable pins corresponding to the two motors must be high for motors to start operating. When an enable input is high, the associated driver gets enabled. As a result, the outputs become active and work in phase with their inputs. Similarly, when the enable input is low, that driver is disabled, and their outputs are off and in the high-impedance state.

ACE-128 Encoders

An encoder is a device, circuit, transducer, software program that converts information from one format or to another, for the purpose of standardization, speed or compression.

Encoding transducers (such as optical or magnetic encoders) sense position or orientation for using as a reference or active feedback to control position:

- A linear encoder similarly converts linear position to an electronic signal.
- A rotary encoder converts rotary position to an analog (e.g., analog quadrature) or digital (e.g., digital quadrature, 32-bit parallel, or USB) electronic signal.

Rotary Encoders

A rotary encoder, also called a shaft encoder, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to analog or digital output signals.

There are two main types of rotary encoder: Absolute and Incremental. The output of an absolute encoder indicates the current shaft position, making it an angle transducer. The output of an incremental encoder provides information about the motion of the shaft, which typically is processed elsewhere into information such as position, speed and distance.

Rotary encoders are used in a wide range of applications that require monitoring or control, or both, of mechanical systems, including industrial controls, robotics, photographic lenses, computer input devices such as optomechanical mice and trackballs, controlled stress rheometers, and rotating radar platforms.

Types of Rotary Encoders

- Conductive: A series of circumferential copper tracks etched onto a PCB is used to encode the information. Contact brushes sense the conductive areas. This form of encoder is now rarely seen except as a user input in digital multimeters.
- Optical: This uses a light shining onto a photodiode through slits in a metal or glass disc. Reflective versions also exist. This is one of the most common technologies. Optical encoders are very sensitive to dust.
- On-Axis Magnetic: This technology typically uses a specially magnetized 2 pole neodymium magnet attached to the motor shaft. Because it can be fixed to the end of the shaft, it can work with motors that only have 1 shaft extending out of the motor body.

- Off-Axis Magnetic: This technology typically employs the use of rubber bonded ferrite magnets attached to a metal hub. This offers flexibility in design and low cost for custom applications. Magnetic encoders operate in harsh environments where optical encoders would fail to work

Recommended Control Diagram For ACE-128:

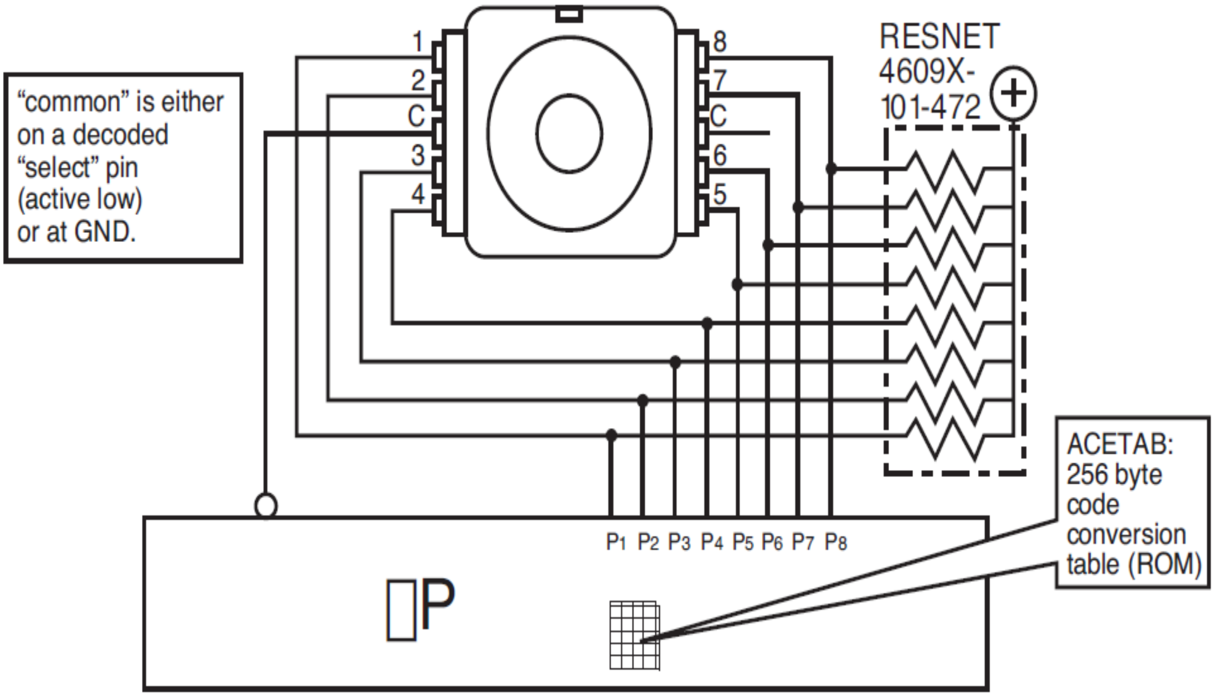


Figure3.8 Control Diagram for CE-128

Power supply

This project requires two batteries, one for the Arduino microcontroller and one for the robotic arm which is containing 3 motors.

To power up the Arduino which operates at 5V, we are using a Hi-Watt 9V battery as it is affordable, reliable, gives dedicated low-power solution to provide sufficient energy to microcontrollers with low power consumption so that it can work for longer durations.

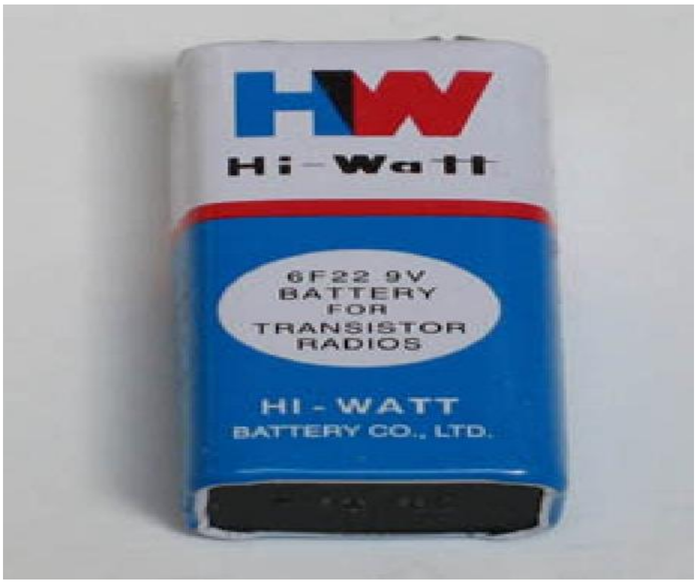


Figure3.9 6F22 9V Battery

Specifications:

- Model Number: 9V 6F 22
- Battery Type: Zinc Carbon
- Jacket: Metal
- Nominal Voltage(V) :9V
- Discharge Resistance(Ω): 620
- Cut-off Voltage(V): 5.4

To power up the robotic arm which operates at 12V, we are using a long-term discharge battery known as Banner Energy Bull Leisure 12V 130aH Battery. The Banner Energy Bull batteries excellent bag separators and a special mass composition, the robust mesh structure of the battery ensures extreme cyclical resistance and easy charging that forms its basis. Moreover, it provides comfort maintenance, leak protection and operational reliability. Ideally suited to a diversity of applications.

Figure3.10 Banner Energy Bull Leisure 12V 130aH Battery (long-term discharge battery)

Specifications:

- Length mm:514
- Width mm:223
- Height mm:220
- Terminal Type: Standard Round Post
- Amp Hour:180
- Electrolyte density: Approx. 1,28 kg/l
- Electrolyte: Diluted sulphuric acid
- Refill water: Distilled or demineralised (DIN 43530)
- Self-discharge: Approx. 9 % per month
- Charging current: Approx. 1/10 of the rated capacity
- Charging voltage: ²) max. 14,4 V
- Manufacturer: Banner

SYSTEM BLOCK DIAGRAM

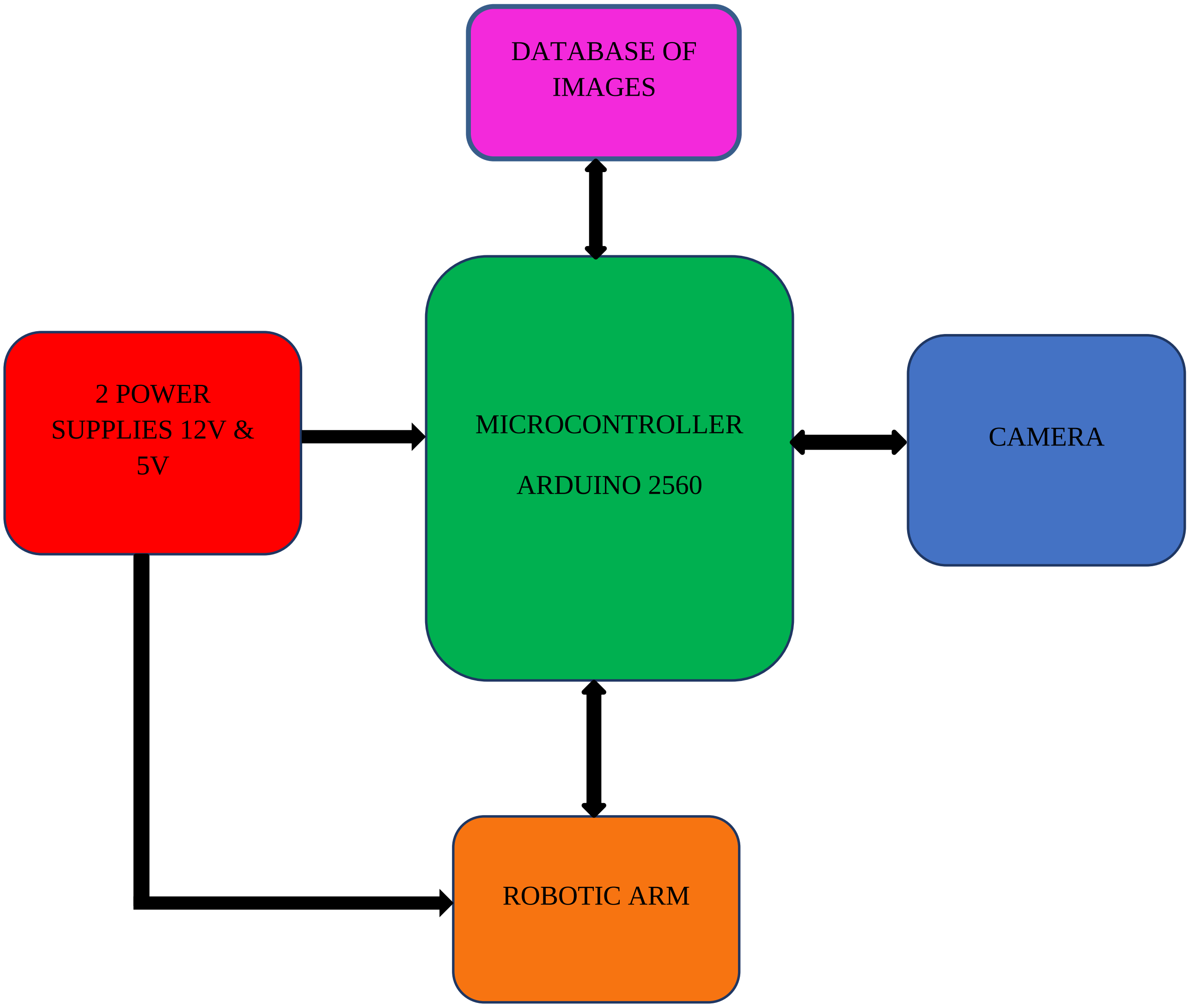


Figure3.11 System Block Diagram

The above block diagram is an illustration of how we have implemented this project as a waste segregation system. In this project, the proposed design uses various functions of Arduino, Robotic arm and image processing to detect a plastic waste, recognize it and segregate it using the robotic arm.

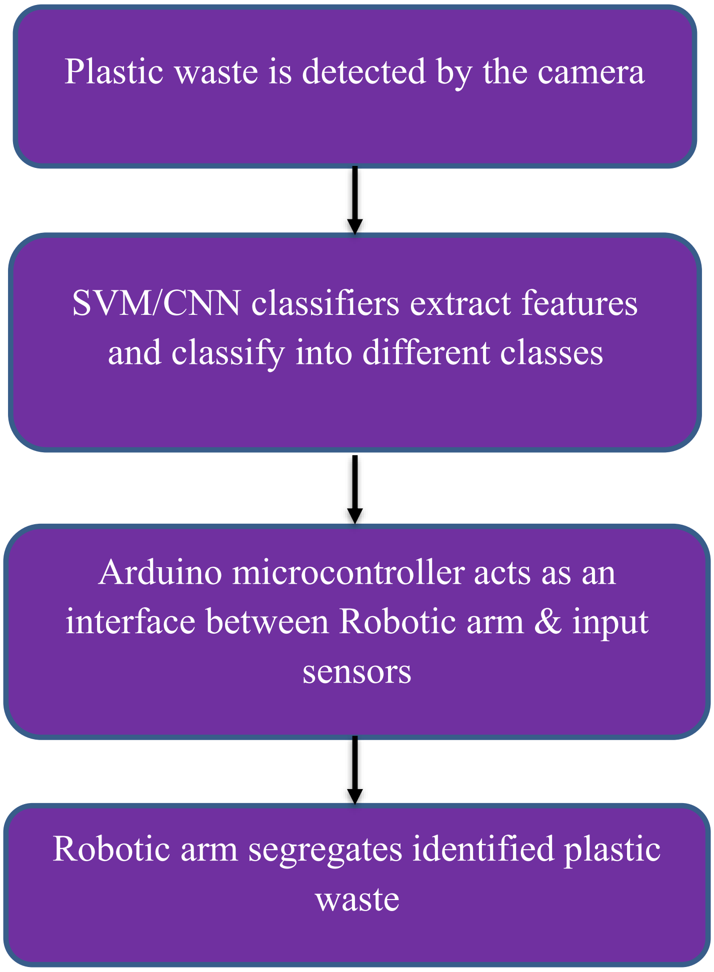
In the given block diagram, there are namely 4 parts, the first part consists of a 2 power supplies. The system consists of two power supplies one with 5V for the Arduino microcontroller and the other being 12V for the operation of robotic arm.

The second part consists of the image database which contains images of different types of plastic bottles that will be used later to compare with the object detected under the camera.

The third part uses a microcontroller board like Arduino and camera to detect the waste object present under the camera and comparing its features with that of the database using different image processing algorithms and identify the type of waste.

The fourth part consists of a 3 degree of freedom Robotic arm. This robotic arm is designed using Gazebo in robotic operating system using an urdf file. After detecting and identifying the plastic waste, Arduino send commands to the robotic arm using encoders to segregate the plastic waste.

SYSTEM FLOW



In our project we aim in providing a safe solution to waste segregation using automated techniques for recognizing particular type of waste and then segregating it safely with an automated robotic arm without any human intervention. The project is designed in replacing the conventional approach of human labours used in segregation plants who manually segregate waste which is time consuming, hectic and usually carried out in unhealthy environments.

OBJECTIVES OF THE PROJECT

The main objective of this project is to segragate plastic waste from the dry waste without having any human being involved in it to make it a fully automated system. The segregation of plastic waste is done with the help of a robotic arm. Manual segregation is observed to be time consuming and hazadous, whereas, segregation by robotic arm ensure safety since human presence is not required and continuous work. The robotic arm can work 24x7 until the power goes off. This increases the segregation speed and safety in the management unit. Once the waste is segregated it can then be sent to the recyclicing units. Faster the segregation, sooner will it be recycled which can reduce the demand for manufacturing new plastic materials and hence can be a good contribution of work in reducing the pollution.

CHAPTER 4

DETECTION AND DATABASE

DETECTION

Digital image processing allows the use of much more complex algorithms, and hence, can offer both more sophisticated performance at simple tasks, and the implementation of different methods.

Methods used for object detection are deep learning-based approaches that are able to do end-to-end object detection such as CNN.

HARDWARE REQUIRED

CMOS Camera:

Figure 4. 1 CMOS Camera

It is a sensor that detects and conveys information used to make an image. It does so by converting the variable attenuation of light waves (as they pass through or reflect off objects) into signals, small bursts of current that convey the information.
CMOS sensors are usually cheaper and have lower power consumption in battery powered devices.

<u>CMOS Camera interface with PC:</u>

Figure 4. 2 Camera interface

To check if the camera is connected Once the USB camera is plugged go to the command window in MATLAB and type “imaqtool” after which a window appears which displays the device which can take images.

Here, the plugged camera can be seen then the camera can be connected and used for the detection of a particular object by programming it in MATLAB Editor.

In this case once the camera is ON it detects the background correlation, the moment an object is placed the background correlation changes and the algorithm runs to detect the object whether it is a plastic bottle or not.

ALGORITHM USED

CONVOLUTIONAL NEURAL NETWORK (CNN)

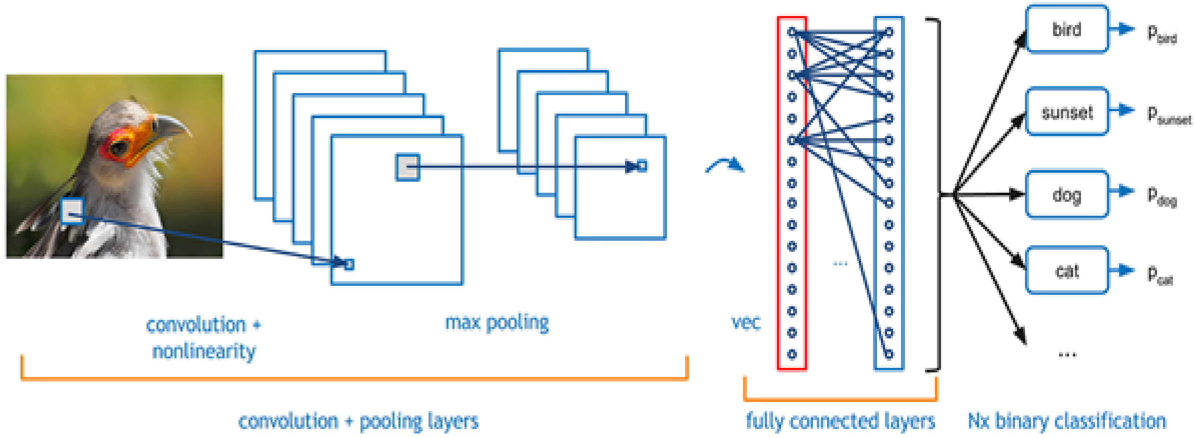


Figure 4. 3 Convolutional neural network

The name "convolutional neural network" indicates that the network employs a mathematical operation called convolution. Convolution is a specialized kind of linear operation. Convolutional networks are simply neural networks that use convolution in place of general matrix multiplication in at least one of their layers.

It is a class of deep neural networks, most commonly applied to analysing visual imagery. CNN image classifications take an input image, process it and classify it under certain categories. CNN works mainly on three layers:

1) **Layer 1:** Convolutional Layer: The convolution is the first layer to extract features from a given input image. Convolution preserves the relationship between the pixels by learning image features using small squares of input data. It is a mathematical operation that takes two inputs such as image matrix and a filter or kernel. The following diagram is an example of CNN Architecture.

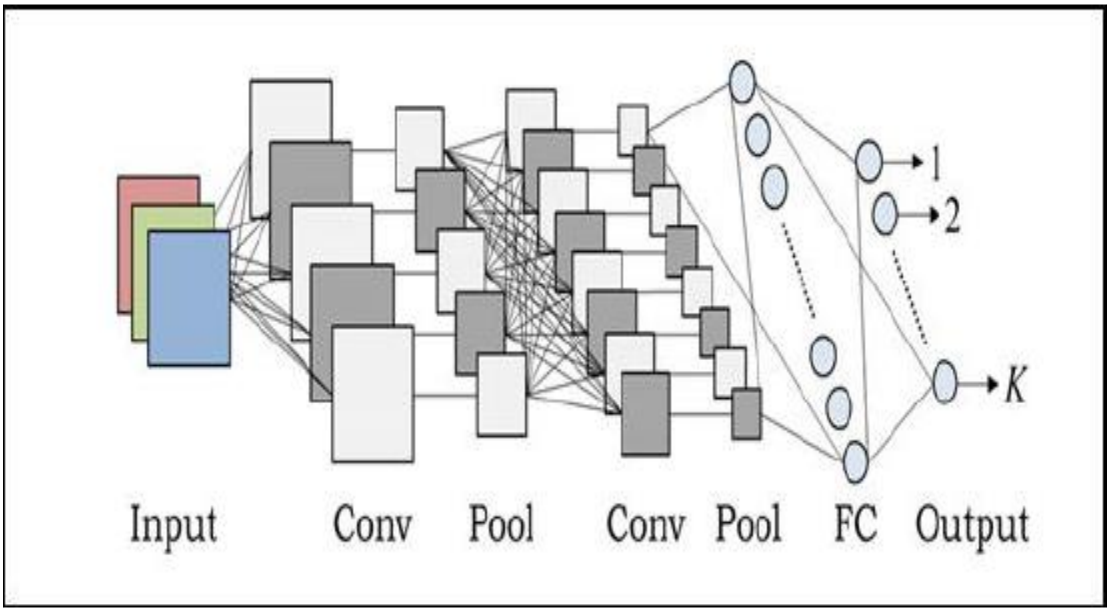


Figure 4. 4 CNN

2) **Layer 2:** Pooling layer: When the images are too large the pooling layers section reduces the number of parameters. It also contains Spatial pooling also called subsampling or downsampling which reduces the dimensionality of each map but retains the important information. Spatial pooling has different types:

a) Max Pooling

b) Average Pooling

c) Sum Pooling

Max pooling take the largest element from the rectified feature map. Taking the largest element could also take the average pooling. Sum of all elements in the feature map is called as sum pooling. It does the two main things:

i) It reduces the number of parameters within using down sampling

ii) It generalizes the result from a convolutional filter. The following figure is an example of Max Pooling.

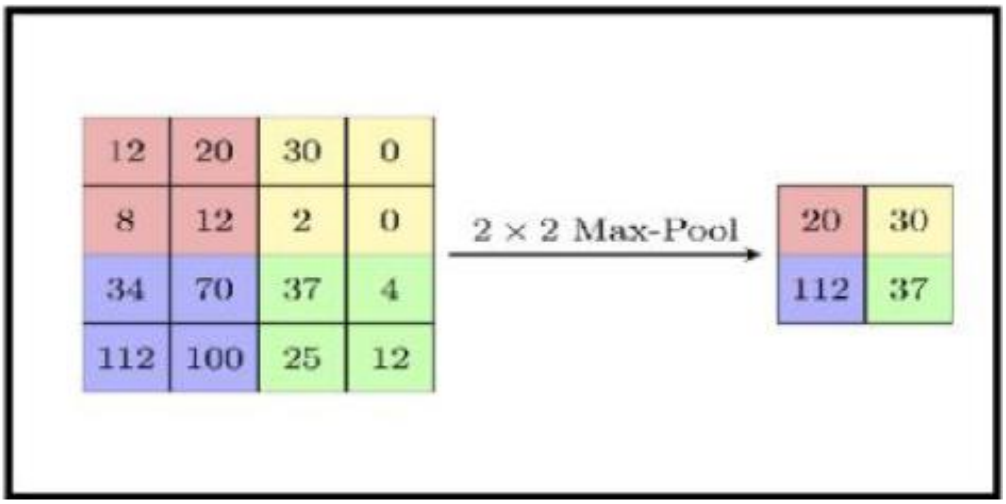


Figure 4. 5 Max Pooling

3) **<u>Layer 3</u>:** Fully Connected Layer: The layer is known as FC layer, the output of the last Pooling Layer acts as input to the Fully Connected Layer. There can be one or more of these layers ("fully connected" means that every node in the first layer is connected to every node in the second layer). Fully Connected layers perform classification based on the features extracted by the previous layers. Typically, this layer is a traditional ANN containing a softmax activation function, which outputs a probability (a number ranging from 0-1) for each of the classification labels the model is trying to predict. With the fully connected layers, we combined these features together to create a model.

<u>Residual neural network (ResNet-50)</u>

Resnet-50 is a convolutional neural network that is 50 layers deep. You can load a pretrained version of the network trained on more than a million images from the ImageNet database. The pretrained network can classify images into 1000 object categories, such as keyboard, mouse, pencil, and many animals. As a result, the network has learned rich feature representations for a wide range of images. The network uses an image input size of 224-by-224. Some of the other pretrained networks include googlenet, alexnet, inception3.

DATABASE

For plastic waste detection a large database consisting of different types of plastics was created. The images were gathered from various sources such as online datasets like Kaggle datasets, google images and smartphone camera. The images were separated into three folders containing around 3000 images each.

Type of plastic waste	Database Size (Unprocessed images)
Plastic Bags	3000
Plastic Bottles	3000
Plastic Cups	3000

Table 1 Database

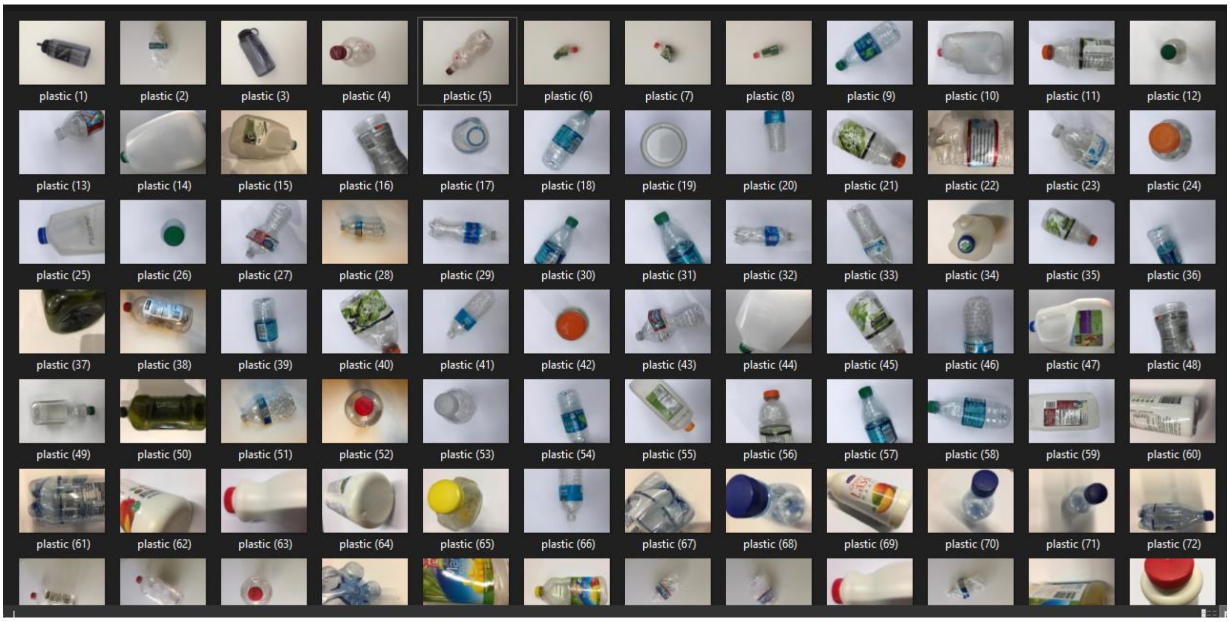


Figure 4. 6 Plastic Bottle Database

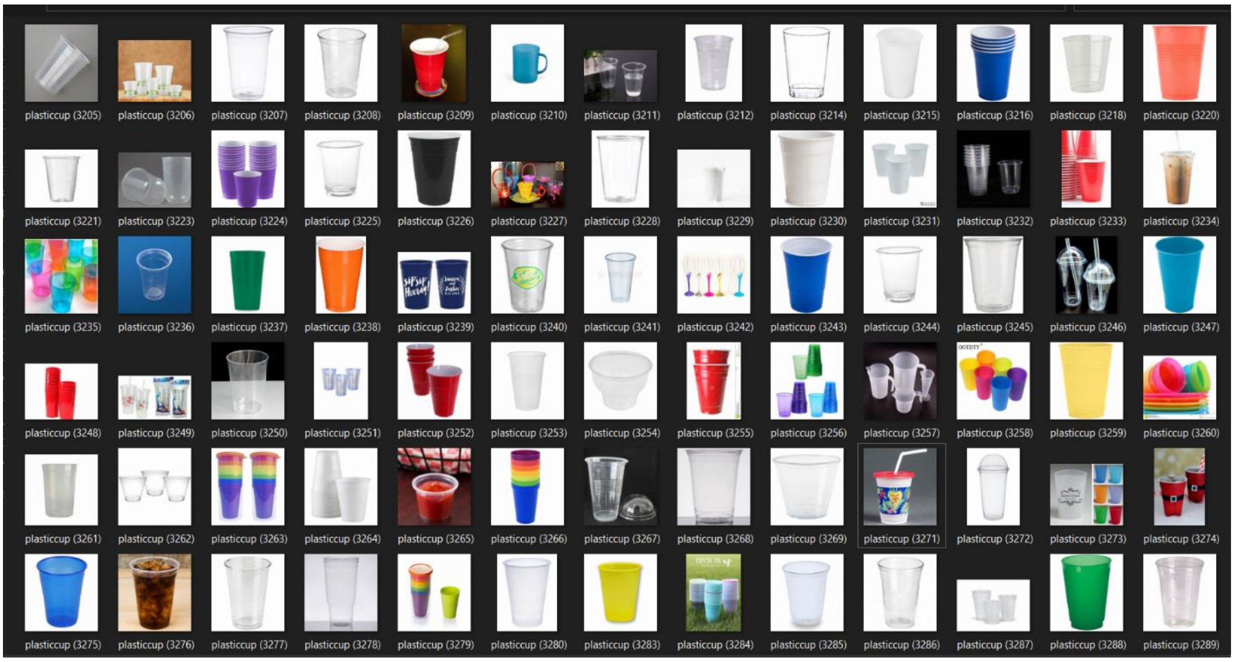


Figure 4.7 Plastic Cup Database

Figure 4.8 Plastic Bag Database

Protocols used for training the CNN model:

For preparing the training and testing sets, the images were split into two sets. 70% of the images from each set were picked for the training data and the remainder 30% for the validation data while randomizing the split to avoid biasing the results. These training and test set is processed by the CNN model.

Training of this images is done using pre-trained CNN model called resnet-50. The images in the datasets needs to be pre-processed before starting to extract training features, network can only process RGB images that are of the size 224-by-224. To avoid re-saving all the images to this format, we use an “augmentedImageDatastore” to resize and convert any grayscale images to RGB on-the-fly.

There are only a few layers within a CNN that are suitable for image feature extraction. Resnet50 CNN model contains 50 deep layers. The layers at the beginning of CNN can capture only basic “primitive” image features, such as blobs and edges. The deep network layers processes this “primitive” features to form higher level image features. To extract features from deeper layers we use activations method, where we select a layer right before the classification layer. i.e. layer named 'fc1000'.

Next, Image features extracted by CNN is used to train a multiclass SVM classifier. The evaluation of the trained classifier is done by first extracting the features from test set images, then passing the CNN image features to trained classifier to generate known labels. The result is then tabulated using confusion matrix which is then converted into percentage form that gives us the accuracy of the trained classifier.

The detection of the waste under the camera is done with the help of auto-correlation method. Once the images of plastic waste are captured by the camera, the images will be added to the testing set and the accuracy generated from this will be compared with that of the trained classifier. If the accuracy obtained is above a certain favourable threshold value, the waste’s plastic type confirmed. The program will than communicate with the microcontroller to signal the robotic arm to segregate the plastic waste.

CHAPTER 5

DESIGNING OF THE ROBOTIC ARM

DESIGNED ROBOTIC ARM

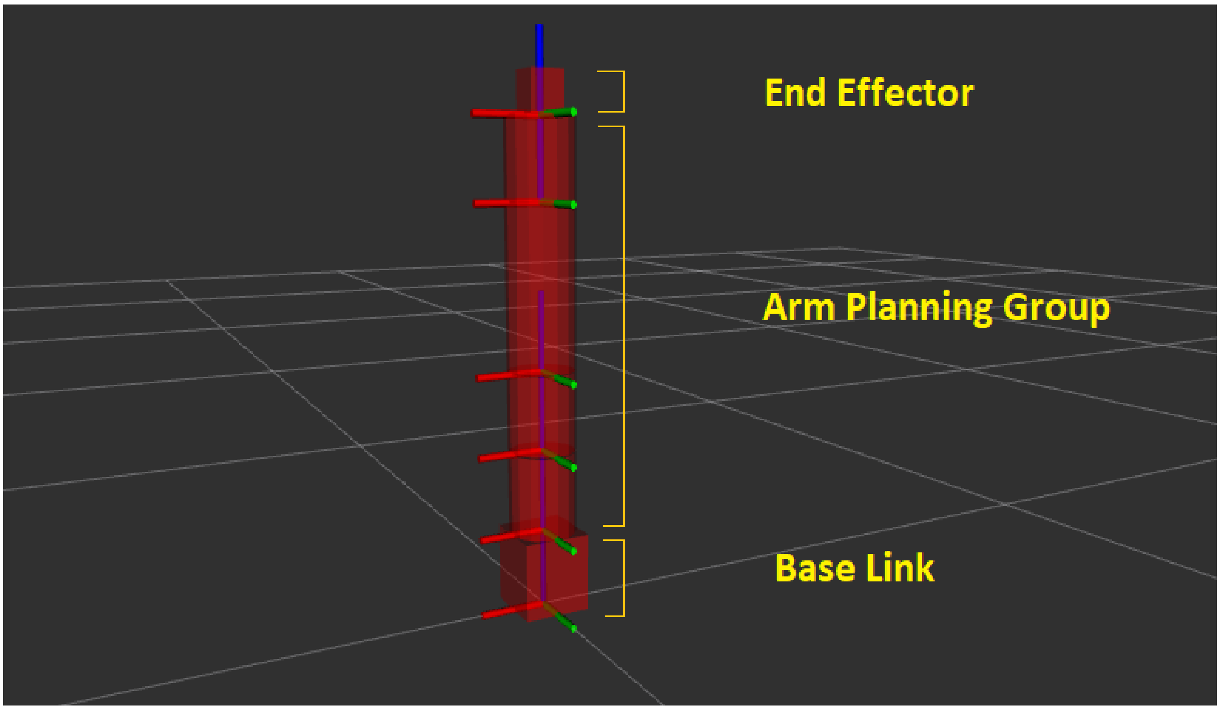


Figure 5.1 5DOF Robotic Arm 3D Design

This is the basic 3D model of the 5DOF robotic arm. The arm consists of five joints and six main Links:

1) The Base link, which forms the main connection link that attaches the ground plane and the robotic arm.

2) The Arm planning group link, that consists group of five revolute joints which itself is connected to the base revolute joint. The arm planning group consisting of arm joints helps in assisting all the movement done by the robotic arm.

3) End effector link, this is a stationary part of the robotic arm. It is used as a reference point in Inverse Kinematics movements. It is connected to the arm planning group via a revolute joint.

Software’s used in designing the Robotic Arm

ROS

Robot Operating System (ROS or ros) is robotics middleware (i.e. collection of software frameworks for robot software development). ROS is not an operating system but it provides services such as hardware abstraction, message-passing between processes, implementation of commonly used functionality, low-level device control and package management. It is a flexible framework for writing robot software and a collection of tools, libraries, and conventions that aims to simplify the task of creating complex and robust robot behaviour across a wide variety of robotic platforms.

ROS's core functionality is augmented by a variety of tools which allow developers to visualize and record data, easily navigate the ROS package structures, and create scripts automating complex configuration and setup processes.

ROS DISTRIBUTIONS

ROS currently releases a version every other year in May, following the release of Ubuntu LTS versions. ROS2 currently releases a new version every six months (in December and July). These releases are supported for a single year.

ROS 1 DISTRIBUTION RELEASES

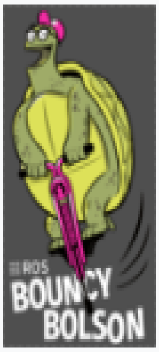
Distribution	Release date	Poster	EOL date
Noetic Ninjemys	May 2020 (expected)[90]	TBA	May 2025
Melodic Morenia	May 23, 2018		**2023-05-30**
Lunar Loggerhead	May 23, 2017		2019-05-30
Kinetic Kame	May 23, 2016		**2021-05-30**
Jade Turtle	May 23, 2015		2017-05-30
Indigo Igloo	July 22, 2014		2019-04-30
Hydro Medusa	September 4, 2013		2014-05-31
Groovy Galapagos	December 31, 2012		2014-07-31

Fuerte Turtle	April 23, 2012		--
Electric Emys	August 30, 2011		--
Diamondback	March 2, 2011		--
C Turtle	August 2, 2010		--
Box Turtle	March 2, 2010		--

Old version Older version, still maintained **Latest version** Future release

Figure 5. 2 ROS1 Distribution Releases

ROS 2 DISTRIBUTION RELEASES

Distribution	Release date	Poster	EOL date
Foxy Fitzroy	May 23, 2020 (assumed)[91]	N/A	t.b.d.
Eloquent Elusor	Nov 22, 2019	N/A	**Nov 2020**
Dashing Diademata	May 31, 2019	N/A	**May 2021**
Crystal Clemmys	December 14, 2018		December 2019
Bouncy Bolson	July 2, 2018		July 2019
Ardent Apalone	December 8, 2017		December 2018
beta3	September 13, 2017	N/A	December 2017
beta2	July 5, 2017	N/A	September 2017
beta1	December 19, 2016	N/A	July 2017
alpha1-alpha8	August 31, 2015	N/A	December 2016

Old version | Older version, still maintained | **Latest version** | Future release

Figure 5. 3 ROS2 Distribution Releases

<u>GAZEBO:</u>

Figure 5. 4 Gazebo

Gazebo is a 3D indoor and outdoor multi-robot simulator, complete with dynamic and kinematic physics, and a pluggable physics engine. Integration between ROS and Gazebo is provided by a set of Gazebo plugins that support many existing robots and sensors. Because the plugins present the same message interface as the rest of the ROS ecosystem. You can develop your application in simulation and then deploy to the physical robot with little or no changes in your code.

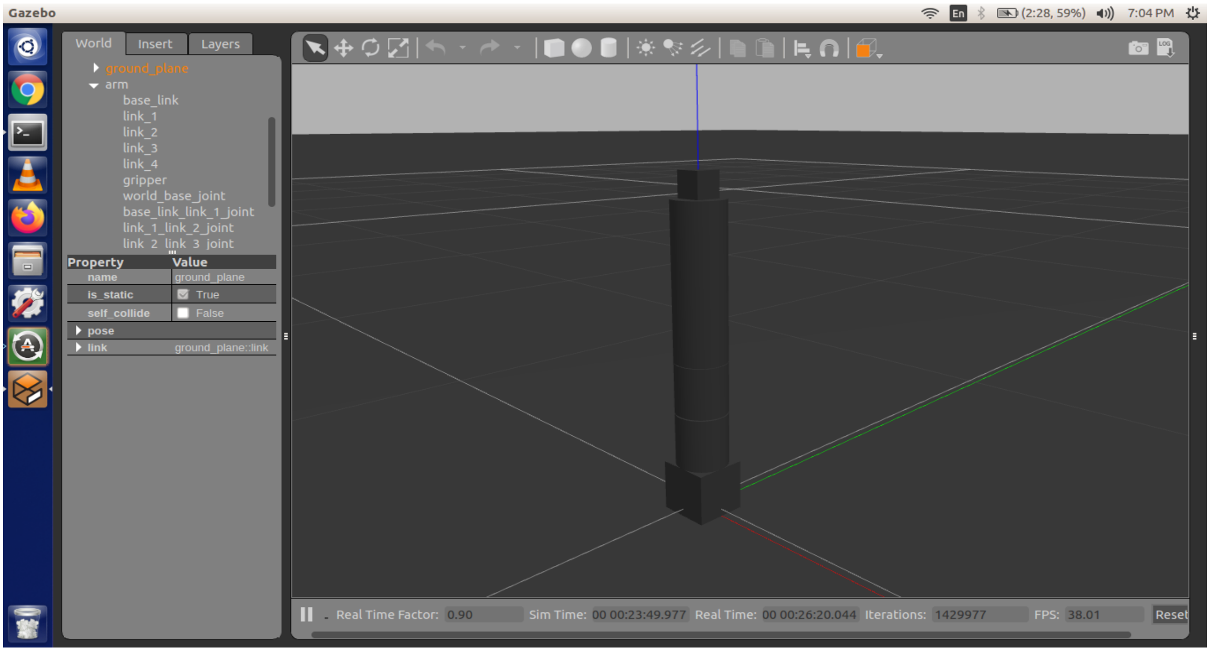


Figure 5.5 Robotic arm designed in Gazebo software

Gazebo offers real world physics simulation at a much higher degree of fidelity, a suite of sensors, and interfaces for both users and *programs*.

The designing of the robotic arm is done using Unified Robotic Description Format (URDF) which is an XML file format used in ROS to describe all elements of a robot. To use an URDF file in Gazebo, some additional simulation-specific tags like link, inertia, mass value, visual, collision, geometry, etc must be added in the URDF to work properly with Gazebo. URDF based robot design in Gazebo, saves you from having to create a separate SDF (Simulation Description Format) file from scratch and duplicating description formats. After programming the design, we run it with gazebo which will then convert the URDF to SDF automatically to provide an optimum design.

The verification of the created URDF file can be done by command line tool **check_urdf,** which attempts to parse the file as a URDF description, and either prints a description of the resulting kinematic chain, or an error message.
To view the URDF file graphically in graphviz use the command:

- urdf_to_graphviz arm.urdf

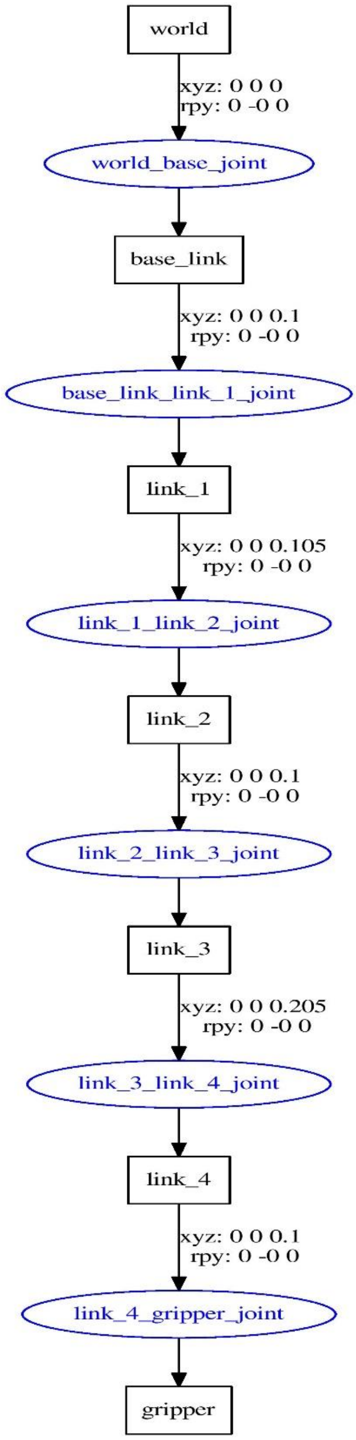


Figure 2 Graphical representation of URDF

The Graphviz represents the all the joints and links that are present in the URDF and are successfully connected. The XYZ- represents the offset (positions) and the RPY- represents the rotation (roll, pitch, yaw).

MOVEIT!

Figure 5. 6 Moveit

MoveIt is a motion planning library that offers efficient, well-tested state-of-the-art planning algorithms that have been used on a wide variety of robots, from simple wheeled platforms to walking humanoids. It runs on top of ROS (Robot Operating System). It is a primary source of the functionality for manipulation in ROS. MoveIt builds on the ROS messaging and build systems and utilizes some of the common tools in ROS like the ROS Visualizer (Rviz) and the ROS robot format (URDF). Planning data can be visualized with Rviz and rqt plugins, and plans can be executed via the ROS control system.

MoveIt is a common entry point into ROS, especially through the use of the MoveIt Setup Assistant which is used for creating configuration packages for new robots such as Semantic robot description Format (SRDF), YAML, kinematic configuration files and other launching files that is required to run MoveIt.

To open the MoveIt assistant setup, in command prompt use the following command in the projects source directory:

- roslaunch moveit_setup_assistant setup_assistant. launch

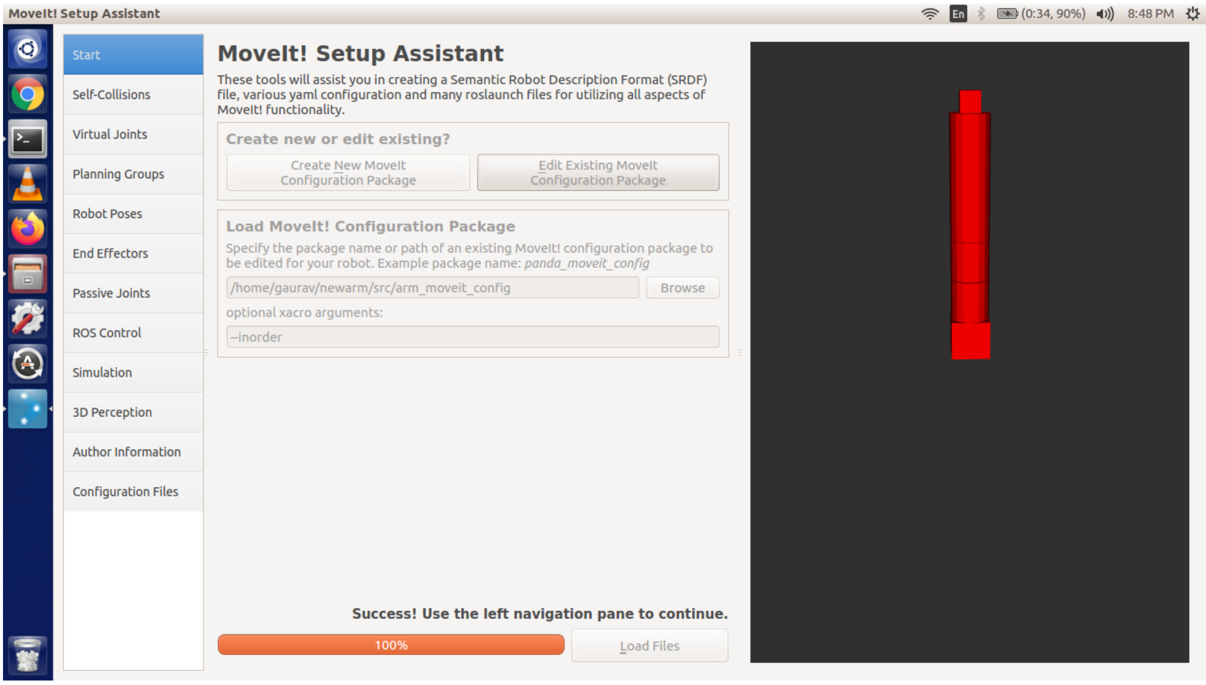


Figure 5.7 Robotic arm in MoveIt Setup Assistant

To start creating the moveit configuration package browse and select the newly created URDF or XACRO file from the source directory and load the files.

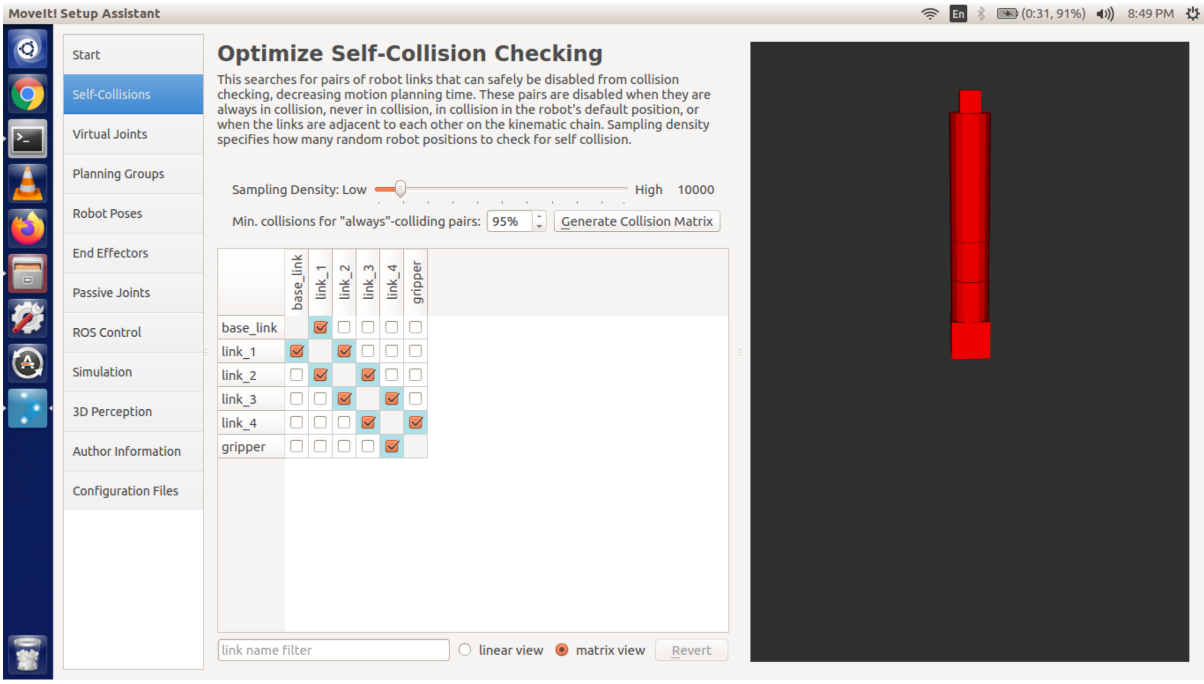


Figure 5.8 Generating self-collision Matrix

Self-collision checks for pairs of robot links that can be disabled from collision checking. This panel allows you to check if the pairs are always in collision, never in collision or check if links are adjacent to each other.

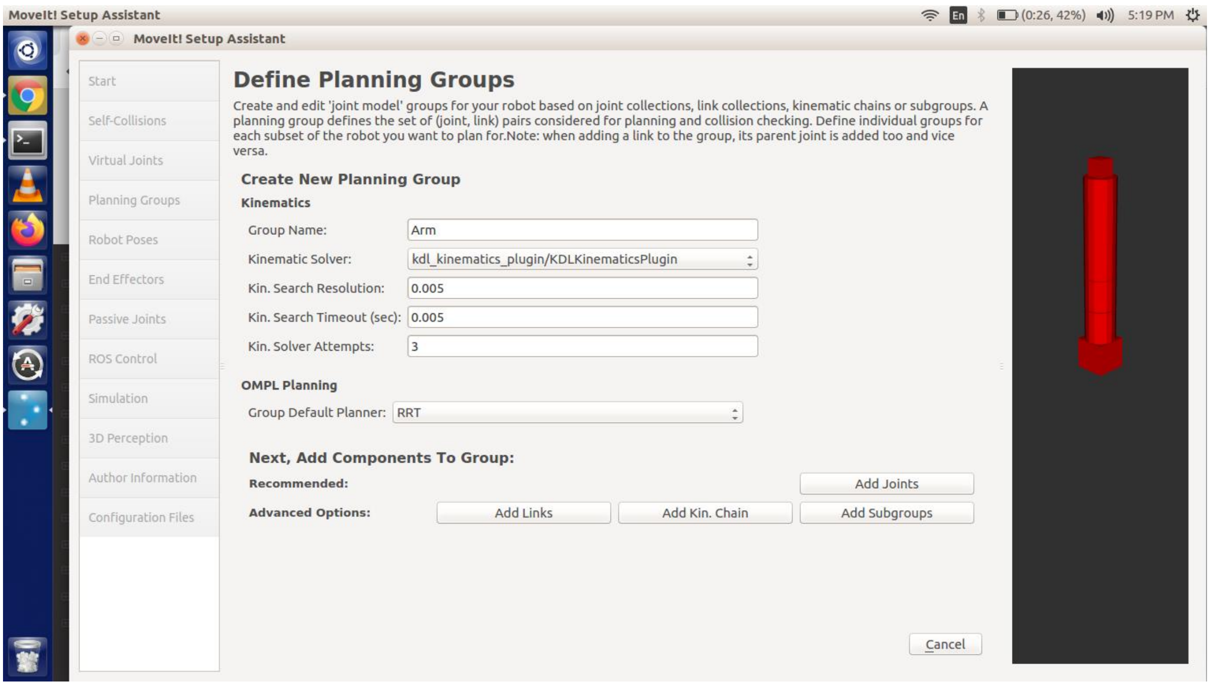


Figure 5.9 Defining Inverse Kinematics for robotic arm

Moveit provides multiple inbuilt kinematics solver libraries that can be used for configuring kinematics for the robot. We have used KDL Kinematics Plugin as the primary kinematics solver. **Kinematics and Dynamics Library (KDL)** can represent a kinematic chain of the robot by a KDL Chain object, and use inbuilt KDL solvers to compute inverse kinematics for the designed robotic arm by transforming the coordinate space to the joint space.

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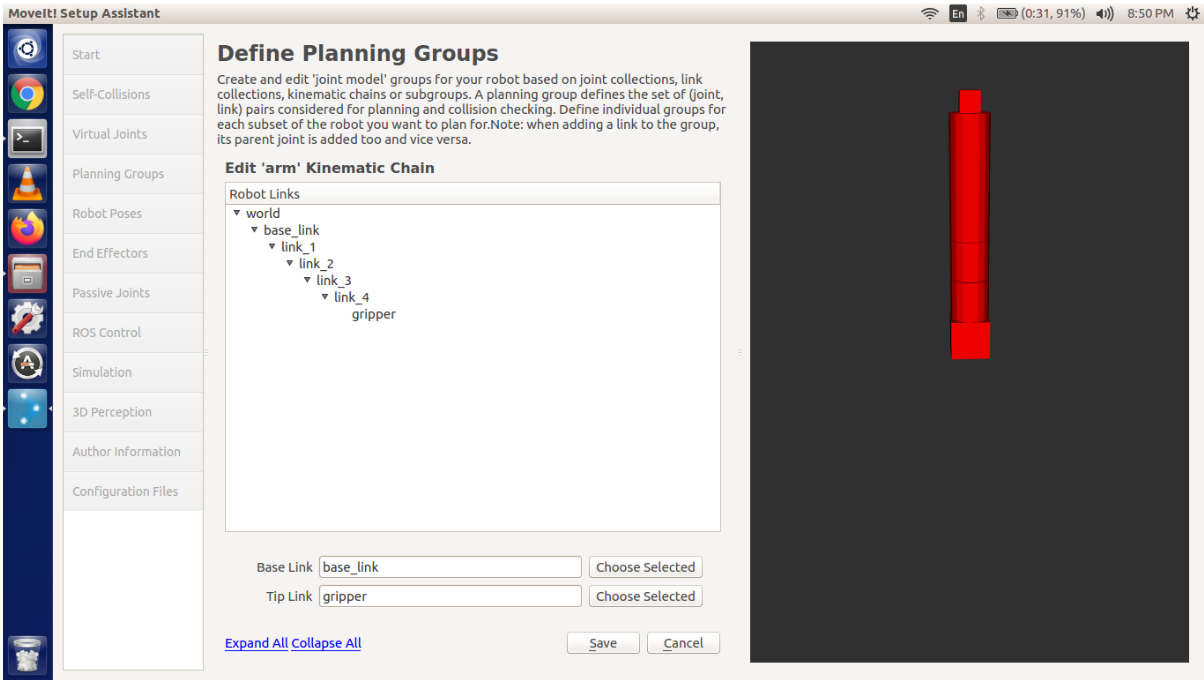


Figure 5.9 Defining planning groups for Robot Arm

Planning groups defines the set of joint, link pairs which are used for planning and collision checking. One can choose links individually or select as a chain by selecting Base link and tip link.

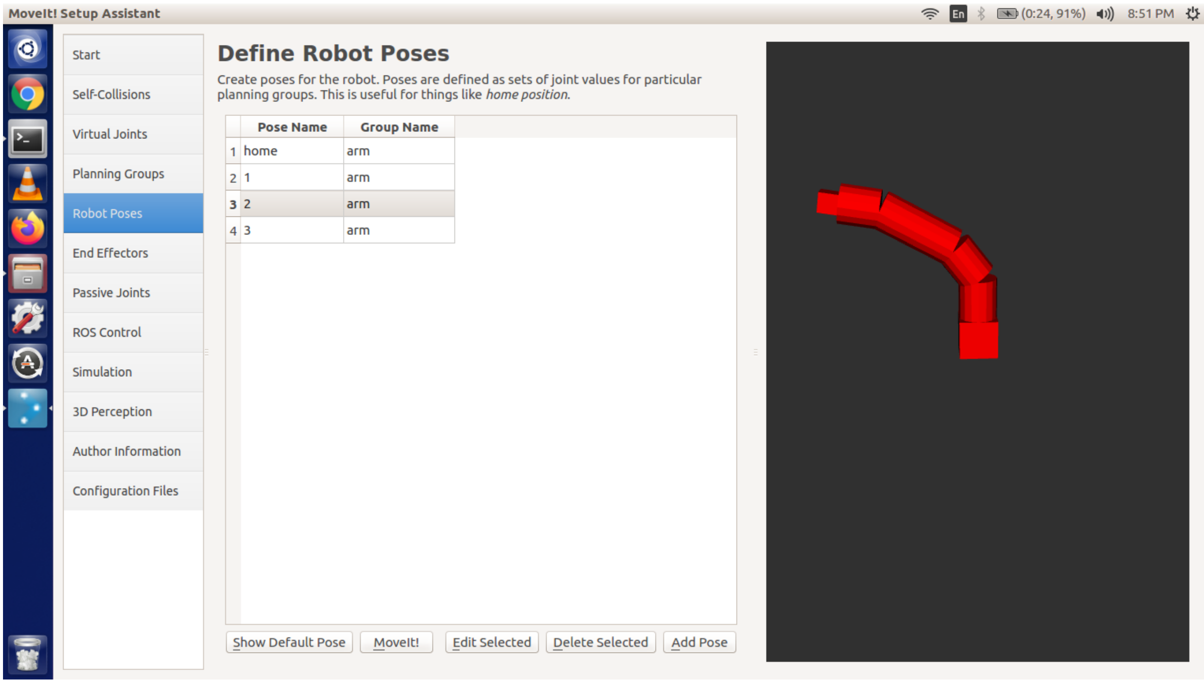


Figure 6.0 Defining desired poses for Robotic Arm

Robot poses allows us to define pre-defined poses for our robotic arm, which can be later used in motion planning & execution. After completing all the steps browse to the source directory and create arm-moveit-config folder to save all the configuration files.

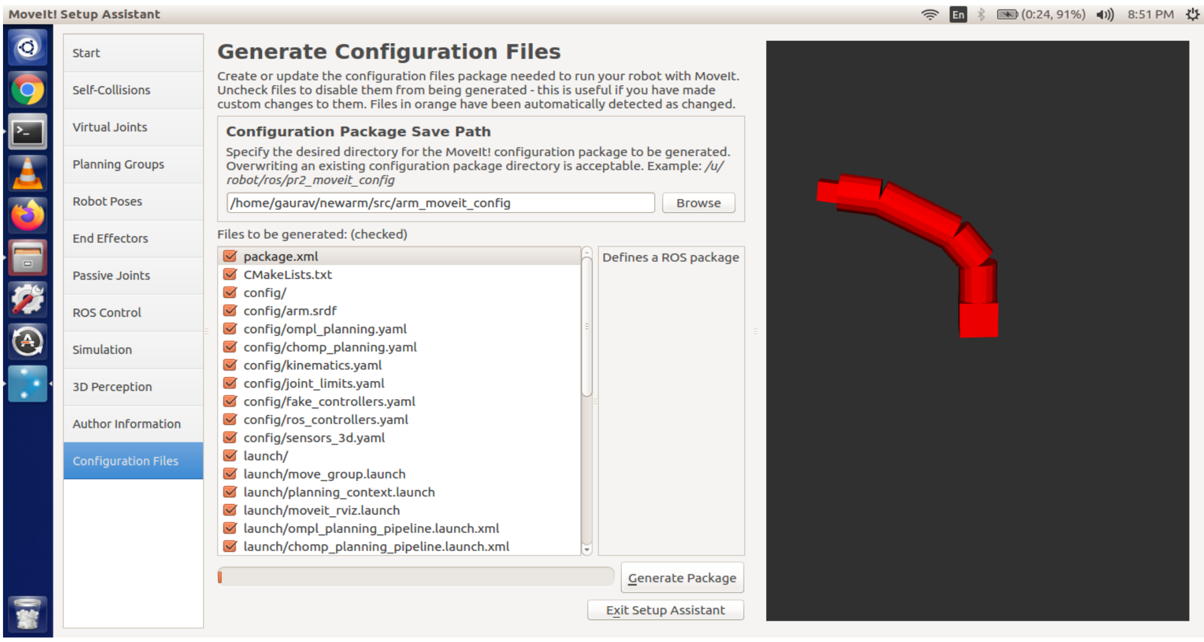


Figure 6.1 Generating Moveit configuration files of the Arm

RVIZ

Rviz (ROS visualization) is a 3D visualizer for displaying sensor data and state information from ROS. Using Rviz, we can visualize arms current configuration on a virtual model of the robot. We can also display live representation of the sensor values coming over ROS Topics including camera data, infrared distance measurements, sonar data, and more.

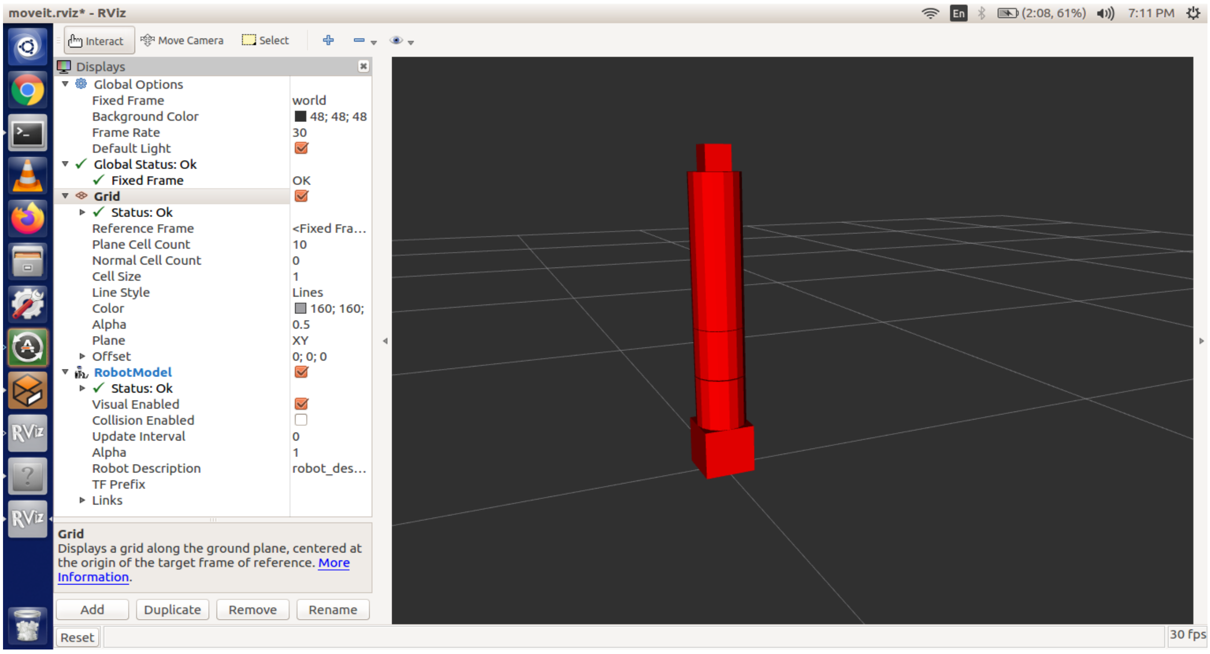


Figure 6.2 Robotic Arm Design in Rviz

After completing the design in Gazebo and creating a MoveIt package, we try to simulate the robotic arm in ROS visualization (Rviz). It is used to simulate the robotic models and to help understand robot systems by providing a 3D environment that lets users see the world from a robot's perspective.

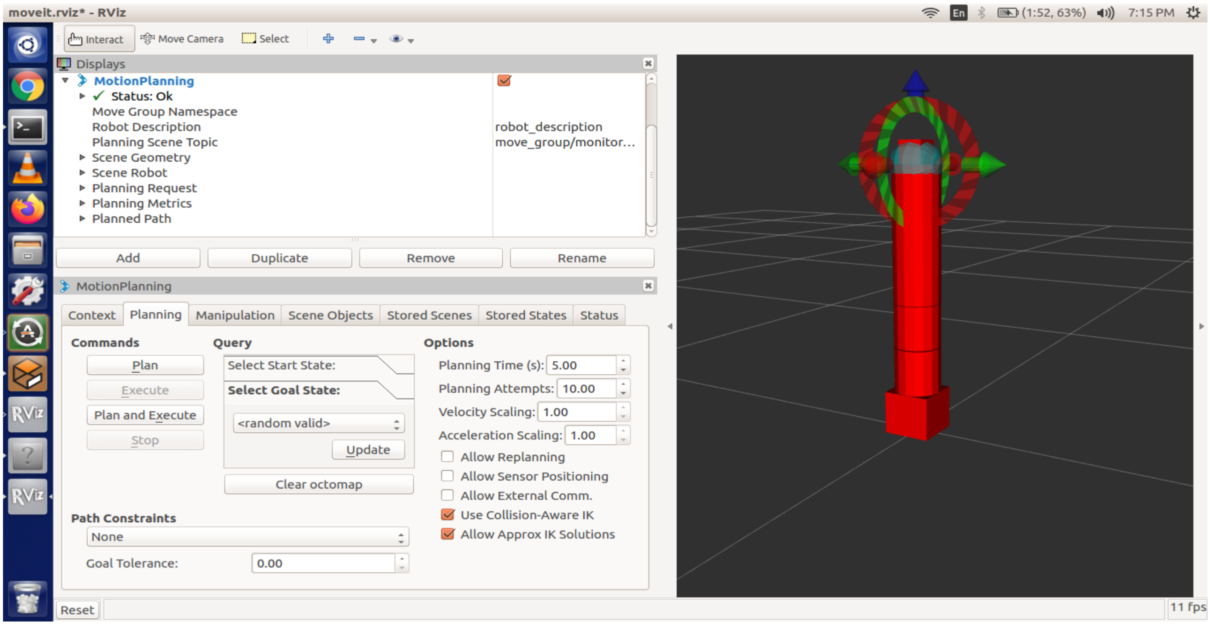


Figure 6.3 Motion Planning in Rviz

Rviz allows different visualization options like motion planning, planning scene, robot state, trajectory and many more. The interactive markers on the end effector allows us to move the robot to different desired poses.

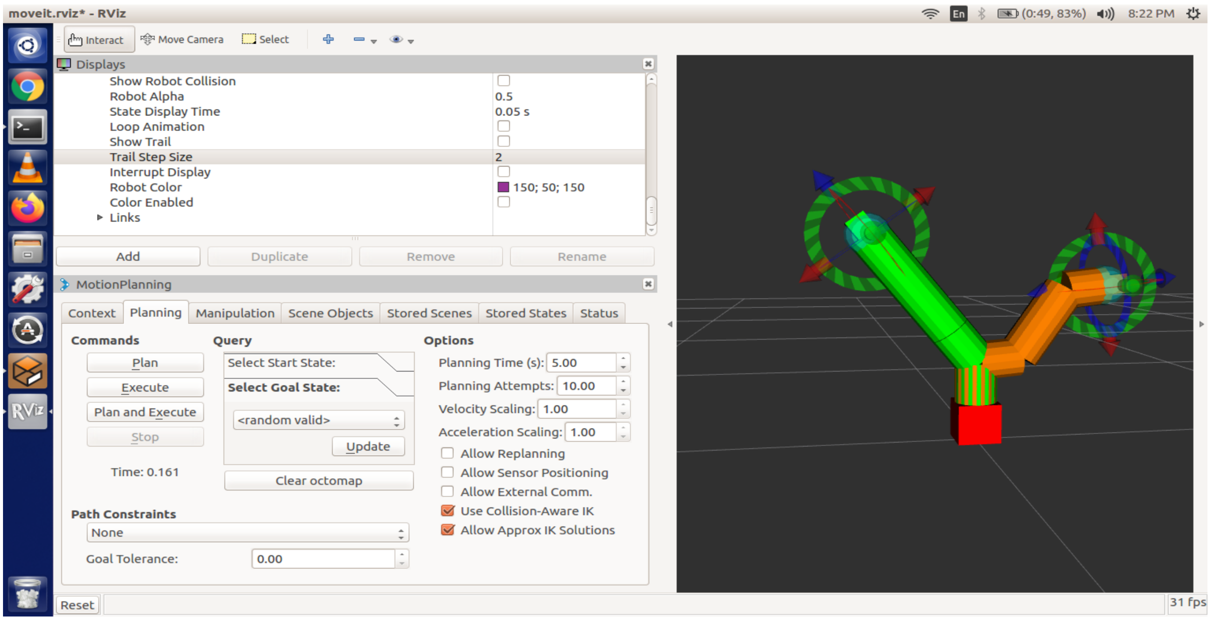


Figure 6.4 Start and Goal state of robot

Motion planning allows us to select start state and goal state of the robot as desired. In the above image, the purple colour shows start state and the orange colour shows goal state. One can select different start and goal state options pre saved in the query option. For better state planning we use the Inverse Kinematic solutions option.

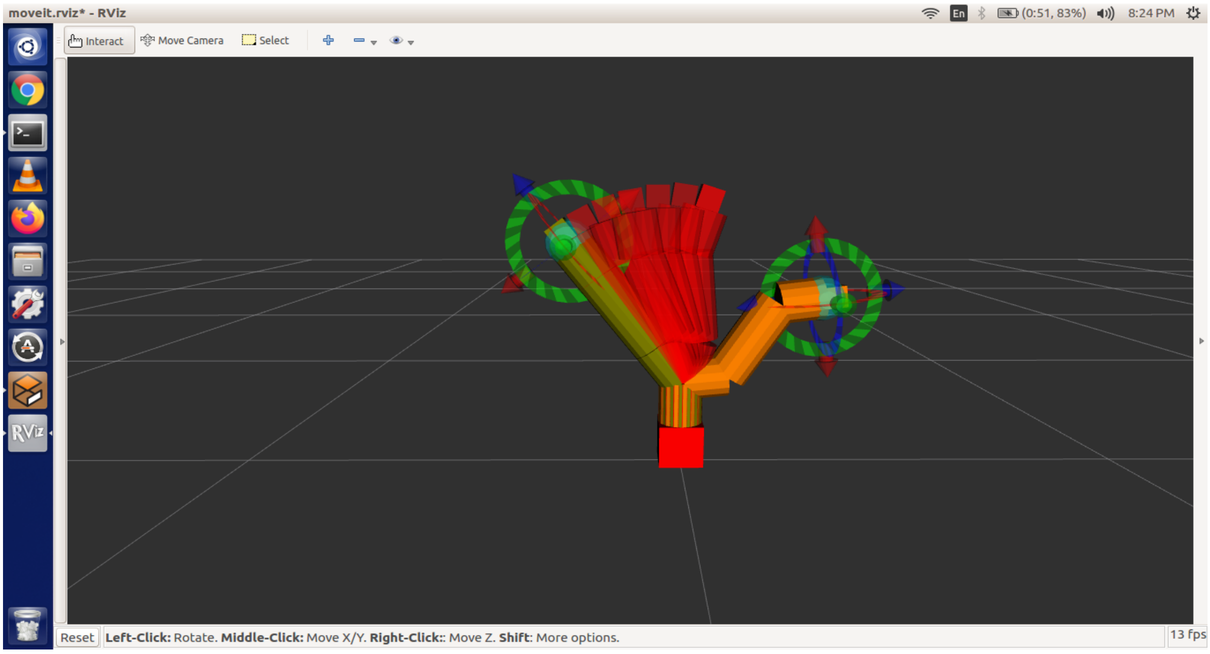


Figure 6.6 Simulating the robot model in Rviz

After finalizing the desired start and goal state we can start with the simulation. We click on the Plan and execute option and the robotic arm starts to move from point A to point B showing the path trails as it moves without any collisions.

DEGREE OF FREEDOM

Degrees of freedom, in a machine context, are specific, defined modes in which a mechanical device or system can move. The number of degrees of freedom is equal to the total number of independent displacements or aspects of motion. A machine may operate in two or three dimensions but have more than three degrees of freedom. The term is widely used to define the motion capabilities of robots.

Consider a robot arm built to work like a human arm. Shoulder motion can take place as pitch (up and down) or yaw (left and right). Elbow motion can occur only as pitch. Wrist motion can occur as pitch or yaw. Rotation (roll) may also be possible for wrist and shoulder. Such a robot arm has five to seven degrees of freedom. If a complex robot has two arms, the total number of degrees of freedom is doubled

KINEMATICS

Kinematics is the branch of mechanics that studies the motion of a body, or a system of bodies, without consideration given to its mass or the forces acting on it. A serial link manipulator comprises a chain of mechanical links and joints. Each joint can move its outward neighbouring link with respect to its inward neighbour. One end of the chain, the base, is generally fixed and the other end is free to move in space and holds the tool or end-effector.

KINEMATIC EQUATIONS

A fundamental tool in robot kinematics is the kinematics equations of the kinematic chains that form the robot. These non-linear equations are used to map the joint parameters to the configuration of the robot system. Kinematics equations are also used in biomechanics of the skeleton and computer animation of articulated characters.

Forward kinematics uses the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters. The reverse process that computes the joint parameters that achieve a specified position of the end-effector is known as inverse kinematics. The dimensions of the robot and its kinematics equations define the volume of space reachable by the robot, known as its workspace.

FORWARD KINEMATICS (FK)

Forward kinematics is the method for determining the orientation and position of the end effector, given the joint angles and link lengths of the robot arm.

The forward kinematics problems are explained with the transformation matrices calculated between a coordinate frame fixed in the end effector and another coordinate frame fixed in the base (reference frame). The rotational operation of the body, attached to a certain frame with respect to the fixed frame is given by a 3×3 rotation matrix. The homogeneous transformation matrix is then used to signify position vectors in a 3-D space along with the rotation matrix of the body. The overall homogeneous transformation matrix is derived by simply multiplying transformations of different frames fixed in contiguous links of the chain.

Denavit and Hartenberg were the first to introduce this convention for the spatial geometric representation of a manipulator, and its benefit is in the universal algorithm to solve the kinematics of a manipulator.

The relationships between angles and sides can be found using the right-angle triangle in the figure below,

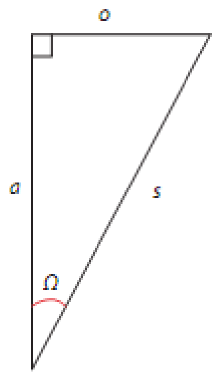


Figure 5. 1 Right angle triangle

s*sin(Ω)=o,

s*cos(Ω)=a and = + (-2*a*s*cos(Ω)) (Cosine Theory)

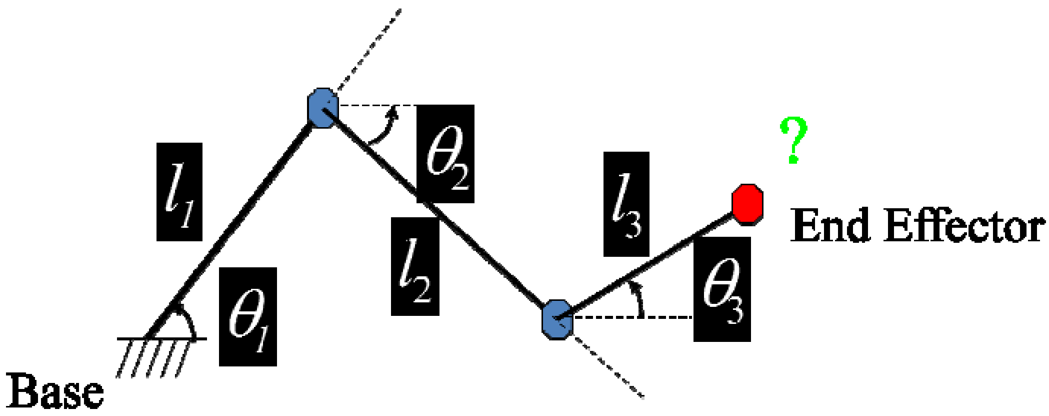


Figure 5. 2 Simple forward Kinematics

INVERSE KINEMATICS (IK)

Inverse kinematics is the opposite of forward kinematics. This is when you have a desired end effector position, but need to know the joint angles required to achieve it. In contrast to the forward problem, the solution of the inverse problem is not always unique: the same end effector pose can be reached in several configurations, correspond position vectors. Although way more useful than forward kinematics, this calculation is much more complicated too.

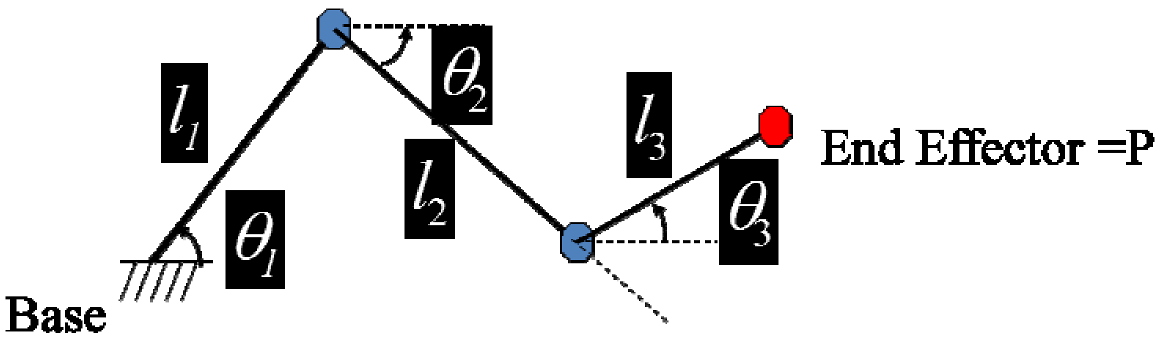


Figure 5. 3 Inverse kinematics

SOLVING THE INVERSE KINEMATICS

Although way more useful than forward kinematics, this calculation is much more complicated. There are several methods to solve the inverse kinematics.

1. ANALYTIC METHOD

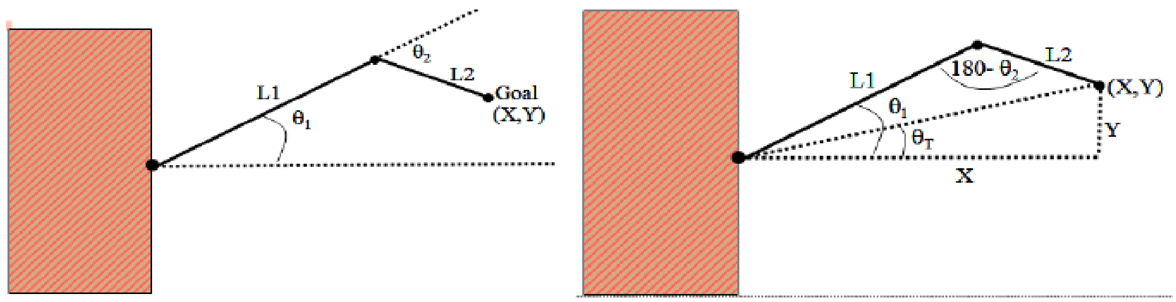


Figure 5. 4 Analytic method to solve inverse kinematics

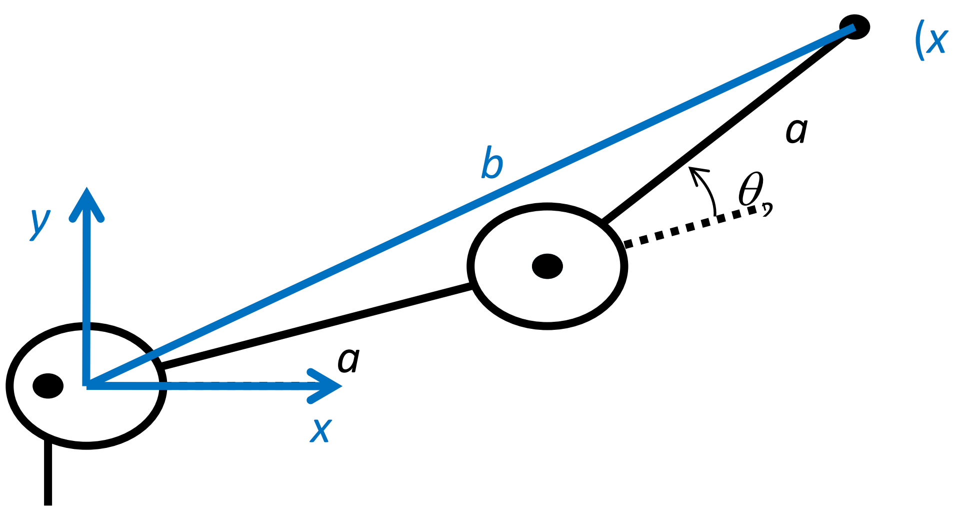


Figure 5. 5 Inverse Kinematics

Cosine Law

$$b^2 = a_1^2 + a_2^2 - 2a_1a_2\cos(\pi - \theta_2) = x^2 + y^2$$

$$\cos\theta_2 = \frac{x^2 + y^2 - a_1^2 - a_2^2}{2a_1a_2} = C_2$$

Instead, use the two trigonometric identities:

$$\sin^2\theta + \cos^2\theta_2 = 1 \qquad \tan\theta = \frac{\sin\theta}{\cos\theta}$$

to obtain

$$\theta_2 = \tan^{-1}\frac{\pm\sqrt{1 - C_2^2}}{C_2}$$

$$\theta_1 = \tan^{-1}\left(\frac{y}{x}\right) - \tan^{-1}\left(\frac{a_2\sin\theta_2}{a_1 + a_2\cos\theta_2}\right)$$

2. CYCLIC COORDINATE DESCENT METHODS

Cyclic coordinate descent method is well known as CCD method. When finding the inverse kinematics solutions for bond link it is very difficult to resolve by using analytical methods. CCD is alternative method which is easy and very effective. CCD resolves inverse kinematics problems by using optimization.

3. JACOBIAN TRANSPOSE METHOD

This method is used to find inverse kinematics solution. This method was first used by A. Balestrino [19]. This method is very simple that change the inverse Jacobian matrix to transpose of Jacobian matrix. The advantages of this method are simple compaction and no matrix inversions.

CHAPTER 6

RESULTS

CNN results:

	PREDICTED		
KNOWN	Plastic Bag	Plastic Bottle	Plastic Cup
Plastic Bag	90.11	7.67	2.22
Plastic Bottle	3.22	94.44	2.33
Plastic Cup	0.89	3.78	95.33

Table 2 Confusion matrix results of CNN training of Images

The above results of the of the confusion matrix shows the percentage correspondence between the known trained images and the predicted test images. It gives a characterized image classification accuracy.

The following table shows the performance accuracy obtained over a pre-processed database. The database contains three different types of plastics, each having around 3000 images. The database was pre-processed, where unclear, distorted images were removed manually leaving clear undistorted images and then cropped to specific size [224 224] which is used by the CNN for training images. After training the network and then validating it with the test images we obtained an accuracy of 93.30%.

	Performance accuracy results		
Labels	**Database size (images)**	**Classification technique**	**Classification Accuracy**
Plastic Bag	3000	CNN-SVM	90.11
Plastic Bottle	3000		94.44
Plastic Cup	3000		95.33
		Mean Accuracy	93.30%

Table 3 Performance accuracy results for image database

To obtain the results as shown in the following figures we used a smartphone with 1260x1080 resolution camera along with IPWebcam android app. The app helps to interface the smartphone camera with MATLAB and allows to capture and control images remotely using IP address. Once the plastic object is detected, the captured image is pre-processed and is compared with the trained network for classification. After successful classification of the plastic object, its type is displayed in a dialog box.

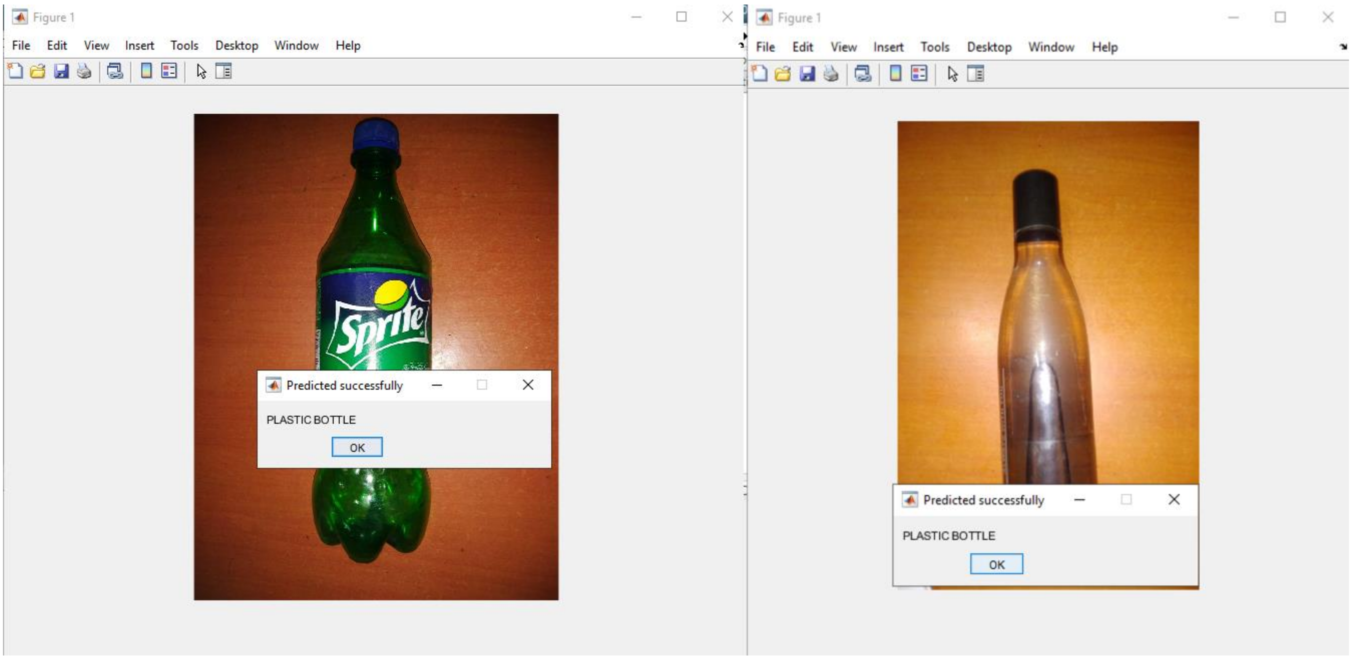


Figure 3 Successful Detection of Plastic Bottles

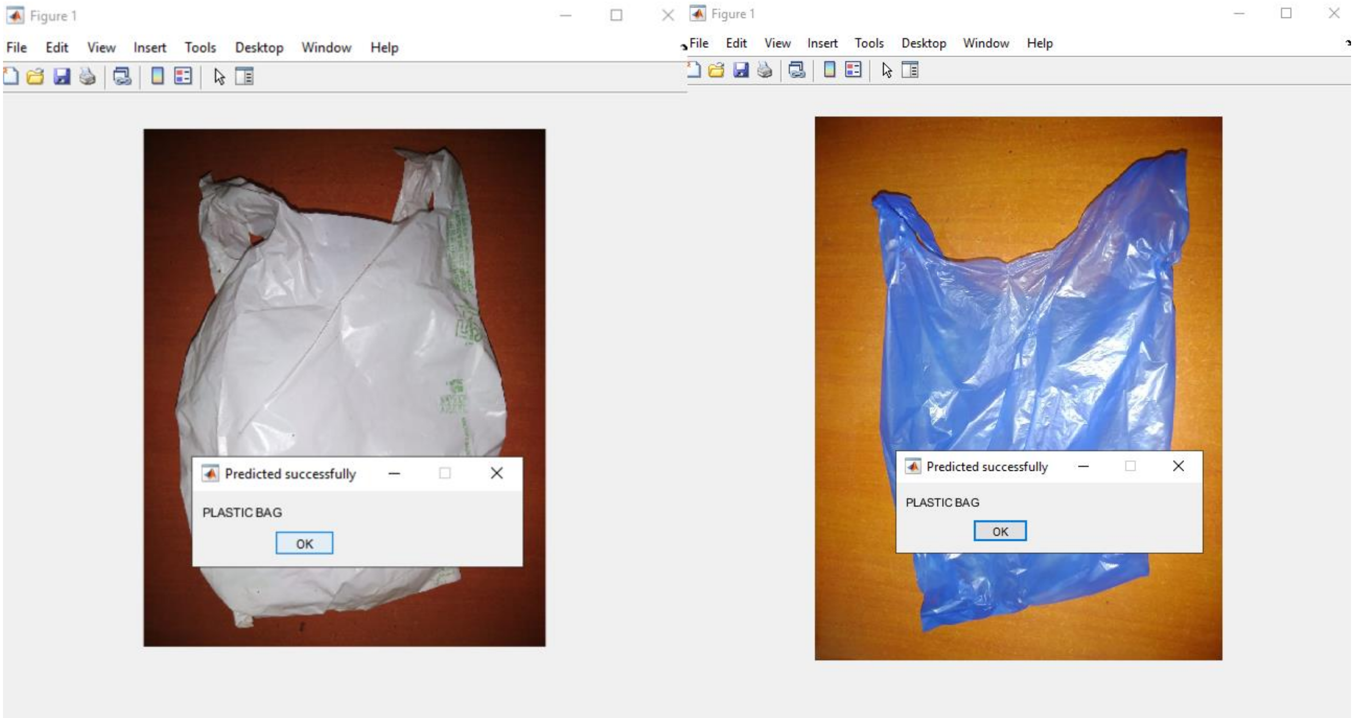


Figure 4 Successful Detection of Plastic Bags

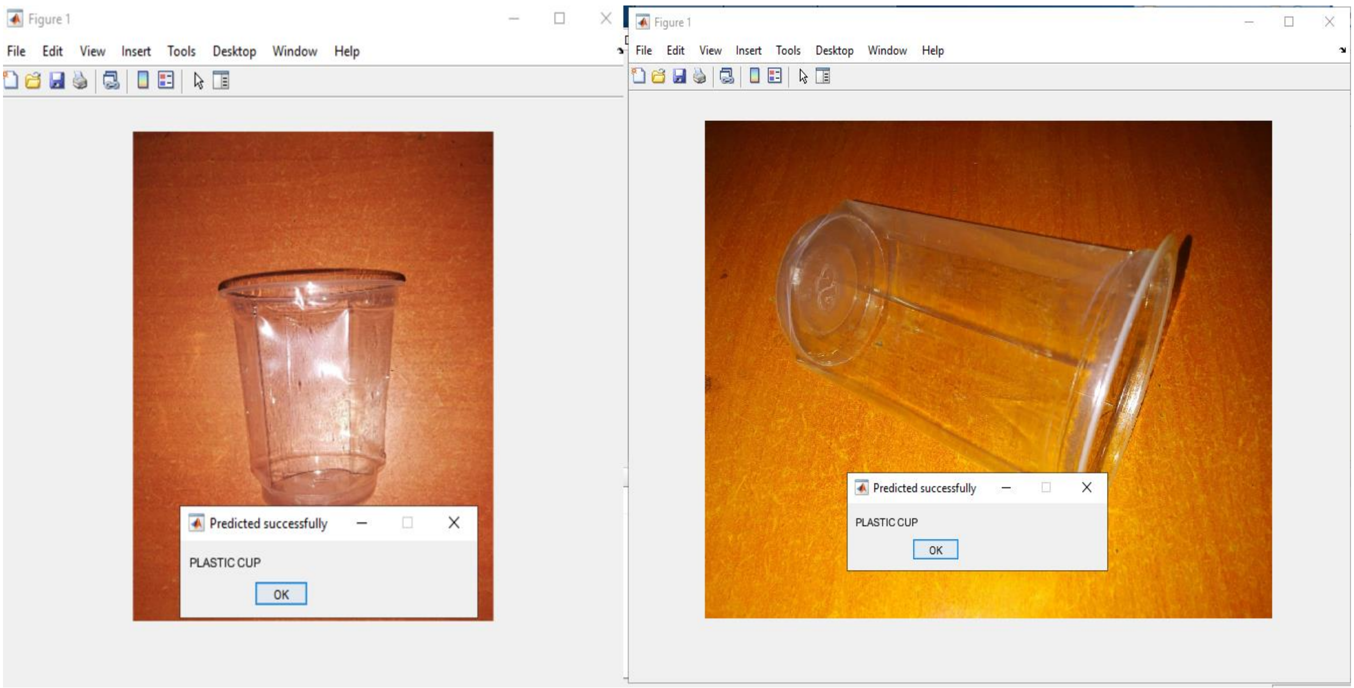


Figure 5 Successful Detection of Plastic Cups

<u>**Controlling Robotic Arm in Gazebo using Moveit-Rviz simulation**</u>

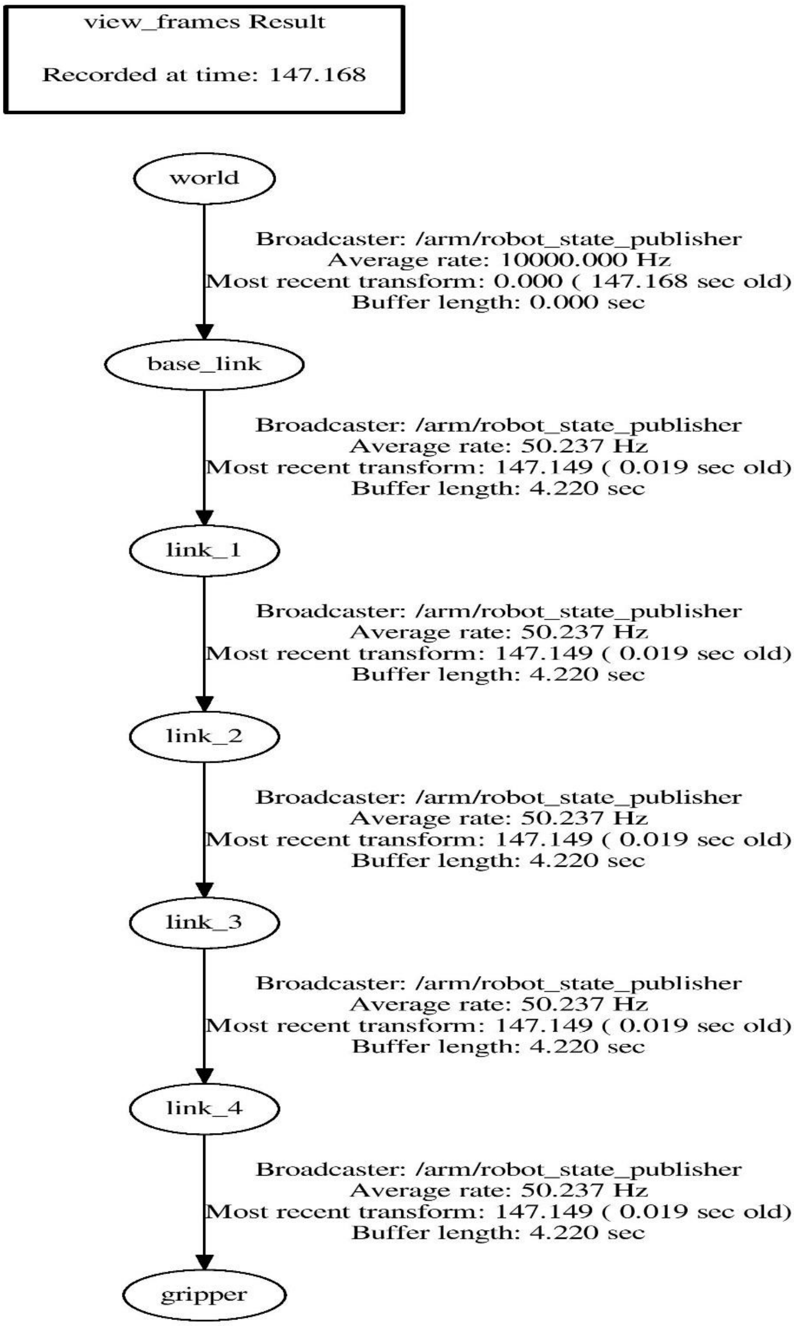


Figure 6 TF frames tree

View frame helps to visualize the entire tree of robot's coordinate transforms. It Broadcasts relative pose of coordinate frames to the rest of the system. A system can have many broadcasters that each provide information about a different part of the robot. With this, one can check if all the links and joints of the robot are successfully connected before publishing state values with joint state publisher.

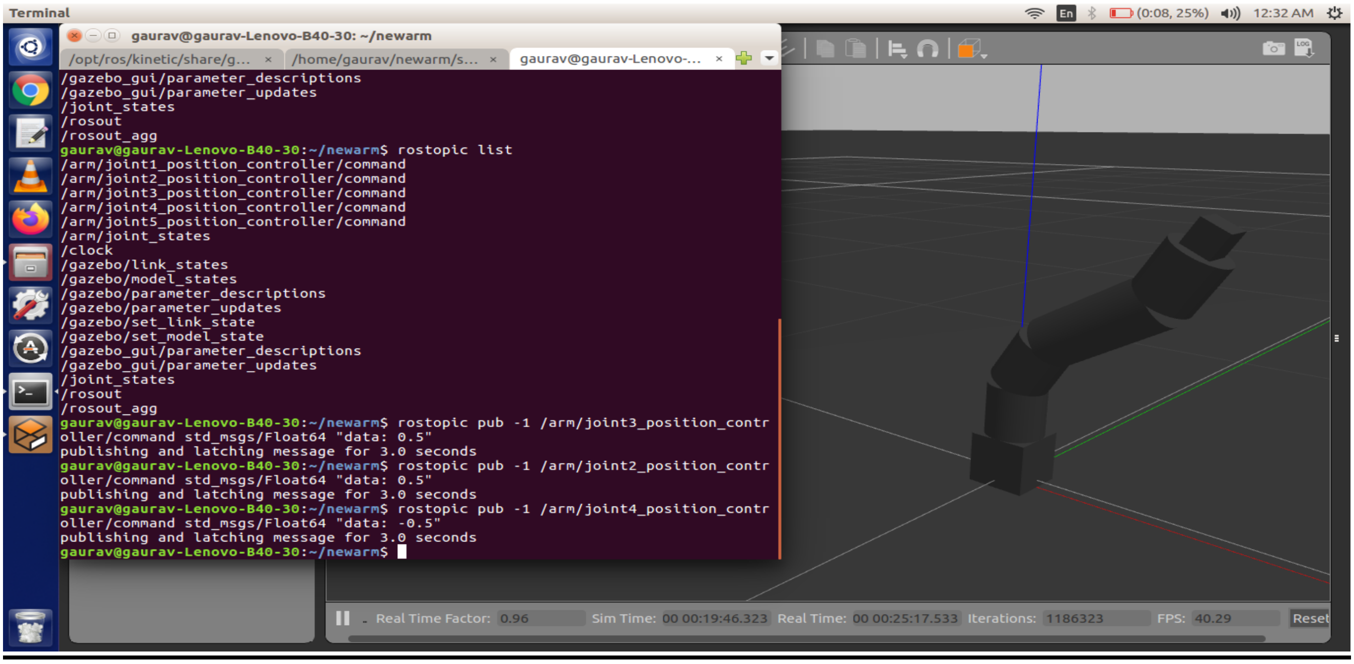


Figure 7 Controlling robot with joint position controller

The above figure shows controlling of robotic arm in Gazebo with Joint State Controller command messages used as type, "position_controllers/JointPositionController". This controller plugin accepts the position [radians (or) meters] value as input. The input position value is simply forwarded as output command to the joint actuator. The values of P, I and D have no effect on output command.

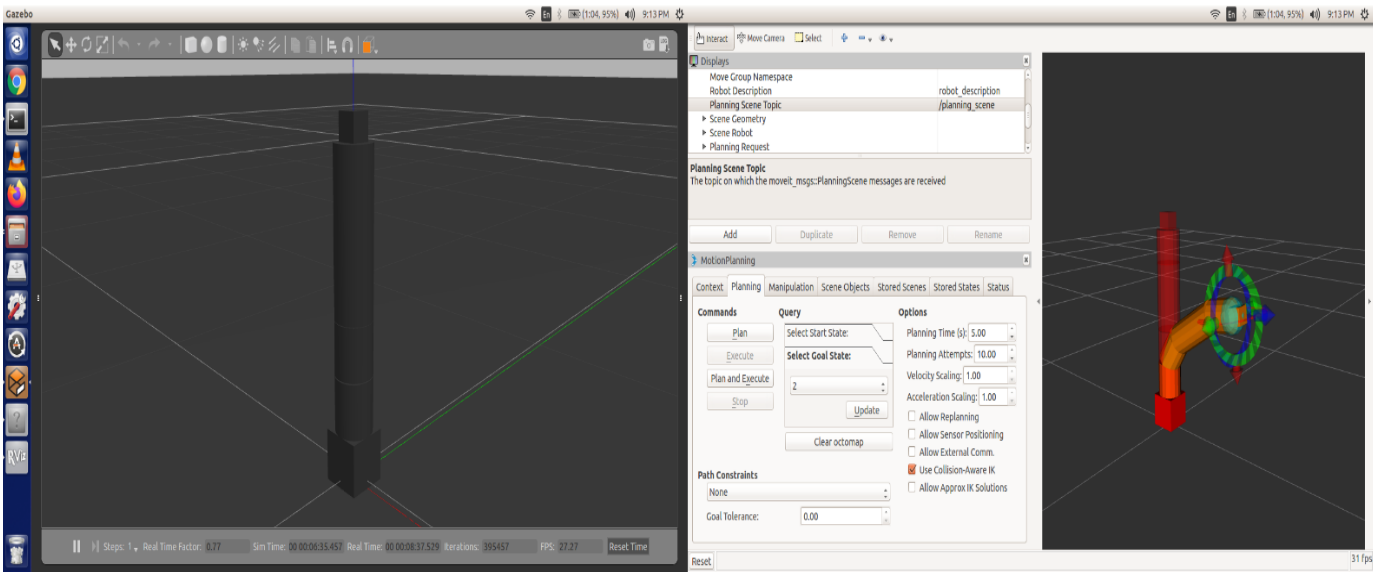


Figure 8 Selecting planning scene for Robotic Arm

For controlling the robotic arm as shown in the above figure (left) in Gazebo, we make use of the FollowJointTrajectory Controller Interface and Planning Scene Topic. By changing the Planning Scene Topic from move_group/monitor_planning_scene to /planning_scene in Rviz (right), we can enable the topic on which the moveit publishes messages. i.e. we can receive planning scene messages from moveit which helps us to set up robot poses for controlling the robot in Gazebo.

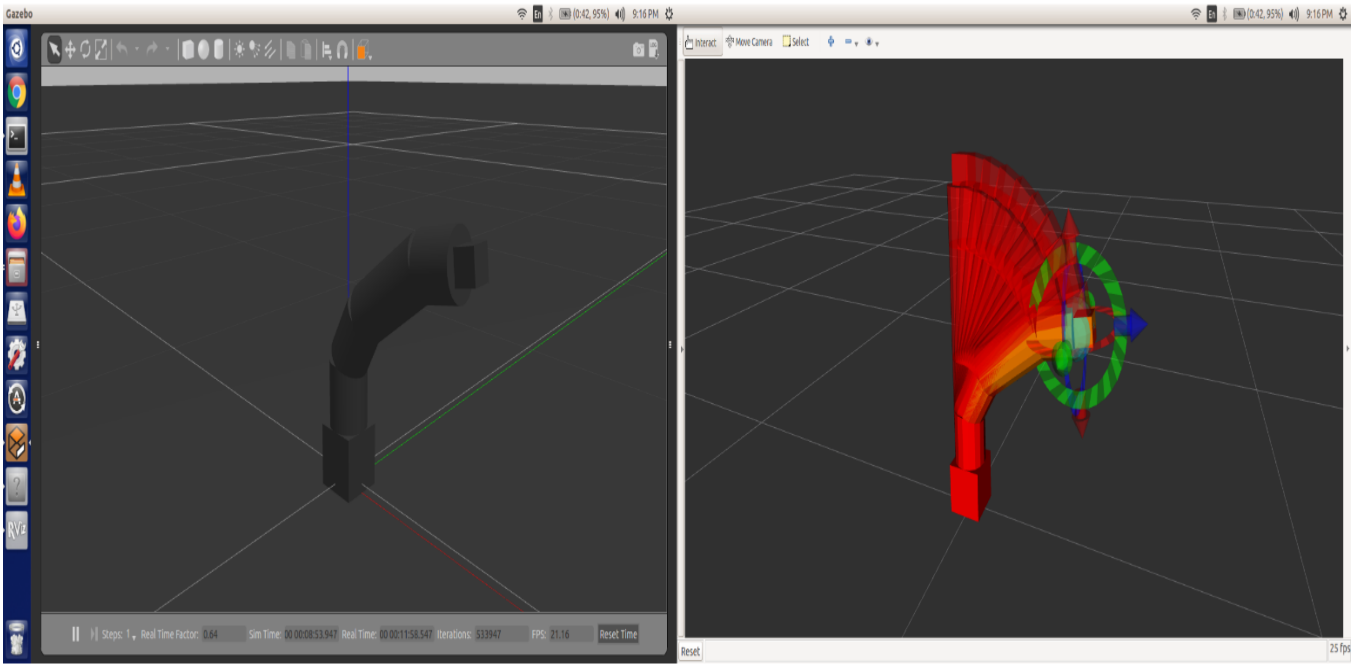
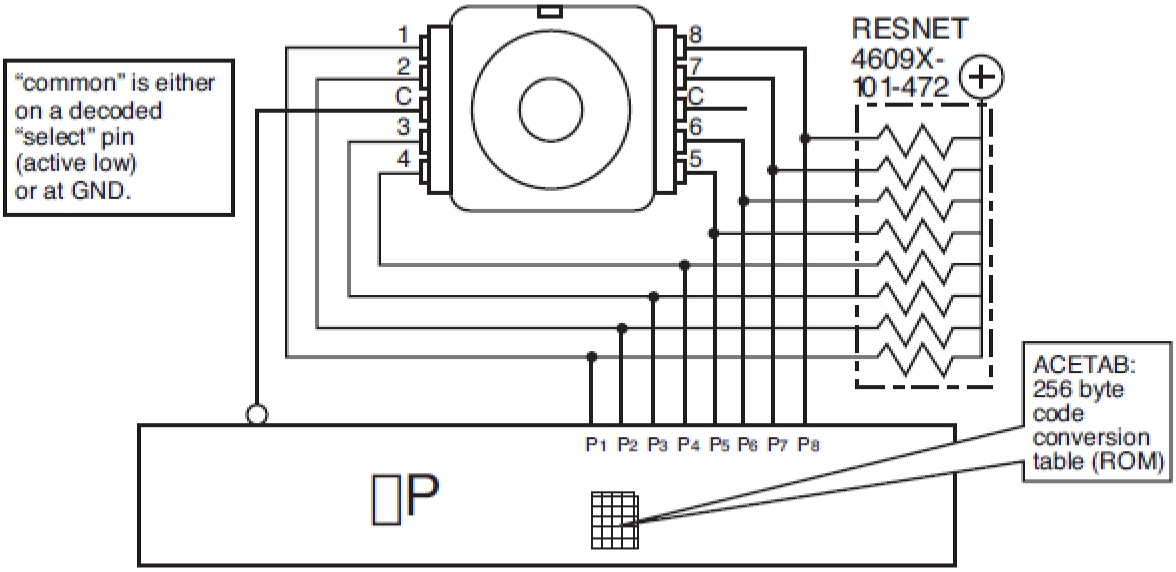


Figure 9 Controlling the Robot in Gazebo using Rviz simulation

The FollowJointTrajectory Controller Interface helps in interfacing Rviz simulation with the Robotic arm in Gazebo. It communicates with the set of joints in the controllers.yaml file and controls the end effector and joints to follow the trajectory executed in Rviz simulation.

ACE-128 ENCODER CONNECTION AND OUTPUT:

Circuit diagram:



Circiut connection:

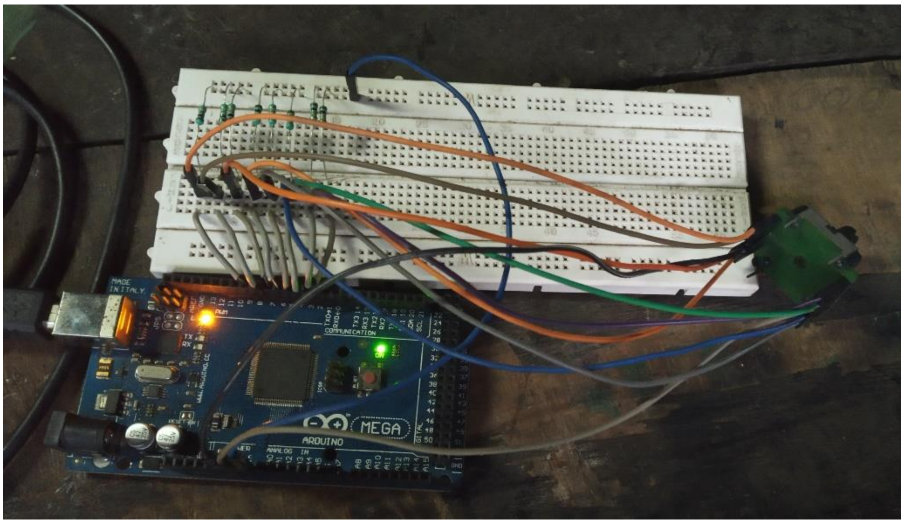
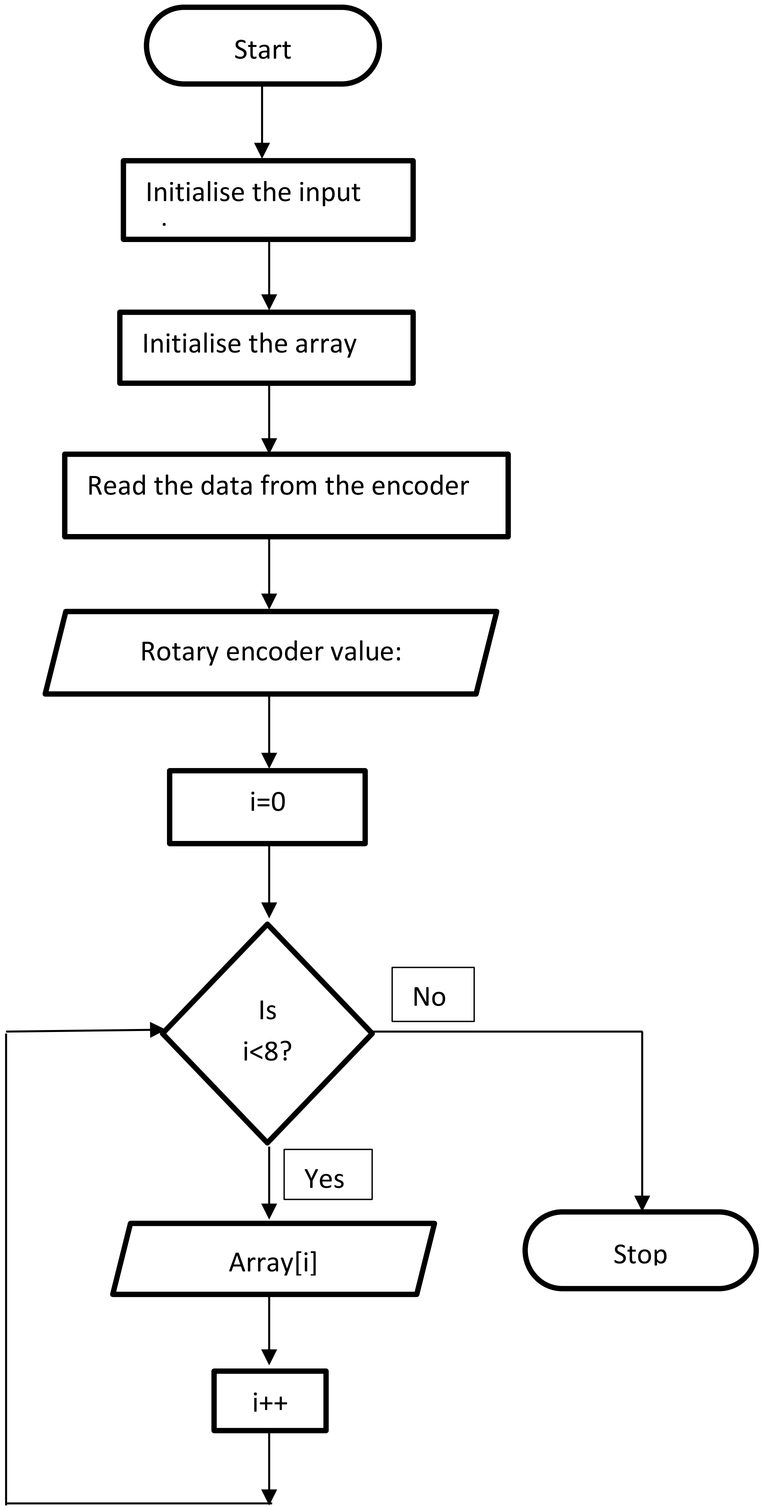


Figure6.1 Circuit for absolute contacting encoder (ace 128)

Flow chart



Start
Initialise the input
Initialise the array
Read the data from the encoder
Rotary encoder value:
i=0
Is
i<8?
No
Yes
Array[i]
Stop
i++

Output of the encoder:

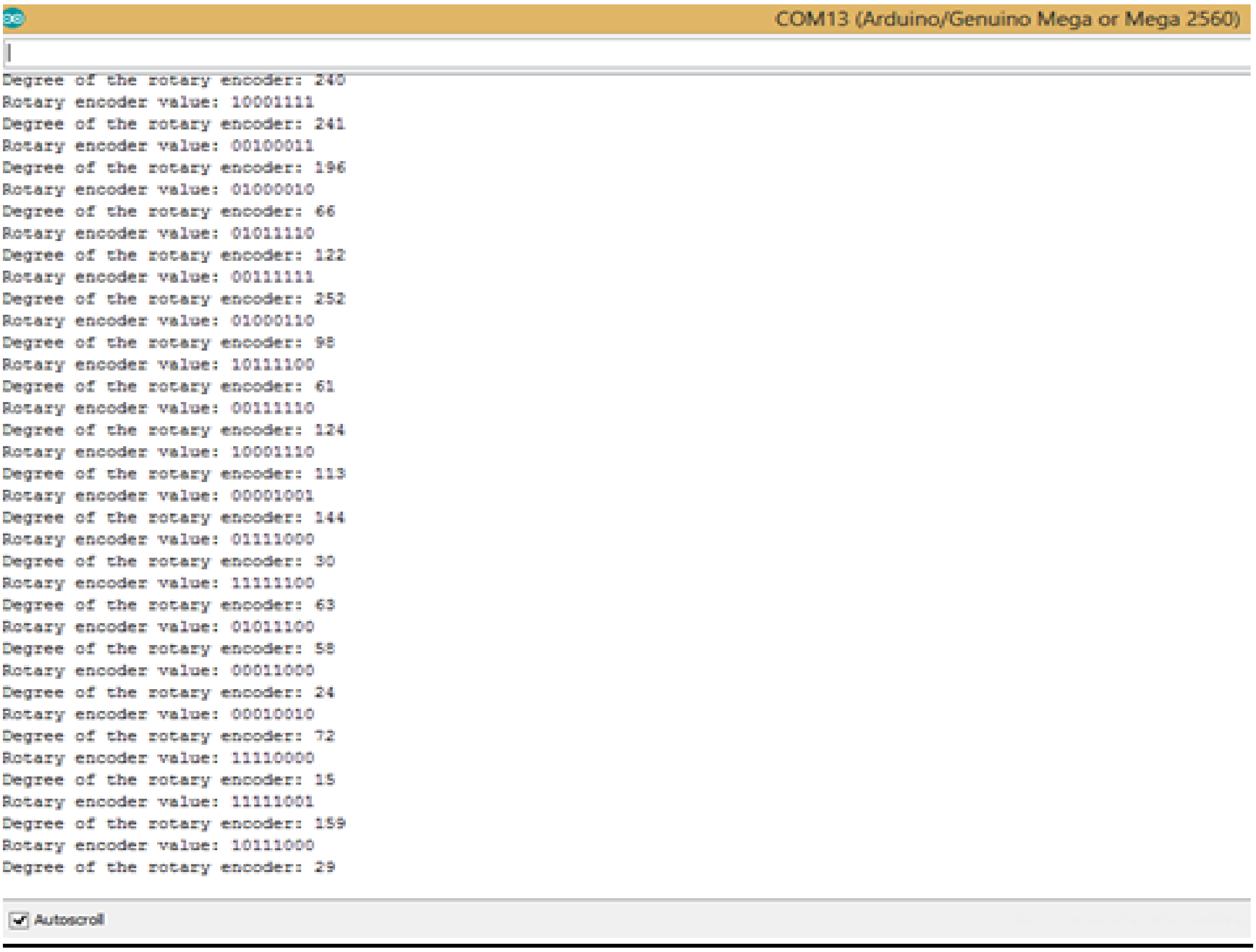


Figure6.2 Output of the rotary encoder (ace 128)

Figure 6.1, shows the circuit connection of the encoder to arduino. Figure 6.2, shows tthe output of the rotary encoder ace128. As the shaft of the encoder is rotated, the change in the position is observed in the serial monitor and the values are obtained.

APPLICATIONS

- The robotic arm can also be implemented in hospitals to pick and place different type of disposed bottles.

- This system can be used by the industries to sort hazardous chemical bottles so that human risk is reduced.

- It can also be used in various plants where sorting is required at high speed as the robotic arm can work for 24x7 hours.

LIMITATIONS

- It is difficult to sort more than one object at the same time by one robotic arm.

- It is necessary that the motors of the robotic arm are functioning all the time or else the incoming plastic will be detected but the arm might delay the pick and place procedure and miss the plastic bottle.

- The DC worm gear motors required high power, hence the driver used should be able to handle the power.

IMPROVEMENTS

- This system can be further improved by building a good database so that accuracy of detecting a plastic bottle is increased.

- By increasing the Degree of freedom of the Robotic arm increase its reach.

- Multiple arms can be installed to segregate different type of waste.

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ANEXURE

ARDUINO MEGA 2560

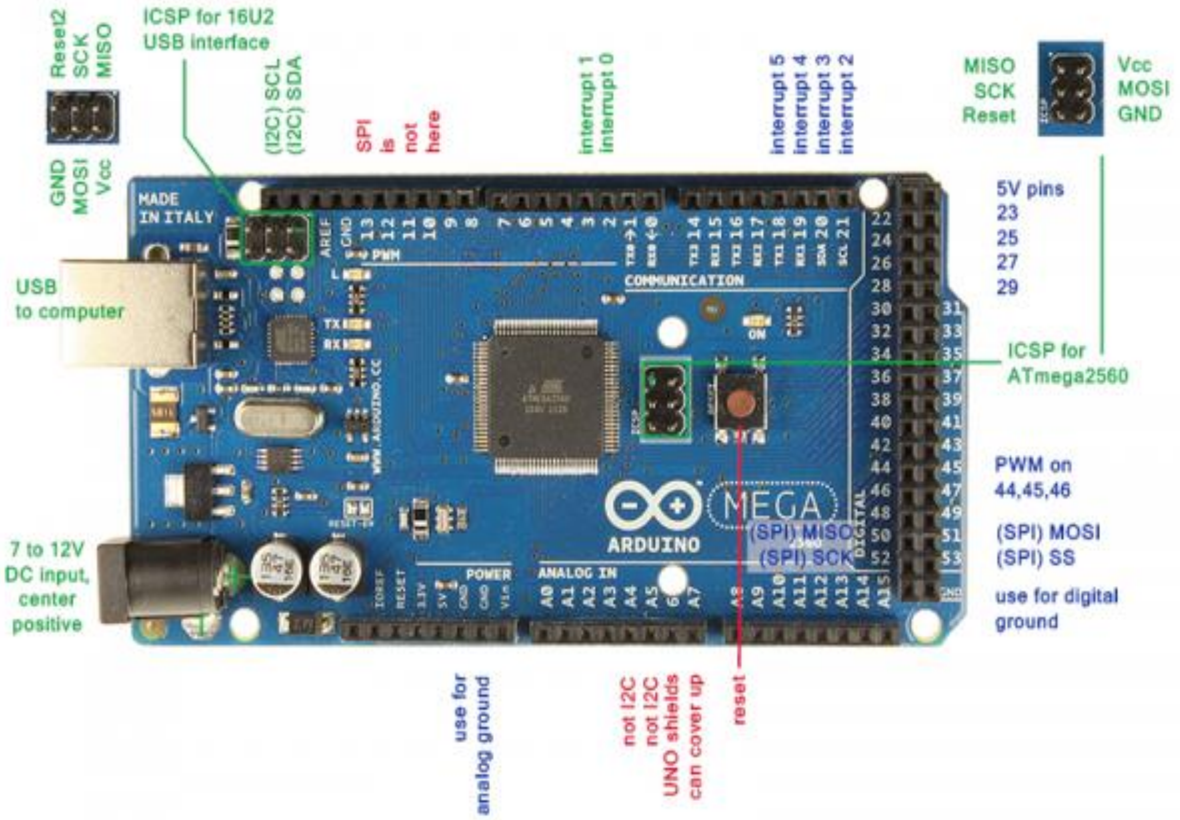

Figure3.1 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 with 54 digital input/output pins, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It is the recommended board for 3D printers and robotics projects. It contains everything needed to run the microcontroller; to get started just connect it to a computer via a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino.

ARDUINO 2560 SPECIFICATIONS

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended / limit)	7-12V / 6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED_BUILTIN	13

Power Specifications:

The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging centre-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 features the ATmega16U2 programmed as a USB-to-serial converter.

Revision 2 of the Mega2560 board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.

Revision 3 power pins are as follows:

- VIN - The input voltage to the Arduino board when it's using an external power source. You can supply voltage through this pin, or, if supplying voltage via the power jack, we can access it through this pin.

- 5V - The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.

- 3V3 - A 3.3volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

- GND - Ground pins.

Memory Specifications:

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

I/O Specifications:

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions operating at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (open by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX). These pins are used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega16U2 USB-to-TTL Serial chip.

- External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2). These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

- PWM: 0 to 13. Provide 8-bit PWM output with the analogWrite() function.

- SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS). These pins support SPI communication using the SPI library. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Uno, Duemilanove and Diecimila.

- LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- TWI: 20 (SDA) and 21 (SCL). Support TWI communication using the Wire library.

The Mega2560 has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- AREF. Reference voltage for the analog inputs. Used with analogReference().

- Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block

Communication:

The Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for TTL (5V) serial communication. An ATmega16U2 on the revision 3 board channels one of these over USB and provides a virtual com port to software on the computer (Linux machines will recognize the board as a COM port automatically). The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2/ATmega16U2 chip and USB connection to the computer.

The ATmega2560 also supports TWI and SPI communication. The Arduino software includes a Wire library to simplify use of the TWI bus; see the documentation for details. For SPI communication, use the SPI library.

Programming:

The Arduino Mega can be programmed with the Arduino IDE software.

The ATmega2560 on the Arduino Mega comes pre-burned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header. The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.

- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.