Harvesting tomatoes in greenhouses by using robot arm

Graduation Project Submitted in Fulfilment of the Requirements for the Degree of B.Sc.

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2024

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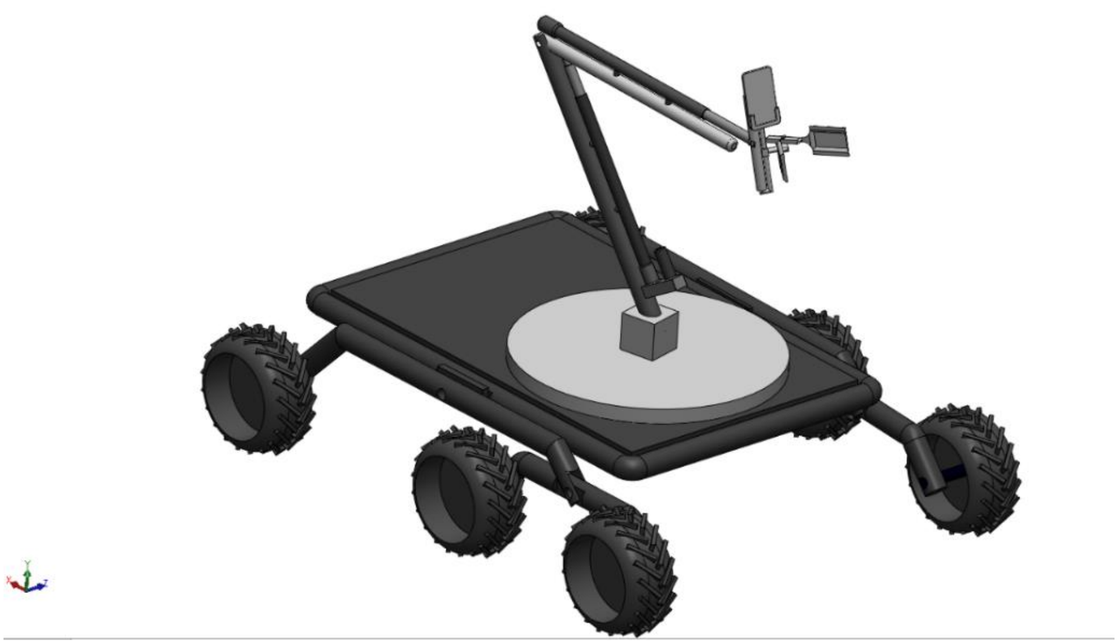
Abstract:

This report outlines an innovative approach to tomato harvesting in greenhouses using a robot arm system. The robotic system features a six-degrees-of-freedom arm with a specially designed end effector. Unlike traditional setups that employ specialized microcontrollers for image processing, this project leverages the capabilities of a mobile application on an Android phone to reduce overall costs. The mobile application utilizes the phone's camera to capture live images within the greenhouse. Image processing is performed on the main application to identify the tomatoes' positions. Subsequently, commands are relayed to the microcontroller to initiate precise movements of each motor, facilitating the arm's smooth navigation towards the targeted tomatoes. The robot comprises two main components: the robotic arm with six motors for controlling individual arm movements and a mobile car assisting the robot's mobility within the greenhouse. The electronic components include a microcontroller, driver, Bluetooth module for communication with the mobile application, and a battery for power. This inventive amalgamation of mobile technology, image processing, and robotic control not only enhances the precision and efficiency of tomato harvesting but also streamlines the overall cost and complexity associated with the use of specialized microcontrollers. The report offers a comprehensive exploration of the design, functionality, and potential impact of this integrated robotic system on greenhouse agriculture.



Automation of Tomato Harvesting in Greenhouses using Robot Arms

1. Introduction:

Greenhouse farming is gaining popularity for its eco-friendly crop cultivation. To revolutionize how we harvest tomatoes, we're turning to robot arms in greenhouses. This report explores how these robot arms can make tomato harvesting easier and more efficient inside greenhouses.

2. Benefits of Robot Arm Implementation:

2.1 Precision and Efficiency:

Picture robot arms delicately picking ripe tomatoes using smart sensors and clever algorithms. This means less damage and more careful handling, making the harvesting process precise and efficient.

2.2 Labor Savings:

Here's the exciting part – robot arms significantly reduce the need for people to manually pick tomatoes. Less human labor not only saves money but also makes the whole process more efficient. It's a win-win, especially considering the global push for sustainable practices.

2.3 Time and Resource Optimization:

Think of robot arms as super helpers. They optimize time and resources by automating the harvesting process in greenhouses. This makes the workflow smoother, helping growers produce more without wasting resources, promoting a sustainable approach to farming.

3. Technological Advancements:

Robot arms owe their success to cool tech advancements. Imagine robots using smart sensors, computer vision, and machine learning to adapt to different greenhouse conditions and pick tomatoes of all shapes and sizes. That's what makes them so effective!

4. Case Studies and Success Stories:

Around the world, greenhouses are showing off their success with robot arms. Real-life stories and examples tell us how adaptable and helpful these robot arms are in different greenhouse settings. These stories give us a peek into how this technology can transform the way we harvest tomatoes.

5. Challenges and Considerations:

While robot arms sound amazing, there are challenges. Things like the initial cost, keeping the systems running smoothly, and making sure they work with all types of tomatoes need some thought. Researchers are working on these challenges, making sure robot arms become more accessible and practical for greenhouse tomato harvesting.

6. Conclusion:

Adding robot arms to tomato harvesting in greenhouses is a big step in making farming smarter. It's not just about being precise or saving labor – it's about making greenhouse farming more sustainable and efficient. As technology gets better, using robot arms might just be the future of growing tomatoes in controlled environments. Exciting times ahead for agriculture!

- **The previous research**

- **The first one is SWEEPER, a sweet pepper harvesting robot. On 13 January 2020 sweeper is released,**

Abstract

a robot for harvesting sweet pepper fruit in greenhouses. The robotic system includes a six degrees of freedom industrial arm equipped with a specially designed end effector, RGB‐D camera, high‐end computer with graphics processing unit, programmable logic controllers, other electronic equipment, and a small container to store harvested fruit. All is mounted on a cart that autonomously drives on pipe rails and concrete floor in the end‐user environment. The overall operation of the harvesting robot is described along with details of the algorithms for fruit detection and localization, grasp pose estimation, and motion control. The main contributions of this paper are the integrated system design and its validation and extensive field testing in a commercial greenhouse for different varieties and growing conditions. A total of 262 fruits were involved in a 4‐week long testing period. The average cycle time to harvest a fruit was 24 s. Logistics took approximately 50% of this time (7.8 s for discharge of fruit and 4.7 s for platform movements). Laboratory experiments have proven that the cycle time can be reduced to 15 s by running the robot manipulator at a higher speed. The harvest success rates were 61% for the best fit crop conditions and 18% in current crop conditions. This reveals the importance of finding the best fit crop conditions and crop varieties for successful robotic harvesting. The SWEEPER robot is the first sweet pepper harvesting robot to demonstrate this kind of performance in a commercial greenhouse.

- **The second one is “BERRY” robot improving its navigation and harvesting speeds.**

Automated strawberry harvesting to come in 2023.

Organ farms revealed “Berry,” its strawberry harvesting robot, at Greentech in 2022 and won the Greentech Innovation Award in the concept category. Since then, the company has continuously worked to improve the robot and develop the minimal viable product (MVP). As Hannah explains, the robot now moves more quickly but is not yet at its final speed; this will be optimized during the winter. “Berry” also now has improved storage capacity and can store four.

crates (up to 20 kg of fruit) before dropping off its payload. The company continues to develop the robot’s navigation skills to ensure that it can effectively maneuver in the plant canopy to harvest fruit without damaging stems and leaves.

“The robot can now change rows autonomously, which it couldn’t do at the time of its introduction. They are still working on the picking speed and are aiming for 10 kg per hour, including all driving time and crate exchanges. And our battery will be able to run 12 hours,” explains Hannah.

Collaborating with Delphy and signing first clients
Organ farms has collaborated with Delphy to test “Berry” at the research center over an entire season and with different strawberry varieties. This was part of a larger project with various partners looking to optimize the production of everbearing varieties through automation. The company is still running trials in Germany and welcomes any growers interested in participating. Otherwise, Organ farms is poised to introduce “Berry” to the market in 2023 and has already secured its first customers.

- **The third one Robotic Tomato Harvesting Enables Faster Innovations in Research and Development 2023-04-18.**

The future of food production will require greater efficiency, sustainable practices, and maximizing yields at every step. To optimize the future production of tomatoes, Syngenta Vegetable Seeds recently worked with Pittsburgh, Pa.-based Four Growers, Inc. to test the GR-100 robotic harvester in tomato research.

“This collaboration helps serve as a link between genetics and automation,” said Ruud Kaagman, Syngenta Global Crop Unit Head – Tomato. “The success of robotization in the future is the application of robotics with different plant characteristics. With this collaboration you’ll see varieties adapted to robotic harvesting to enable growers’ success.”

Robotics paired with genetics put technology and nature together to create a better future for this healthy crop eaten around the world. The partnership between Syngenta and Four Growers could lead to faster crop advancements, reduced food waste, and more satisfied growers and consumers.

Enable Labor Cost Reduction

Today tomatoes are harvested with human hands, which accounts for a sizeable portion of overall production costs – up to 30% of the total. On top of costs, growers are finding it more difficult to find enough laborers. With rampant labor shortages growers need solutions to ensure consumers have access to the tomatoes they need.

Enter robotic harvesting.

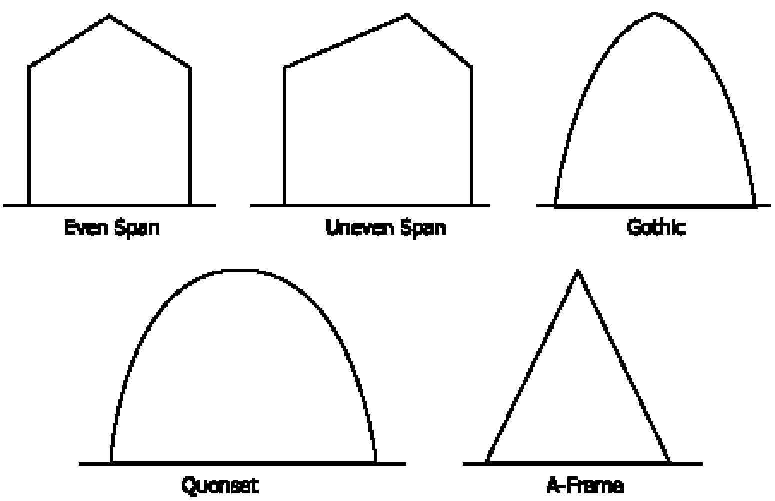
“Using robotics in agriculture will enable us to eat higher quality, healthier, more affordable produce,” said Brandon Contino, Four Growers CEO. “Unlike other machines that we see in the field today that harvest every crop (ripe or unripe) in one pass, at Four Growers, our robotics and AI enable us to pick produce individually so that we only harvest those that are perfectly ripe.”

Harvesting robots can save time and human resources. For Syngenta, it is important to partner with Four Growers to be ready for the production styles of the future and fully understand the needs of the grower.

Types of Greenhouse Structures

The two basic types of greenhouse structures are freestanding (detached) and connected (attached). Freestanding structures can be constructed in several frame styles. The *even span (gabled)* frame is commonly used. The angle and width of its roof are equal. This frame type can be lengthened. It has more usable space than other types and promotes good air circulation and maintains even temperatures in the greenhouse. The *uneven span* frame, with one roof side longer than the other, is used if the land's slope is not too steep. This structure is placed on hillsides with southern exposure. It captures more of the low light during winter than the even span greenhouses.

The high *gothic arch* frame provides ample headroom and is used primarily to grow potted crops and spring flowering annuals. The *Quonset* frame, developed during World War II, is extremely simple to build and efficiently designed, but its circular frame lowers the sidewall height, which limits headroom and storage space. The design of the *A-frame* provides more space along the sidewalls, which promotes good air circulation. Figure 1 illustrates each of these frame types.



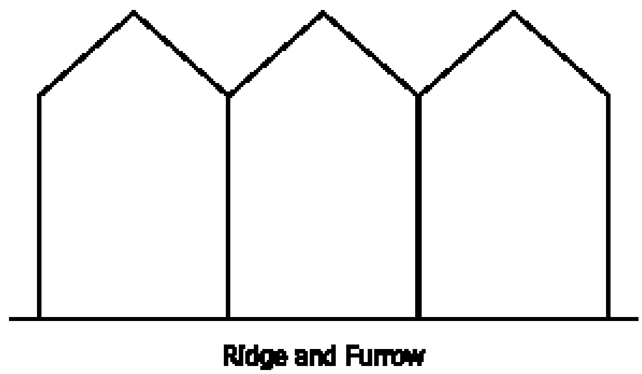


Figure 2

Figure 1

Freestanding structures are easy to maintain. Because there is space between these buildings, shoveling snow from the rooftops can be done with minimal difficulty. Regulating the temperature and ventilating the air are also easier to perform. As a result, plants are not exposed to erratic temperature fluctuations or harsh blasts of cold air. Another advantage of freestanding structures is uniform light with minimal shadows. However, this type of structure costs more to construct because it requires additional sidewalls and occupies more space than a single connected structure. It is also less energy efficient because more surfaces are exposed to the outdoor elements. The framing styles of connected structures are similar to those listed above, but they are joined by a common roof, typically a *ridge and furrow* construction. The furrows form gutters. (See Figure 2) The interior walls create separate zones for crops.

Figure 2 - Ridge and Furrow Construction

Connected structures occupy less land and have no sidewalls; therefore, fewer materials are needed for construction. Because there are no walls where the gutters are, more interior space is available than in several freestanding structures. Less energy is required to heat and cool the greenhouse because the exposed wall surface area is reduced.

But being connected to another building makes it harder to apply insecticides that produce vapors, gas, smoke, or fumes and to zone heat to specific plants. Another drawback is that the gutters collect snow, making removal very difficult. To avoid excessive accumulation that can collapse the greenhouse, the owner may have to add expensive heat lines to induce melting. Gutters also create shadows, thereby diminishing light intensity. As a result, plants may ripen later than expected. This delay in harvest time can affect the grower's market opportunities.
The *lean-to* is a common example of the connected structure. It is attached to an existing building that generally faces east or south. Confined to a width of about 7-12 feet, this is the least expensive growing structure. Heat, water, and electricity come from the adjacent building. It is often used for forcing bulbs and starting seeds. However, lean-to greenhouses have limited space and less roof support. Figure 3 illustrates a lean-to greenhouse.

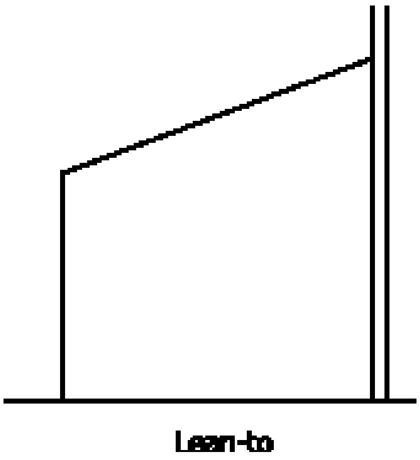


Figure 3

Figure 3 - Lean-To Greenhouse

Construction of a Growing Structure

The basic components of a greenhouse are illustrated in Figure 4. *Figure 4 - Parts of a Greenhouse*

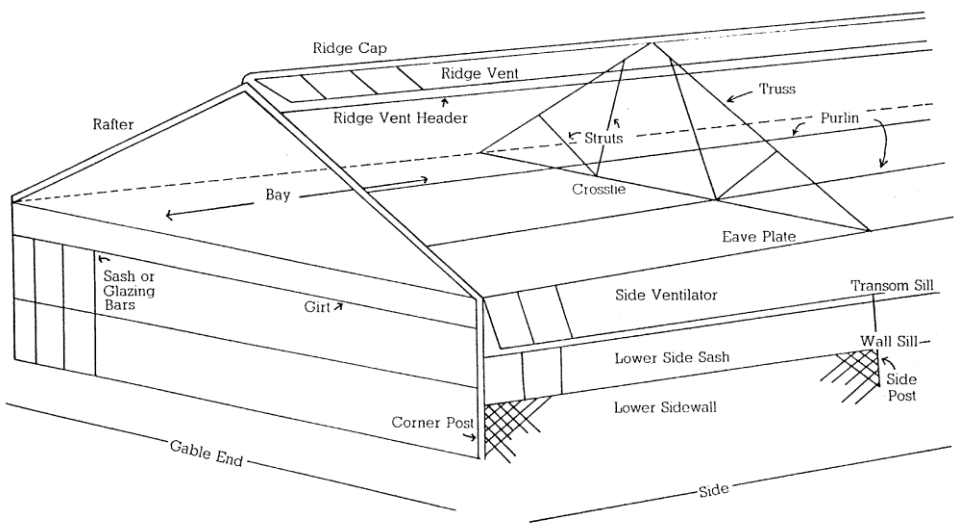


Figure 4

The owner has several decisions to make concerning how to frame the greenhouse: cost of construction and maintenance, strength of the structure, choice of covering materials, and amount of light blocked.The framing materials may be used alone or in combination. If *wood* is used, it must resist decay. Some trees (e.g., ash, birch, cottonwood, hickory, and pine) are naturally resistant to decay even when untreated and have an average expected life of 15 years. Other trees such as redwood must be treated with either an oil-based or a waterborne, salt-type preservative that is safe for plants. Wood must NOT be treated with chemicals that emit toxic fumes to plants (e.g., creosote and pentachlorophenol, known as PENTA). Painting preservative-treated wood with light-reflecting, white, water-based paint provides further protection. A better choice of framing material is *aluminum* alloy because it is flexible, durable, affordable, and long lasting. It is a versatile metal, able to conform to various shapes and thicknesses, and can be molded into the desired framing structures.

Greenhouse Tomato Production

Tomatoes are the most widely produced greenhouse crop in the world. A large percentage of fresh-market tomatoes are grown in Canada and Mexico, and the United States is slowly building a market presence.

As with any business, profitability is the driving factor for this type of venture. Larger greenhouse facilities are typically better able to earn a profit due to volume produced and more efficient labor. Enterprises located near urban areas where direct-market customers are more willing to pay a premium also tend to be more profitable. Small facilities of one to two greenhouses struggle to profit with direct market sales. The most limiting factors to profitability in Alabama are winter heating costs and labor.

Another factor that affects profitability is the type of tomato grown. Greenhouse tomatoes are grown vertically on a trellis system to maximize space, and most are *indeterminate* tomato varieties, meaning they continue to grow after setting fruit. Conventional field- growing operations grow *determinate* tomato varieties that stop growing once fruiting has occurred. Growing indeterminate varieties helps spread the cost of starting a crop over an extended period of time, thus lowering the cost of startup.

Greenhouse tomato production consists of several stages and requires some decision making and planning up front. Some considerations include the crop cycle to use, the seed variety to plant, the growing and support system to use, plant spacing and training methods, and fruit thinning, pollinating, irrigating, and fertilizing.

Crop Cycle

Greenhouses allow for year-round production of many crops; however, summer temperatures in southern states, including Alabama, can inhibit tomato production by reducing fruit quality and yield. Plants stressed by extreme heat are also more susceptible to pest damage. For these reasons, greenhouse tomatoes are only sometimes grown in standard greenhouses during the summer months. In other areas of the country, evaporative cooling can significantly reduce greenhouse temperatures, but this technology is limited in the highly humid southern United States.

Two crop-scheduling options are available for the extreme summer temperatures in the greenhouse. The first is a single, 10-month crop that is started in August and finished the following June. The second is the two-crop method, developed by Mississippi State University, which can produce similar yields during the same time span. The two-crop system also begins with an August planting date, but the first crop ends in December when a second crop is immediately transplanted for spring. The new, young crop is better able to handle the disease pressure associated with January and February, when ventilation rates are reduced, and humidity remains high for extended periods.

Temperature

Tomatoes are a warm-season annual plant. Significant growth and yield can be achieved when daytime temperatures are maintained between 80-and 85-degrees F. Low temperatures damage tomato tissue. One sign of cold damage in tomato plants is leaves that turn purple and curl inward. In greenhouse tomato production where tomatoes are grown in the off season, adequate temperature is important, particularly during periods of cold weather. Therefore, growers should maintain nighttime temperatures between 65-and 60-degrees F but no lower.

In Alabama, growers more often must deal with temperatures that are too high rather than too low. Excessively high temperatures can affect fruit development, resulting in cracked fruit and reduced fruit set. Shading during the warmer months can help reduce temperatures inside the greenhouse. Shading reduces light levels, which decreases photosynthesis and therefore yield; however, any reduction in yield due to shading is less than that caused by excessive heat. Shade cloths of 30 to 50 percent are common grades used with greenhouse vegetables. For more information about evaporative cooling, visit the Alabama Extension website at www.aces.edu.

Seedling Production

The first step in growing greenhouse tomatoes is to plant seeds. Start tomato seeds in 36-, 50-, or 72-cell nursery trays using a peat-based potting mix or in 1-inch block media, such as oasis cubes or Rockwool, and later transplant them into larger cells. Irrigate seedlings using clear water until the first true leaves appear. Once true leaves appear, switch plants to 50 parts per million (ppm) nitrogen. If using a 20-20-20 or 20-10-20 soluble fertilizer, 50 ppm of nitrogen will equal about 1 gram per gallon of water. Allow the media to dry slightly between waterings to encourage the roots to grow throughout the growing mix. Overwatered tomato transplants tend to grow tall and have thin, weak stems and poor root systems. Transplant seedlings when they are 4 to 6 inches high. Since warmer temperatures speed germination and seedling growth, use greenhouse- grade heating mats to supplement heat when needed to maintain a rootzone temperature of 84 degrees F. Most transplants can be produced in 4 to 6 weeks, depending on temperatures.

When choosing varieties, select those that are adapted to greenhouse conditions. Greenhouse tomatoes are typically labeled as such in commercial seed catalogs. These varieties are bred to be disease resistant and better able to tolerate low winter light conditions.

Growing Systems

Substrate-based systems are often used in greenhouse tomato production because large, vining plants need adequate root support that traditional hydroponic systems cannot provide. The three main substrates used in greenhouse production are perlite, pine bark, and Rockwool. Perlite and pine bark are used with container systems in which containers are placed on the greenhouse floor and the plants are trained up a wire or trellis throughout the growing cycle. The three types of containers commonly used in greenhouse production are the Dutch bucket, bag culture, and nursery pots. A Dutch bucket is a rectangular, 11-liter bucket that has a drainage hole. Bag culture uses a flexible plastic bag with drainage holes cut into its underside. Perlite works best in bag culture, but pine bark can also be used. Nursery pots are 3- or 5-gallon plastic pots used in ornamental production.

Rockwool, the other greenhouse substrate, is not used in container systems but is commonly used in highwire tomato-growing systems, typically in advanced greenhouses in cooler regions. Trellis wires are suspended at least 12 feet off the ground, as opposed to 6 to 8 feet in traditional greenhouses. Rockwool slabs are used in these taller systems to anchor roots and provide adequate moisture as plants can reach much larger sizes with the added vertical growing space. These large slabs or cubes have a high water- holding capacity and are often set on plastic troughs in production systems where the nutrients can drain. Smaller Rockwool cubes are used for transplant production. Rockwool is recommended for greenhouse production instead of soil because soil-based systems have a higher risk of bacterial infection from soil-borne diseases.

Plant Spacing and Training

Space tomato plants so that each has 3.5 to 5 square feet of growing area. Spacing should result in 16 inches of in-row spacing between plants and 5 feet of spacing between rows. A 30- by 96-foot greenhouse can accommodate five double rows of tomato plants. Typically, each growing container has two transplants, and each transplant is trained to one of two steel cables used as a trellis. These cables are suspended 8 to 10 feet above the crop, run the greenhouse length, and are 24 inches apart within each row. To train the plants, suspend strings from the cables and wrap the string around the growing point as the plant grows, or use plastic tomato clips every 10 inches along the plant's main stem as shown in figure 5. To maintain a single leader and distribute energy to fruit production instead of secondary vegetative growth, remove all suckers (secondary shoots that will form into a branch if left to grow) as they form. If left to grow, secondary growth will make vertical training difficult and interfere with airflow and light penetration into the canopy. Remove suckers when they are small and at least once a week. Remove the terminal bud at the overhead wire six weeks before the end of the crop cycle. Fruit will continue to develop and ripen along the main stem until the production cycle is finished.

Support Systems

It is essential to use a well-designed support system for the tomato trellis. Do not use the greenhouse structure for support unless it was specifically designed to handle the weight; otherwise, structural damage may occur. Recommendations for support system designs can be found in the Mississippi State University “Greenhouse Tomato Handbook.”

Figure 5 a. Wooden structures hold steel cables for trellising twine to support tomato growth in a standard greenhouse.

Figure 5 b. Metal structures hold steel cables for trellising twine to support tomato growth in a standard greenhouse.

Usually there's about 36 inches (91 cm.) of workspace between pairs of tomato rows that are spaced 28-30 inches (71-76 cm.) apart.

According to the Egyptian stander the distant between row is (95-80cm).

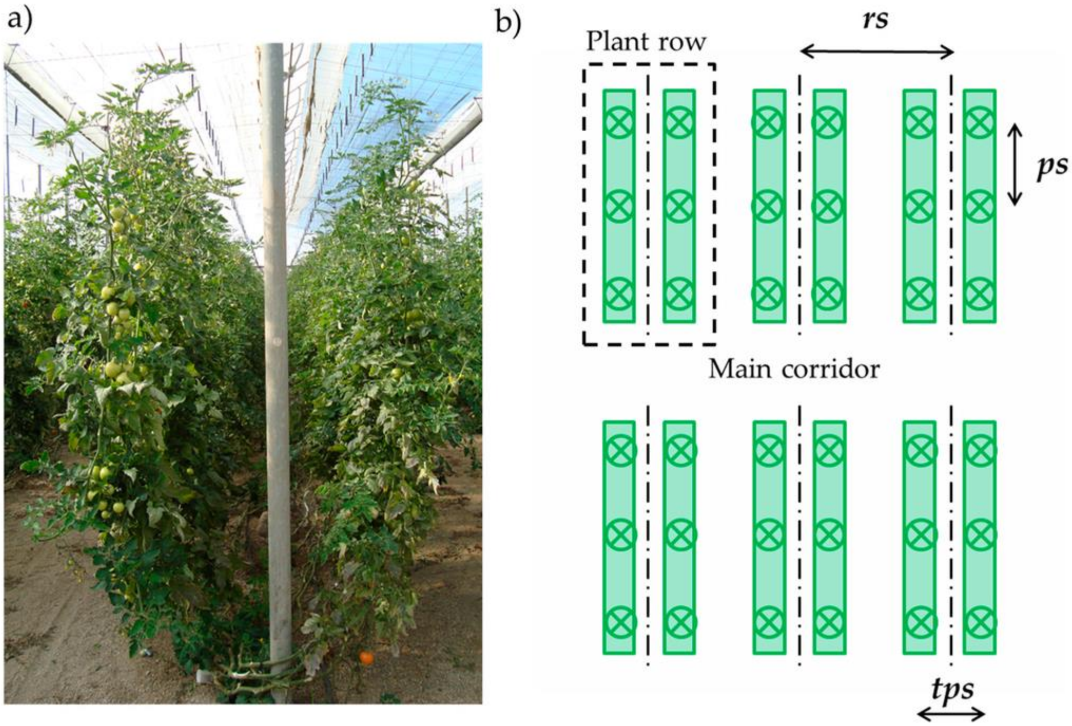


Figure 6

So,the maximum width of the robot will be 80cm&maximum length 100cm.

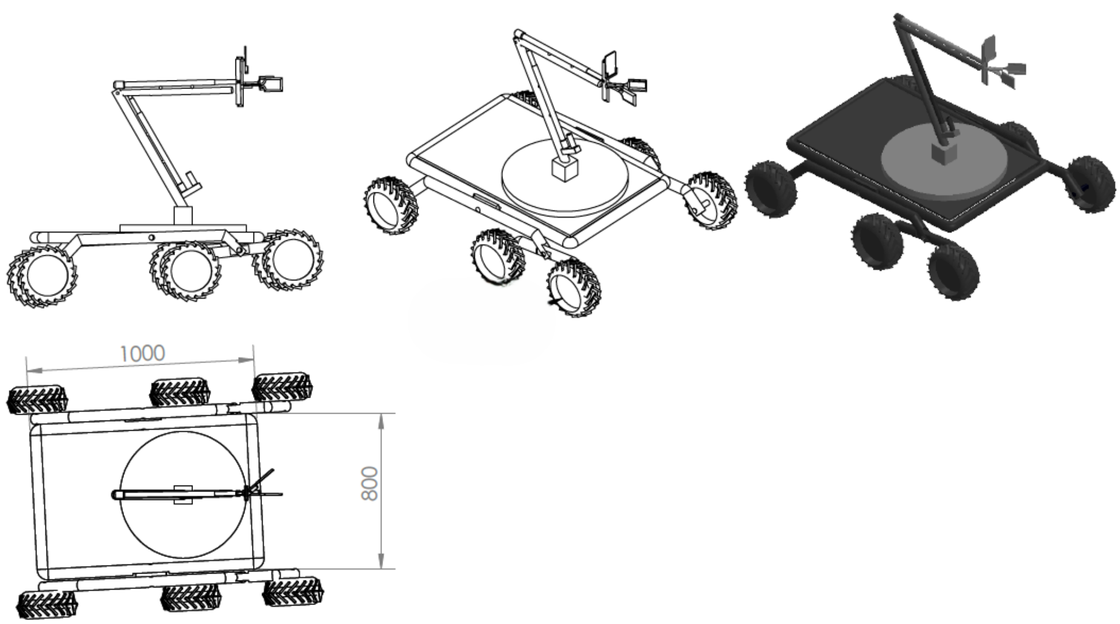


Figure 7

So, our purpose is to build robot arm with high efficiency and low price.

And to do that we will have three main parts.

1. Mechanic
2. Electronics
3. Programing

- In The mechanic part we have two main sections
  - The arm
  - The car

In FIGURE 8 showing the robot design

This is a simple design for the robot using SOLIDWORKS software.

FIGURE 8

The main material chosen to create the robot's body is PVC pipes and the Polyvinyl Chloride (PVC or Vinyl) is a high-strength thermoplastic material. It is widely used in applications such as pipes, medical devices, and wire & cable insulation...the list is endless. It is the world's third-most widely produced synthetic plastic polymer.

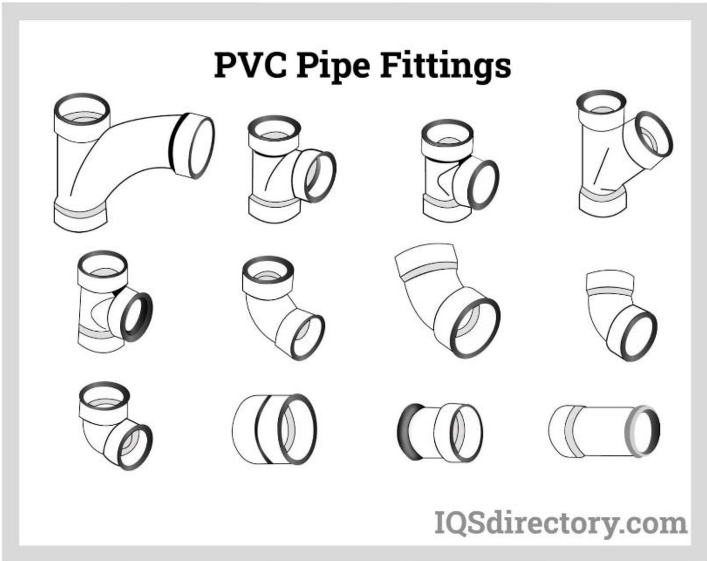
What is PVC (Polyvinyl Chloride)?

Polyvinyl Chloride (PVC or Vinyl) is an economical and versatile thermoplastic polymer. It is widely used in the building and construction industry to produce door and window profiles. It also finds use in:

- drinking and wastewater pipes,
- wire and cable insulation,
- medical devices, etc.

It is the world’s third-largest thermoplastic by volume after polyethylene and polypropylene.

It is a white, brittle solid material available in powder form or granules. PVC is now replacing traditional building materials in several applications. These materials include wood, metal, concrete, rubber, ceramics, etc. in several applications. This is due to its versatile properties such as:



- lightweight.
- Durable.
- low cost.
- easy processability.

Tensile Testing

The purpose of this test was to obtain the mechanical properties of PVC materials under tensile conditions. According to the ASTM D638-14 standard, the cylindrical hourglass-shaped (CHS) specimens were taken from the PVC pipe and processed parallel to the axial direction carefully. the uniaxial tensile test was carried out at 23 °C and the tensile rate was set to 50 mm/min using an extensometer with a gauge length of 50 mm. The resulting curve of the PVC pipe material after averaging treatment is presented in Figure 9.

Three stages that can reflect the characteristics of the material are observed clearly from the stress-strain curve: (1) the initial linear elastic response before yielding; (2) after the initial linear elastic response, the stress-strain curve rollover due to the material yielding; and finally (3) a stage of strain hardening. Mechanical parameters can be achieved from the curve, such as the yield stress σ_y (43.67 MPa) and Young's modulus E (1259 MPa). The detailed parameter values of the five tests are listed in Table 1.

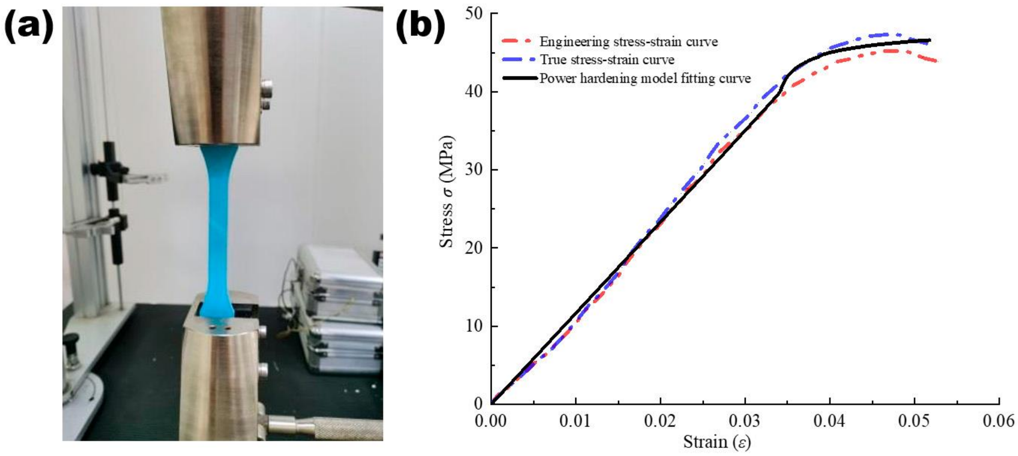


Figure 9. Stress–strain curve of PVC material and tensile loading device: (**a**) tensile testing and (**b**) stress–strain curve.

Table 1. PVC material tensile testing result.

Parameters	σ_y (MPa)	σ_t (MPa)	ε_t	E (MPa)	σ_t' (MPa)	ε_t'	n	K
value	43.67	45.15	0.047	1259.43	47.28	0.046	0.046	57.05

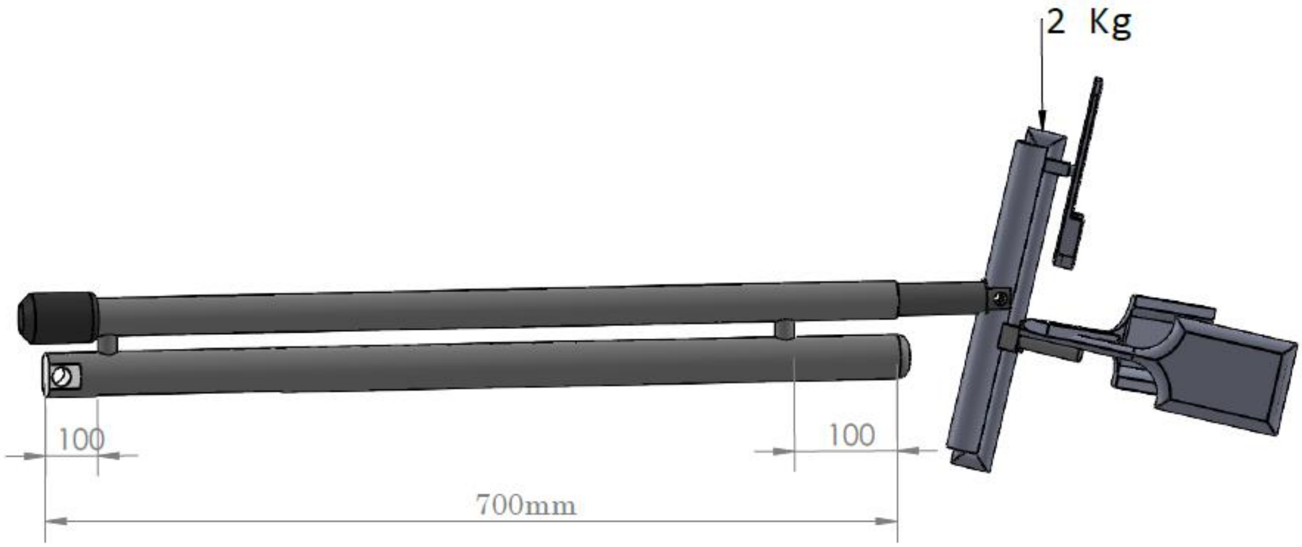


FIGURE 10

The inner diameter of PVC is 1.5in = 38.1*mm.*

And the thickness of PVC is 3*mm.*

$f_y = 43.67\ MPa.\quad f_t = 47.28\ MPa.\quad F.S = 2.$ **P= 2kg = 20N.**

$$m = 20 \times 600 = 12000\ N.mm$$

$$m = z \times f_b$$

$$m = \frac{\pi}{32}\left[\frac{{d_o}^4 - {d_i}^4}{{d_o}^4}\right] \times f_b$$

$$12000 = \frac{\pi}{32}\left[\frac{41.1^4 - 38.1^4}{41.1}\right] \times f_b$$

$$f_b = 6.731838\ Mpa$$

$$f_{max} = \frac{f_y}{f.s} = \frac{43.67}{2} = 21.835\ Mpa$$

$$f_{max} > f_b$$

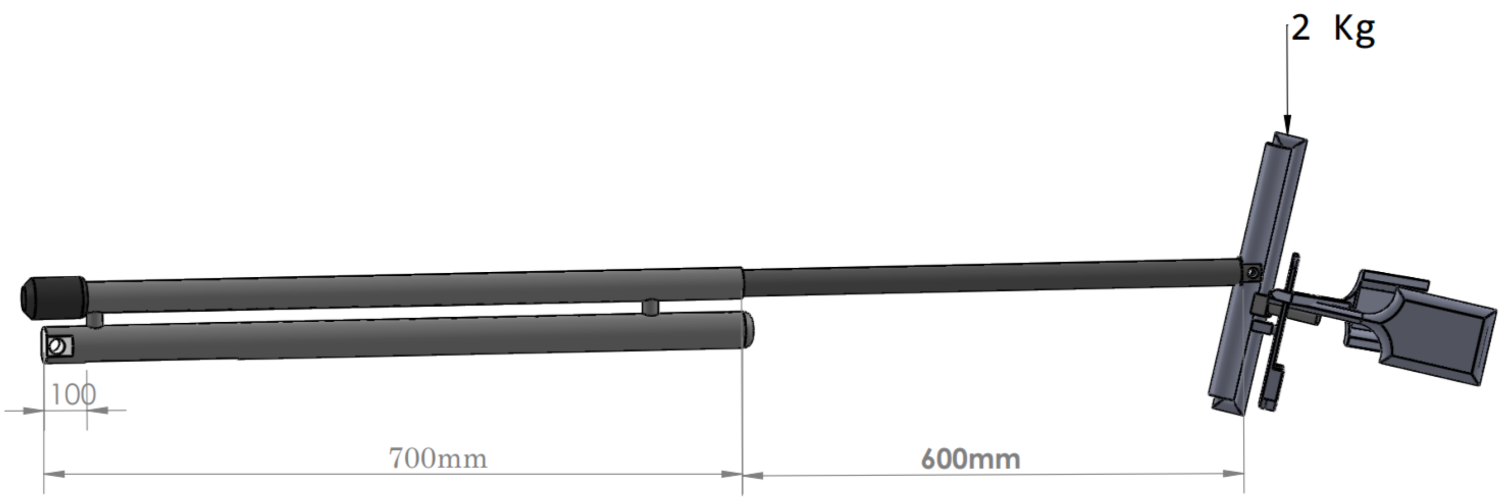


FIGURE 11

The inner diameter of PVC is 1.5in = 38.1*mm.*

And the thickness of PVC is 3*mm.*

$f_y = 43.67\ MPa.$ $f_t = 47.28\ MPa.$ $F.S = 2.$ **P= 2kg = 20N.**

$m = 20 \times 1200 = 24000\ N.mm$

$m = z \times f_b$

$$m = \frac{\pi}{32}\left[\frac{{d_o}^4 - {d_i}^4}{{d_o}^4}\right] \times f_b$$

$$24000 = \frac{\pi}{32}\left[\frac{41.1^4 - 38.1^4}{41.1}\right] \times f_b$$

$f_b = 13.46367\ Mpa$

$f_{max} > f_b$

Distribution of load on the bolt

FIGURE 12

The bolt is M 8 p= $12000N$ $= 350\ MPa$

The lode in case 1 p= *12000N* The lode in case 2 p= *24000N*

$A = d \times t$

$A = 8 \times 15 = 120\ mm^2$

$f_s = \frac{p}{A}$

shear in case 1:

$f_{s1} = \frac{12000}{120} = 100\ MPa$-----------------------(1)

shear in case 2:

$f_{s2} = \frac{24000}{120} = 200\ MPa$-----------------------(2)

From 1 & 2 $f_s\ of\ bolt > f_{s1}\ \&\ f_{s2}$

➢ First the arm

The size of the PVC out dimeter no.1 is 2 in = 50.8mm,

The length of PVC no.1 is 800mm.

The size of the PVC out dimeter no.2 is 1.5 in = 38.1mm.

The length of PVC no.2 is 600mm.

The size of the PVC out dimeter no.3 is 1 in = 25.4mm.

The length of PVC no.3 is 250mm.

The size of the PVC out dimeter no.4 is 0.5 in = 12.7mm.

The length of PVC no.4 is 300mm.

Figure 13 shows the design of the arm and the dimensions.

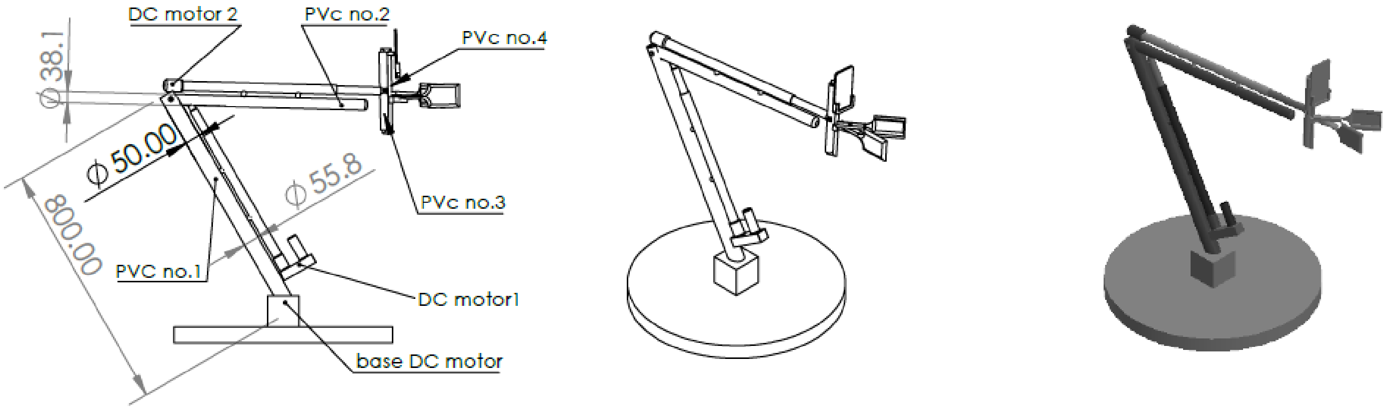


Figure 13.

- The DC motor 1 is mounted on PVC no.1 and it used to move the PVC no.2 and the rest of arm up & down.
- The DC motor 2 is mounted on PVC no.2 and it used to move the head of the robot forward & backward.
- Base DC motor is used to move the arm left and right smoothly.

The metal Pipe Hanger was chosen to join the robot's parts together.
Split Ring PVC Hangers made of steel.

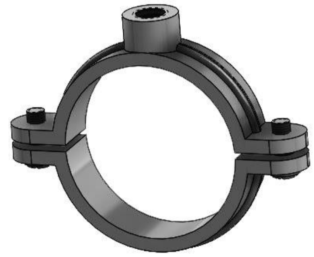


Figure 14

The DC motor 1 & DC motor 2

Heavy Duty LINEAR ACTUATOR Arm C-Band Dish Mover Motor

Features

Standard strokes 36"=90cm.

30% duty cycle motor rating

Clutch

Limit switches

3000 lb =static capacity,250 lb =110kg dynamic compression or tension

Lifetimelubrication

Designed for outdoor use.

Compression or tension loads

Mounting clamp included

Figure 15

High strength steel tube assembly with all-steel load support members.

Long Life Acme Screw.

24VDC/36VDC Gearbox Design.

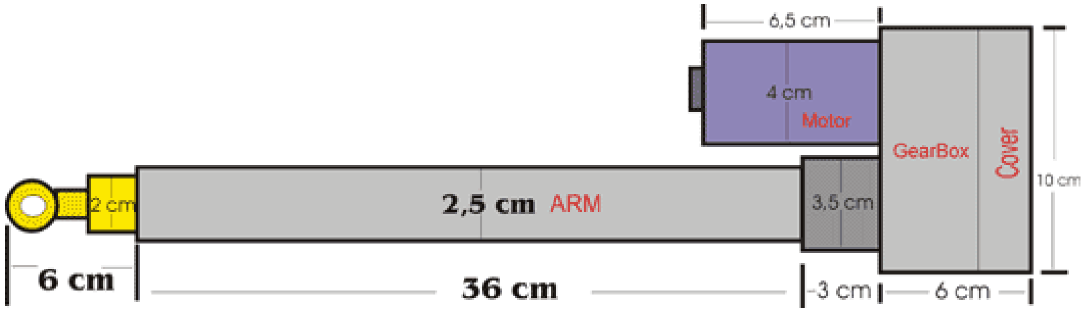
Base DC motor is 24v with Gearbox Design is used to move the arm left and right smoothly.

About actuators

Behind this not very common word is the device, which perhaps everyone has seen. Used to shoot SAT TV dishes. It's a hand (in English it is also used to refer to arm - hand), so cheap, but a solid and powerful device designed to control antenna systems. In the following lines, we will break into the secrets of the actuators.

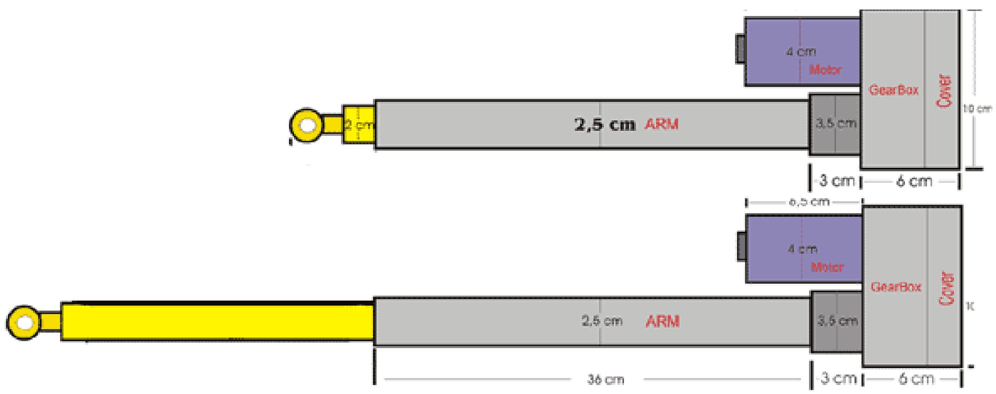
Figure 16

In the market, actuators are pushed by more modern DiSEq systems supplied with digital receivers. In sales, it is possible to buy solid actuators for cheap money (approx. 1000, -Sk) solid actuator. The supply voltage varies, actuators with a supply voltage of 12V are the most suitable for us, alternatively also 18V (the engine will run at a lower speed, weaker shot at 13.8V). An important parameter is the actuator stroke in inches. This is the maximum length of the arm extension. Commonly sold actuators range from eight to thirty-six inches (20 – 92cm). Figure 10 shows a 12-inch rotator with dimensions.

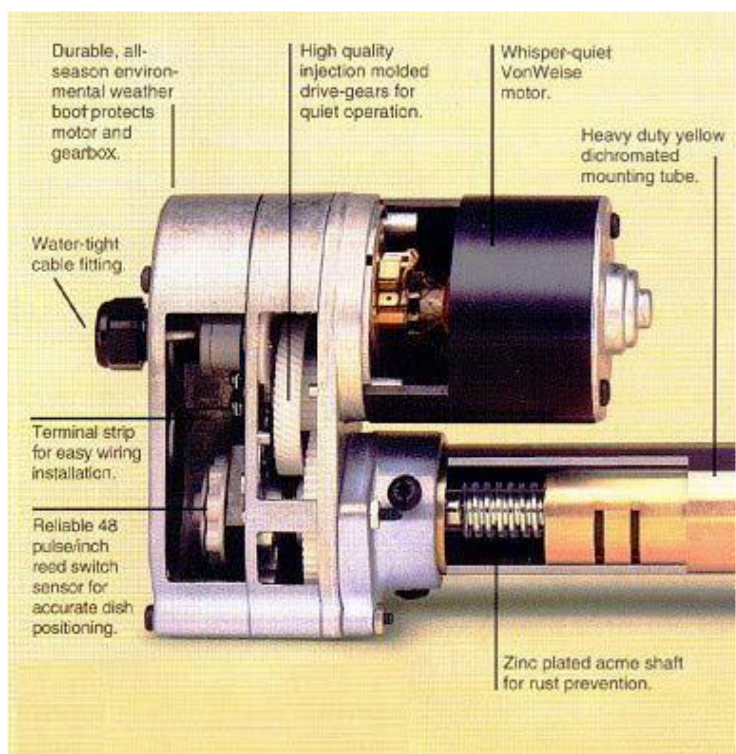


Permalink to Schema RX Rohde?

As already mentioned, the actuator consists of a direct current motor, gears, and helices, which converts circular motion into rectilinear motion. Finally, due to the different potential, a larger amount of HF current flows after the outer braiding of the coaxial cable. When you apply voltage to the actuator, the arm starts to extend and retracts when the polarity changes.



The motors need a voltage in the range 12 up to 36V. I used a 36V model. At higher voltages, the current is much lower (details in the power section). However, the motor also rotates at 12V, but much slower. It is suitable for minor corrections, especially for satellites in higher orbit and narrower antenna beam angles. In practice, the tension between 12 up to 24V, at 36V the speed is already too high.



The Phone holder Mounted on the head of the robot, The bike phone holder was used to place the phone in the appropriate place, allowing us to use the phone's camera correctly.

The catcher uses to collect the tomatoes and we control it by using small dc motor and on the catcher, there is tow limit switch to help the robot to indenting the size of the tomato and the right time to stop without making any damage to the tomato, The limit switch single pole double throw type

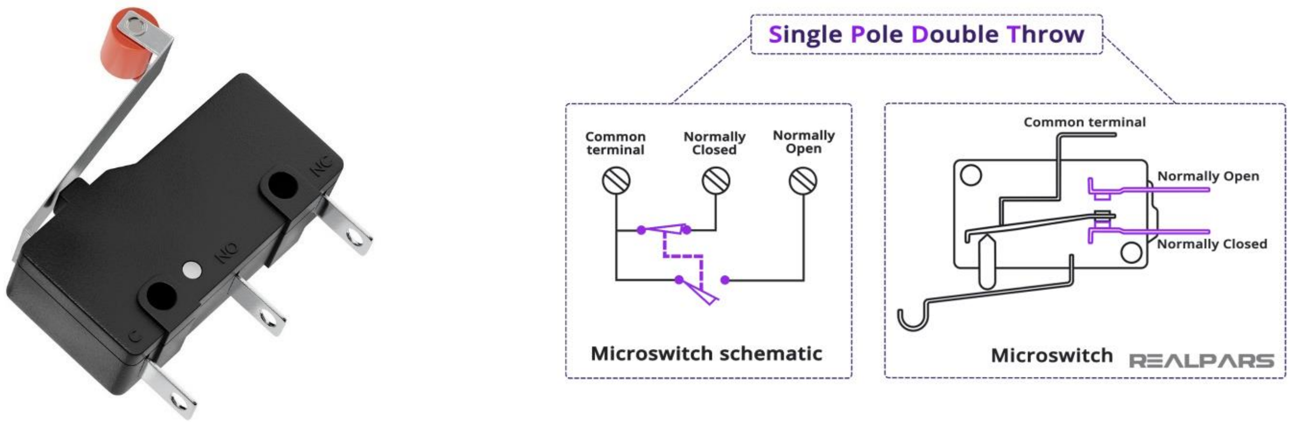


Figure 17 limit switch

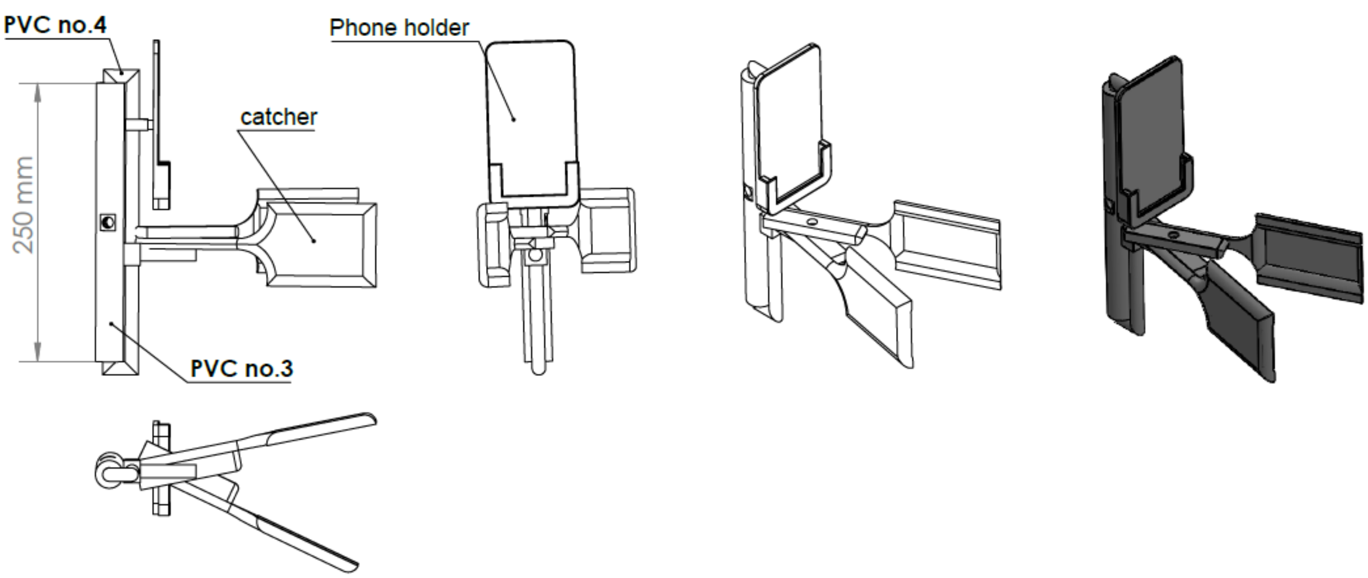


Figure 18

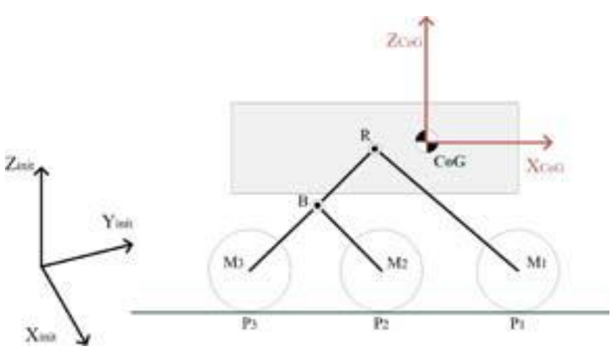
Figure 18 showing the robot head.

- **Second the car**

The main martial of the car is PVC also.

The Rocker-Bogie Mechanism

The rocker-bogie suspension system was first used for the Mars Rover Sojourner and is currently NASA s favored design for rover wheel suspension. The intelligently designed wheel suspension allows the vehicle to traverse over very uneven or rough terrain and even climb over obstacles. The rocker-bogie allows the chassis of the rover to average its pitch over all wheel deflections, while still maintaining load equalization on all wheels and avoiding a low oscillation frequency. The suspension has symmetric structure on both sides of the rover chassis and supports a total of six wheels, three on each side. The mechanism is constructed from two rigid parts. The link connected with a rotary joint to the chassis is called the rocker. The bogie is connected to the rocker via another rotary joint, as shown in the kinematics diagram in Fig. 19. The rockers are connected to each other via a differential mechanism, which allows the rover body to minimize its pitch. The rocker-bogie suspension mechanism has two main advantages. The total load that is put on the rover is distributed evenly over all wheels. This ensures equal working conditions for all wheels and prevents from excessive sinkage of wheels in soft terrain [12]. The second advantage is that all wheels stay in touch with the ground while climbing obstacles. This ensures stability and prevents the rover from tilting on a slope. The rocker-bogie is a passive suspension system and has no axles or springs, all wheels are kept in contact with the ground without any actuators, decreasing power consumption of the rover. Each of the six wheels is independently driven and steered. This also allows the rover to turn in place or move sidewards. The system therefore is redundant and can move forwards, backwards and sidewards.



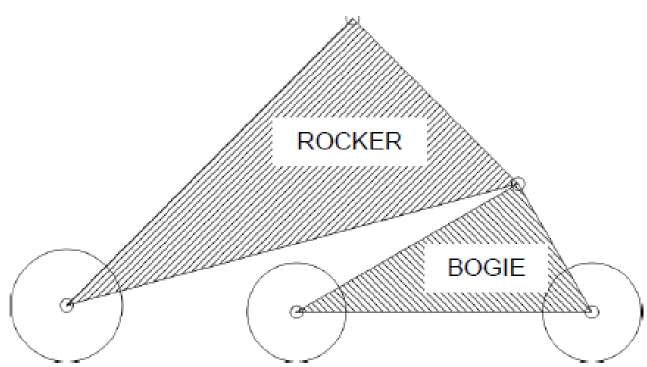


Figure19 Kinematic diagram of Rocker-Bogie suspension

Load Equalization

Load equalization over all n wheels ensures equal work conditions for all wheels. The following Fig. 20 shows the two-dimensional mechanical model of the rocker-bogie suspension. Weights G, normal forces N and traction forces T are shown as well as geometric dimensions. The weight G_b is the total weight of the rover body while G_i denotes the respective weight from the rocker-bogie mechanism acting on wheel i. A quasi-static force balance is conducted, as suggested by Li et al. [10], and the conditions $X_B = \frac{3}{2}X_C$ and $X_B = \frac{1}{2}(X_1 + X_2)$ are derived for load equalization. These geometrical constraints for the suspension structure are used to maximize load equalization.

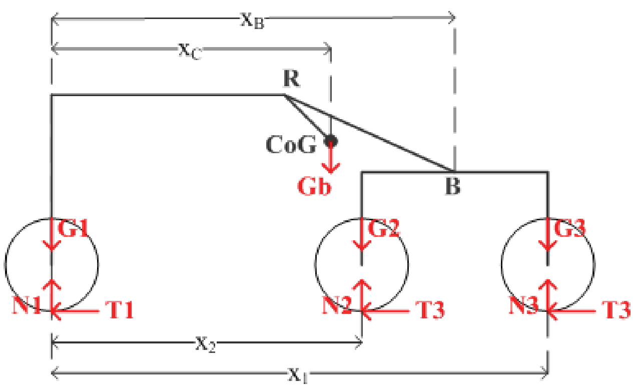


Figure 20

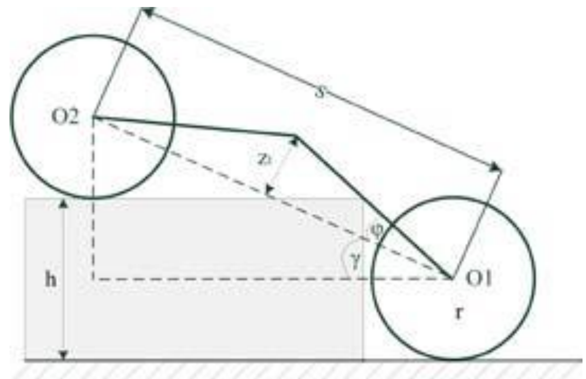


Figure 21

Geometric Trafficability

Geometric trafficability ensures that the suspension structure does not interfere with the ground. The analysis of geometric trafficability is only done for the bogie, as the swinging scope for the bogie is much bigger than that of the rocker. The analysis of geometric trafficability is done according to [10]. From geometry the maximum vertical distance Z_t between the center of the wheels to the edge of the obstacle is determined according to (3), where r is the wheel radius and h and s are geometric properties, seen in Fig. 21.

$$Z_t = \frac{s}{\sqrt{\left(\frac{r\sqrt{s^2 - h^2} + (h-r)h}{(h-r)\sqrt{s^2 - h^s} - hr}\right)^2 + 1}} \quad (3)$$

$$Z_t \leq c \quad (4)$$

From geometry the maximum vertical distance Z_t between the center of the wheels to the edge of the obstacle is determined. Geometric trafficability is given if the parameter Z_t is larger or equal to the rovers ground clearance.
The car will have 6 wheel ever wheel should have a dc motor and to decrease the cost we will use 4 dc motor instead 6 dc motor The dc motor we have choose is

windshield wipers motor, Figure 22 showing the dc wipers motor

TECHNICAL DATA

DESCRIPTION	1 speed		2 speed	
Nominal voltage(V)	12v	24v	12v	24v
Testing voltage (V)	13.5v	27v	13.5v	27v
Nominal Current (A)	2	1.5	2/2.5	1.5/2
Max. Current (A)	12	10	12/15	10/13
No Load Speed (RPM)	30		30/45	
Nominal Torque (Nm)	4		4	
Starting Torque (Nm)	40		40/35	
Gear Ratio	2/110		2/110	
IP Grade	40		40	
Weight (kg)	1.2		1.2	

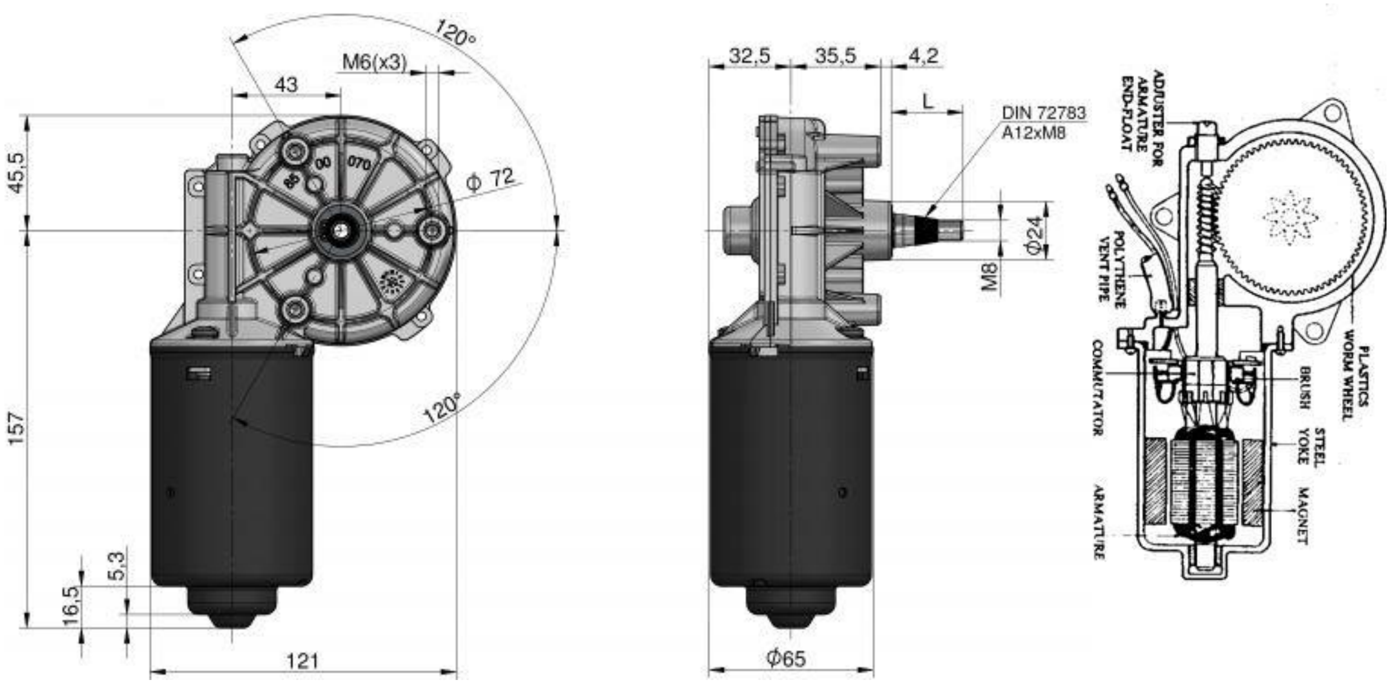


Figure 22

Figure 23 illustrates the streamlined car design inspired by the Rocker-Bogie Mechanism of the Mars rover. The car incorporates a 6-wheel configuration, with independent DC motors powering only the front and rear sets. The primary construction material for the car is PVC, utilizing PVC pipes with an outer diameter of 2 inches (50.8 mm). The wheels are designed with an outer diameter of 8 inches (203.2 mm).

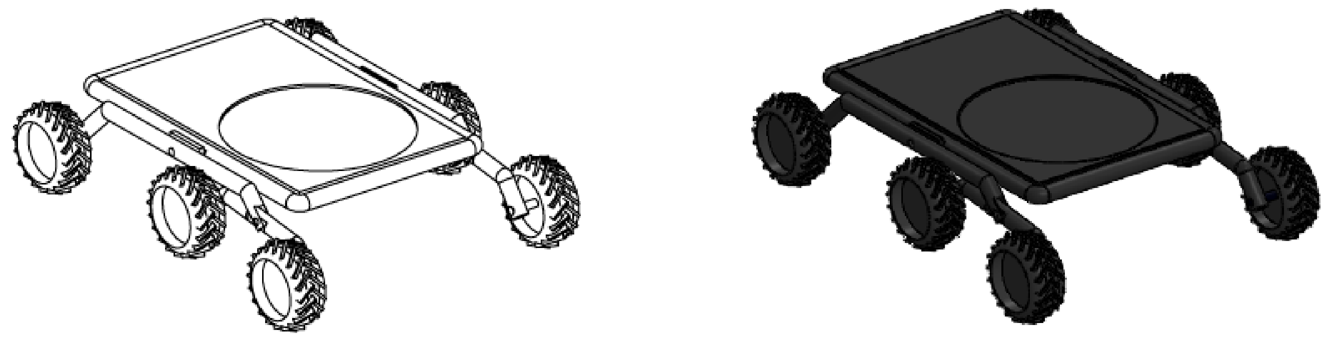


Figure 23

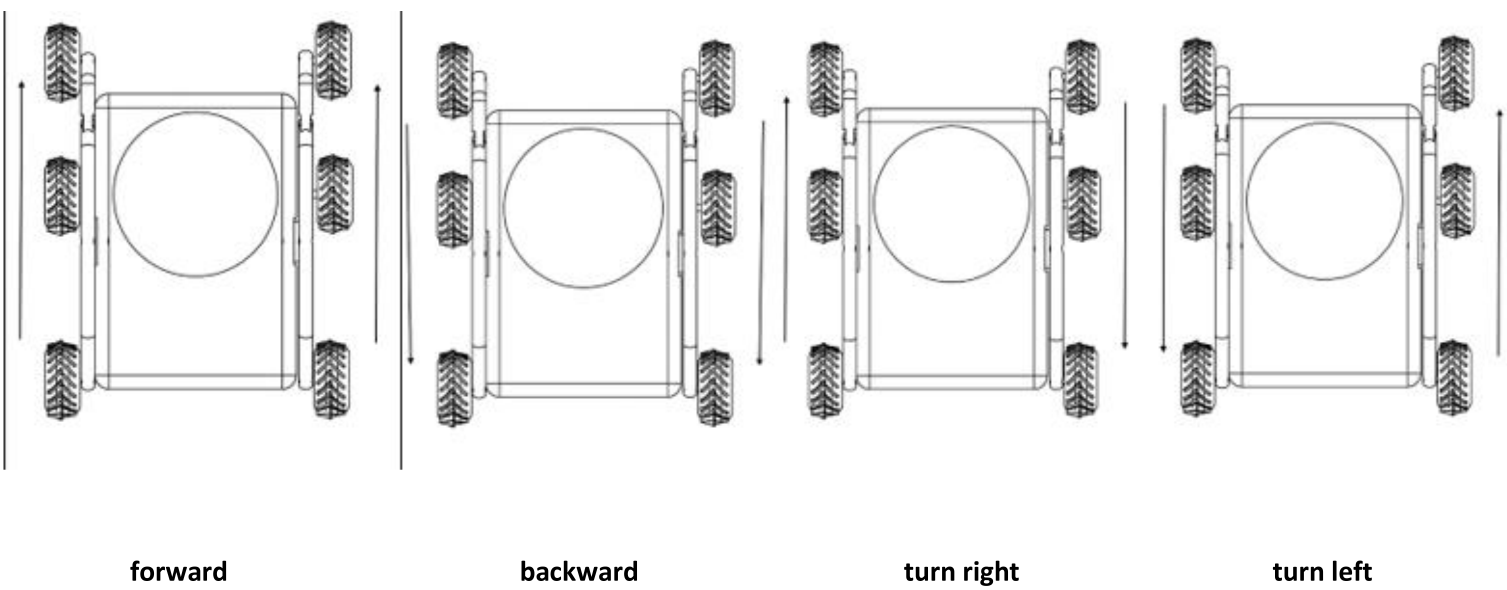


Figure 24

And to control the car direction we will have four moves forward & backward, right & left and to do that we must move ever motor on pacific direction to move car forward we must wove the left row of motor and the right row in the seam direction "cw" and to move the car backward we must move the left row and right row in opposite direction "ccw" , to make the car turn right the right row of motor move "ccw" and left row move "cw" , to make car turn left the left row of motor move "ccw" and the right row move "cw" figure show the car direction.

Second the electronics

To control the arm and the car including the motor and sensors we must have a microcontroller and to choose the right type we should first identifying how many motors and senser we will control to know how many GIOP we will use in, the arm we will use 7 DC motor and to control each it take to pin from the microcontroller and one pin for the sensor also the car will have4 motor and it will takes 2 pin for each motor also the sum of pins will be 23 so we choose the Atmel ATmega2560 and to make it easy to communicate with the microcontroller we will use the Arduino mega , The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno. Figure 25, 26 showing the ATMEGA2560 and Arduino mega.

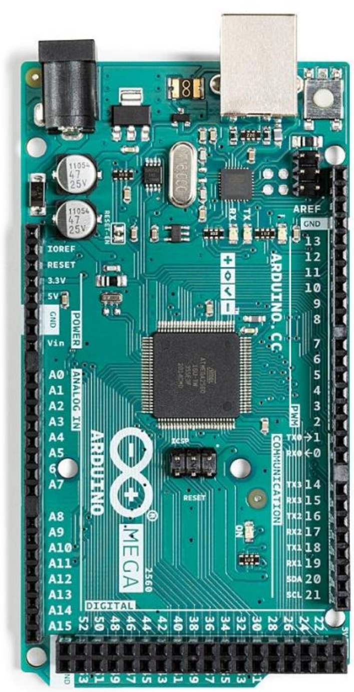
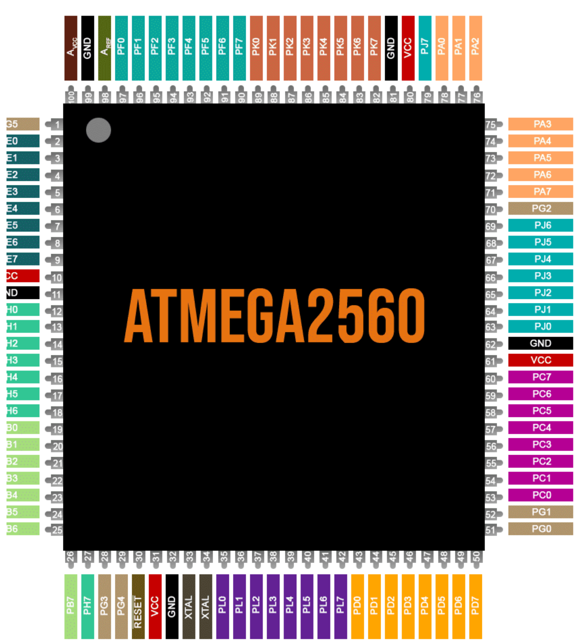


Figure 26



Pin Number	Pin Name	Description
10, 31, 61, 80	Vcc	IC Supply pins
11, 32, 62, 81, 99	GND	IC ground reference pins
98	AREF	Reference supply for ADC
100	AVCC	Supply pin for analog peripherals
33, 34	XTAL	Crystal oscillator pins
30	RESET	Reset pin, active low
2 - 9	PE0 – PE7	GPIO Port E pins
12 – 18, 27	PH0 – PH6, PH7	GPIO Port H pins
19 - 26	PB0 – PB7	GPIO Port B pins
28 – 29, 51 – 52, 70, 1	PG3 – PG4, PG0 – PG1, PG2, PG5	GPIO Port G pins
35 - 42	PL0 – PL7	GPIO Port L pins
43 - 50	PD0 – PD7	GPIO Port D pins
53 - 60	PC0 – PC7	GPIO Port C pins
63 – 69, 79	PJ0 – PJ6, PJ7	GPIO Port J pins
71 - 78	PA7 – PA0	GPIO Port A pins
82 - 89	PK7 – PK0	GPIO Port K pins
90 - 97	PF7 – PF0	GPIO Port F pins

Figure 25

Figure 27 showing the schematic of the electronics components, the electronics components include Arduino mega the microcontroller and L298 Driver module , 8channel relay module, Bluetooth module & limit switch and the motor of the arm &car this schematic by using fritzing software , to control the motor arm require high volt so we use the relay module to control each motor white L298 driver module or the relay module we use tow pin from the microcontroller the Arduino mega2560 and we use one pin for the limit switch

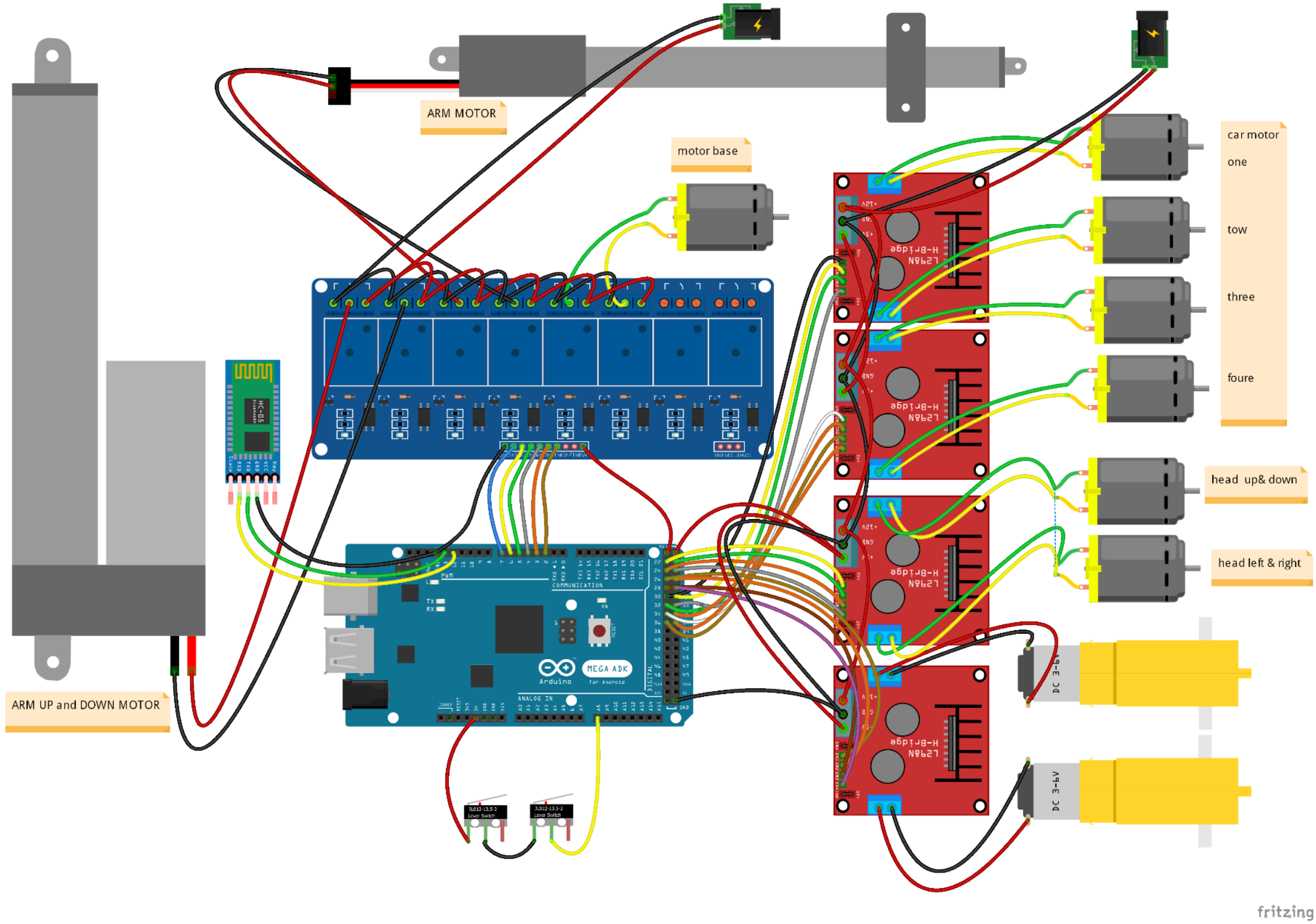


Figure 27

Controlling a DC Motor

We can only have full control over a DC motor if we can control its speed and spinning direction. This is possible by combining these two techniques.

- PWM – to control speed.
- H-Bridge – to control the spinning direction.

PWM – to control speed

The speed of a DC motor can be controlled by changing its input voltage. A widely used technique to accomplish this is Pulse Width Modulation (PWM).

PWM is a technique in which the average value of the input voltage is adjusted by sending a series of ON-OFF pulses. This average voltage is proportional to the width of the pulses, which is referred to as the Duty Cycle.

The higher the duty cycle, the higher the average voltage applied to the DC motor, resulting in an increase in motor speed. The shorter the duty cycle, the lower the average voltage applied to the DC motor, resulting in a decrease in motor speed.

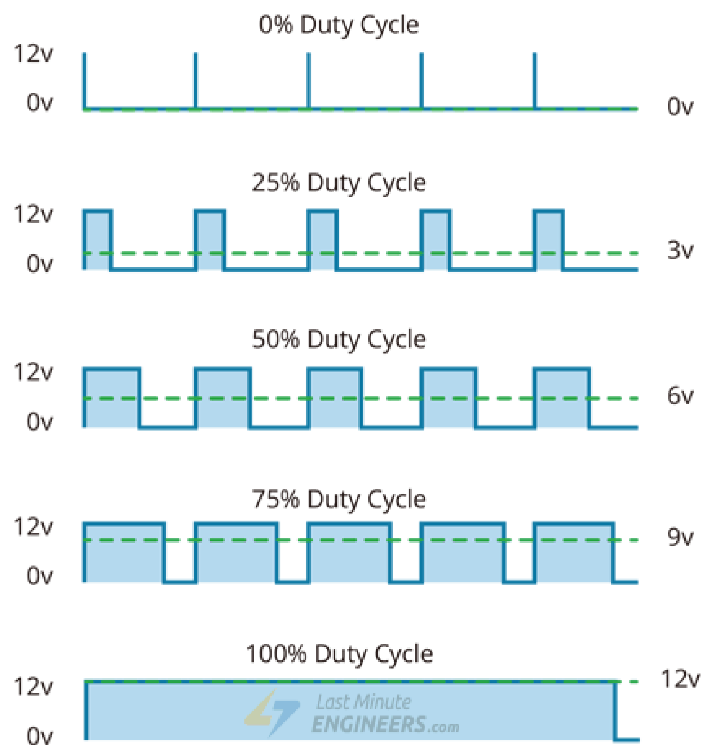


Figure 28

H-Bridge – to control the spinning direction.

The spinning direction of a DC motor can be controlled by changing the polarity of its input voltage. A widely used technique to accomplish this is to use an H-bridge An H-bridge circuit is made up of four switches arranged in a H shape, with the motor in the center. Closing two specific switches at the same time reverses the polarity of the voltage applied to the motor. This causes a change in the spinning direction of the motor. The following animation shows the working of the H-bridge circuit.

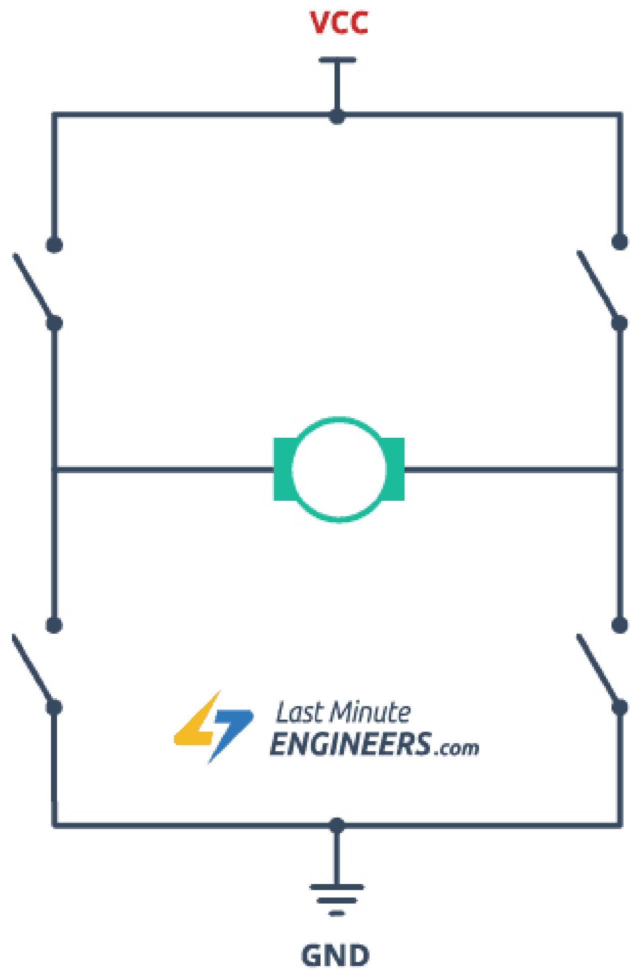


Figure 29

L298N Motor Driver Chip

At the center of the module is a big, black chip with a chunky heat sink – the L298N. The L298N chip contains two standard H-bridges capable of driving a pair of DC motors, making it ideal for building a two-wheeled robotic platform. The L298N motor driver has a supply range of 5V to 35V and is capable of 2A continuous current per channel, so it works very well with most of our DC motors.

Technical Specifications

Here are the specifications:

Motor output voltage	5V – 35V
Motor output voltage (Recommended)	7V – 12V
Logic input voltage	5V – 7V
Continuous current per channel	2A
Max Power Dissipation	25W

For more details, please refer below datasheet.

L298N Motor Driver Module Pinout

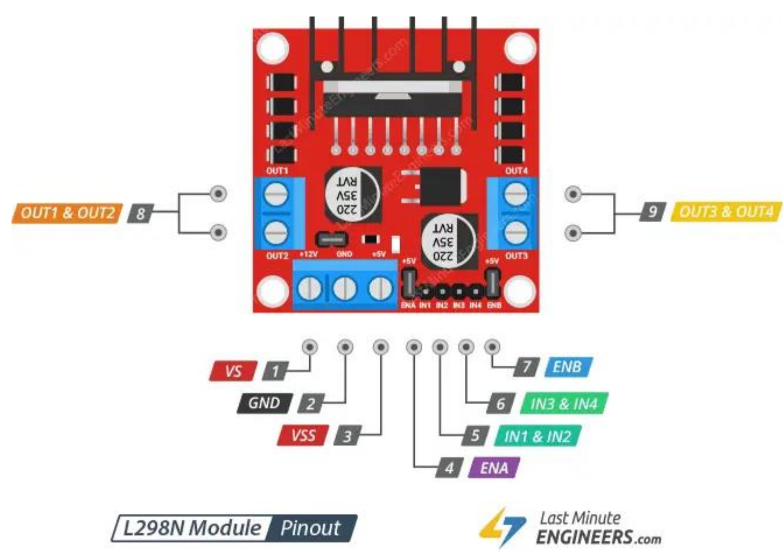


Figure 30

The L298N module has 11 pins that allow it to communicate with the outside world. The pinout is as follows.

We will use the L298N driver module to control the small motor doesn't need high volt or current but whit motor need high volt we must use another driver to be able to control it and we have chosen the relay to control the motor like motor up & down or motor base and to make it easy we will use the relay module 8 channel.

8 Channel 5V Relay Module

This is a LOW Level 5V 8-channel relay interface board, and each channel needs a 15-20mA driver current. It can be used to control.
various appliances and equipment with large current. It is equipped with high-current relays that work under AC250V 10A or DC30V. 10A. It has a standard interface that can be controlled directly by a microcontroller.

Features

- Power Supply Voltage: 5VDC, 12VDC
- Current: Greater than 100mA
- Load: 250V 10A AC or 30V 10A DC
- Size: 134.6mm x 53.6mm x 19.5mm (L x W x H)
- Equipped with mounting holes around, hole diameter 3.1mm
- Relay Type: Single Pole Double Throw (SPDT)
- Optocoupler isolation, good anti-interference capability
- When input is at low level, the relay is off, and the indicator light is on.
- Standard interface that can be directly controlled by microcontroller (8051, AVR, PIC, DSP, ARM, MSP430, TTL logic)

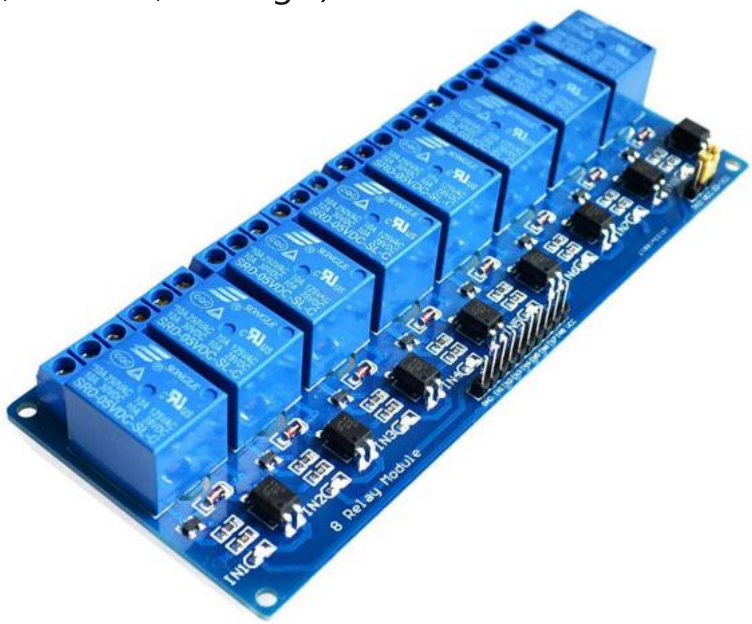
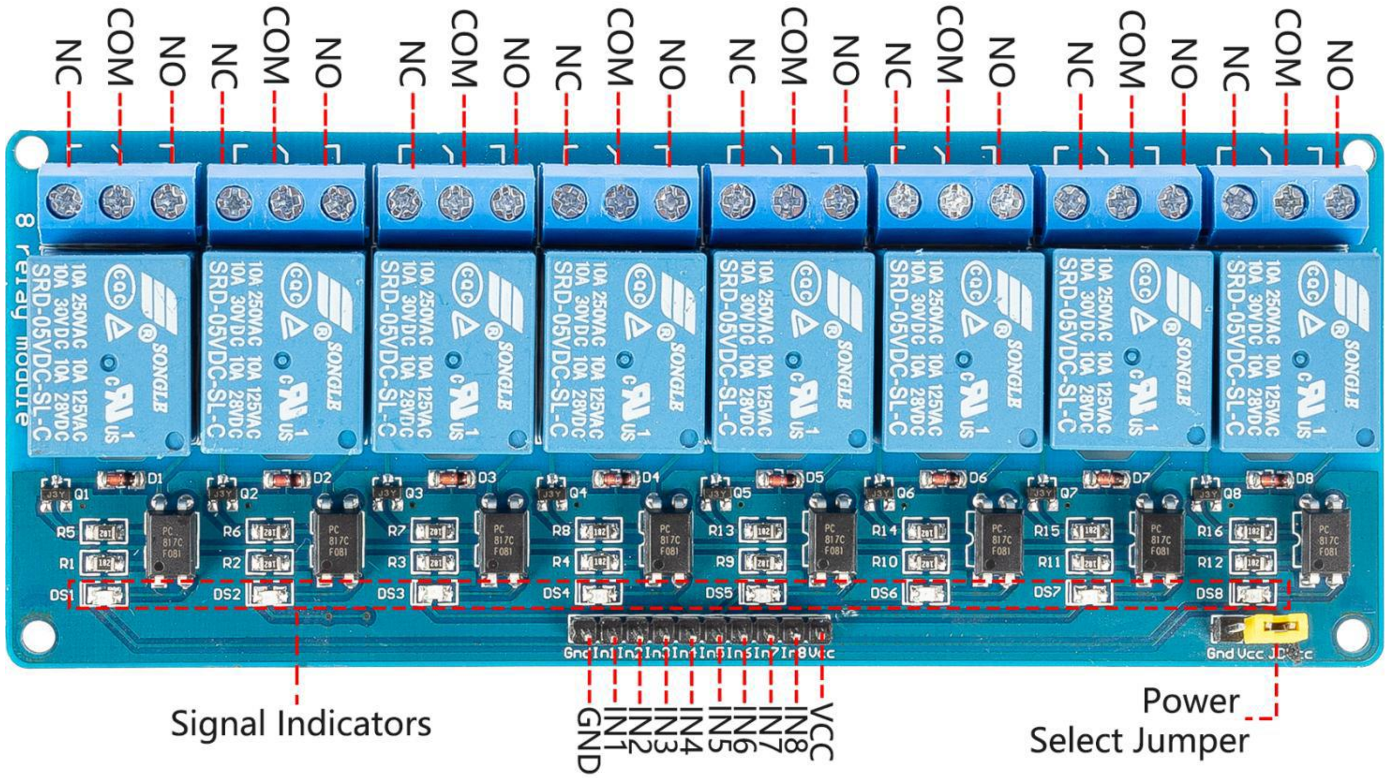


Figure 31

Pinout



The module features a design that includes both input and output connections.

Figure 32

On the input side, where it receives the trigger signal, the connections typically include three or four pins, as outlined in the relay.

module circuit diagram:

VCC: This is the positive power supply input from the main control.

GND: Ground connection.

IN1~IN8: The signal input pins for the relays. When a low-level signal is input, the Normally Open (NO) contact of the relay.

connects with the Common (COM) terminal.

JD-VCC: This pin is for the relay's power supply. Connecting JD-VCC and VCC with a jumper cap indicates that the relay is powered by the main control board's power supply. Alternatively, an external power supply can be connected to this pin to power the relay.

On the output side, the relay module has three connections:

NO (Normally Open): This is the load connection when the relay is active (ON). In the off state, NO is not connected to the COM (Common) terminal.

COM (Common): This terminal serves as the common connection for both NO and NC (Normally Closed) pins.

NC (Normally Closed): This is the default load connection, which is connected to the COM terminal when the relay is OFF or in its default state.

How the Relay Work?

As we may know, a relay is a device which is used to provide connection between two or more points or devices in response to the input signal applied. In other words, relays provide isolation between the controller and the device as devices may work on AC as well. as on DC. However, they receive signals from a micro-controller which works on DC hence requiring a relay to bridge the gap. Relay is extremely useful when you need to control a large amount of current or voltage with a small electrical signal.

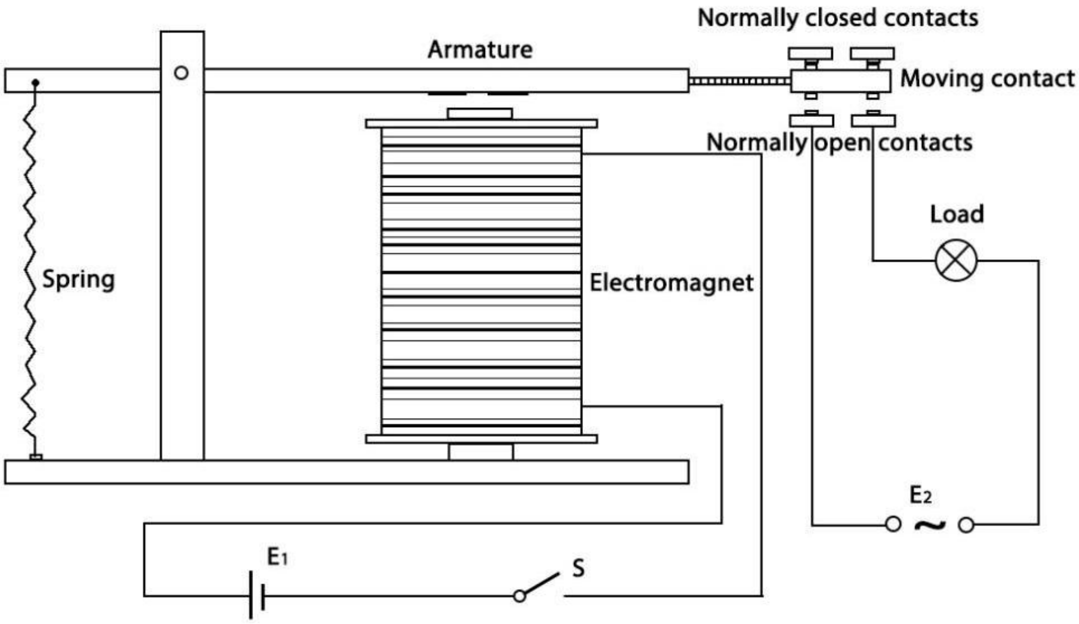


Figure 33

There are 5 parts in every relay:

- **Electromagnet** - It consists of an iron core wounded by coil of wires. When electricity is passed through, it becomes magnetic.
  Therefore, it is called electromagnet.
- **Armature** - The movable magnetic strip is known as armature. When current flows through them, the coil is energized thus producing a magnetic field which is used to make or break the normally open (N/O) or normally close (N/C) points. And the armature can be moved with direct current (DC) as well as alternating current (AC).
- **Spring** - When no currents flow through the coil on the electromagnet, the spring pulls the armature away so the circuit cannot be completed.

Set of electrical **contacts** - There are two contact points:

- Normally open - connected when the relay is activated, and disconnected when it is inactive.
- **Normally close** - not connected when the relay is activated, and connected when it is inactive.
- **Molded frame** - Relays are covered with plastic for protection.

The working principle of relay is simple. When power is supplied to the relay, currents start flowing through the control coil; as a result, the electromagnet starts energizing. Then the armature is attracted to the coil, pulling down the moving contact together thus connecting with the normally open contacts. So, the circuit with the load is energized. Then breaking the circuit would be a similar case, as the moving contact will be pulled up to the normally closed contacts under the force of the spring. In this way, the switching on and off of the relay can control the s bate of a load circuit.

And to control the dc motor we will use tow relay

we then have two-bit motor control:

0 0 Both sides of motor connected to V-. Motor braked.

0 1 One side of motor connected to V+, other side to V-. motor runs in one direction.

1 0 One side of motor connected to V-, other side to V+. motor runs in opposite direction.

1 1 Both sides of motor connected to V+. Motor braked.

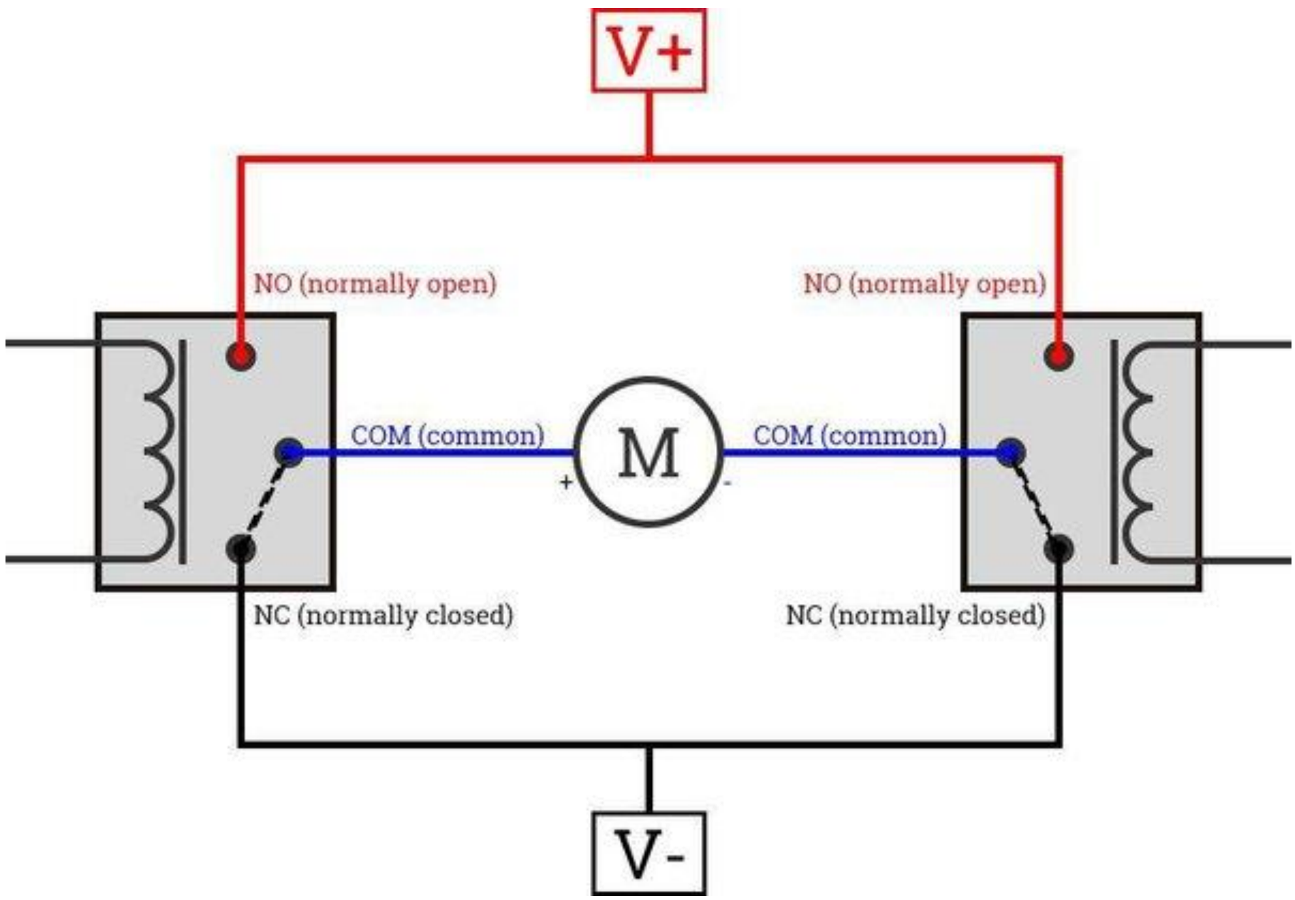


Figure 34

BLUETOOTH TO SERIAL PORT MODULE HC05

We will use the Bluetooth module to communicate white the mobile application and the microcontroller.

Overview

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). It has the footprint as small as 12.7mmx27mm. Hope it will simplify your overall design/development cycle.

Specifications

Hardware features

- Typical -80dBm sensitivity.
- Up to +4dBm RF transmit power.
- Low Power 1.8V Operation, 3.3 to 5 V I/O.
- PIO control.
- UART interface with programmable baud rate.
- With integrated antenna.
- With edge connector. Software features
- Slave default Baud rate: 9600, Data bits:8, Stop bit:1,Parity:No parity.

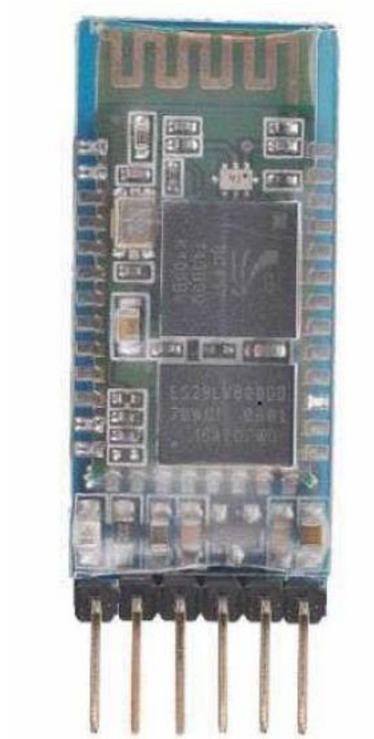


Figure 35

- PIO9 and PIO8 can be connected to red and blue led separately. When master and slave are paired, red and blue led blinks 1time/2s in interval, while disconnected only blue led blinks 2times/s.
- Auto-connect to the last device on power as default.
- Permit pairing device to connect as default.
- Auto-pairing PINCODE:"1234" as default.

• Auto-reconnect in 30 min when disconnected as a result of beyond the range of connection.

The limit switch single pole double throw type, we will use the limit switch in the o catcher, there are two limit switches to help the robot to indenting the size of the tomato and the right time to stop without making any damage to the tomato.

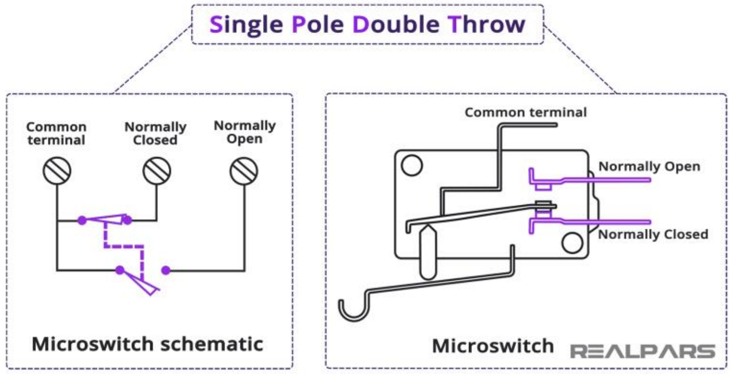
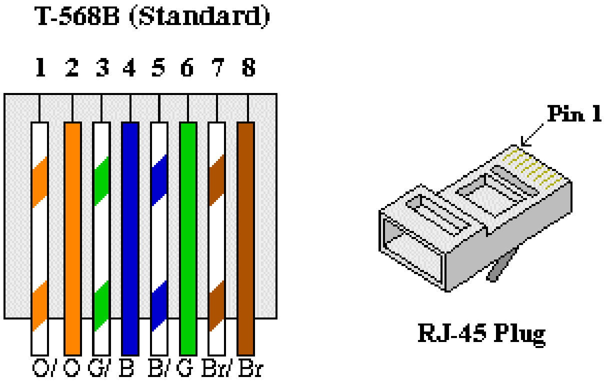


Figure 36 limit switch

And to connect the motor with the drivers and to the power source through the arm of the robot and the robot head we will need a wire and to make it easy to connect in the definite position in the robot we will use ETHERNET CABLE

Ethernet cables come in different lengths, types, and categories, and the structure can differ. But all of them feature eight wires twisted into four pairs and a rip cord. A twisted pair can reduce crosstalk from the neighboring pairs to be more resistant to electromagnetic interference (EMI). A rip cord is usually designed to cut the cable jacket for convenience.



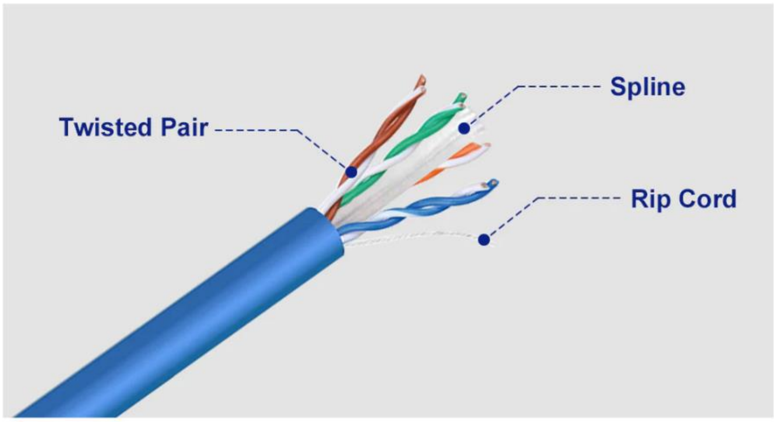


Figure 37

And to make it easy to put all of electronics components we design a PCB to make sure ever thing will be stable and connected correctly.

A printed circuit board (PCB).

also called printed wiring board (PWB), is a medium used to connect or "wire" components to one another in a circuit. It takes the form of a laminated sandwich structure of conductive and insulating layers: each of the conductive layers is designed with a pattern of traces, planes and other features (similar to wires on a flat surface) etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate.[1] Electrical components may be fixed to conductive pads on the outer layers in the shape designed to accept the component's terminals, generally by means of soldering, to both electrically connect and mechanically fasten them to it. Another manufacturing process adds vias, plated-through holes that allow interconnections between layers.

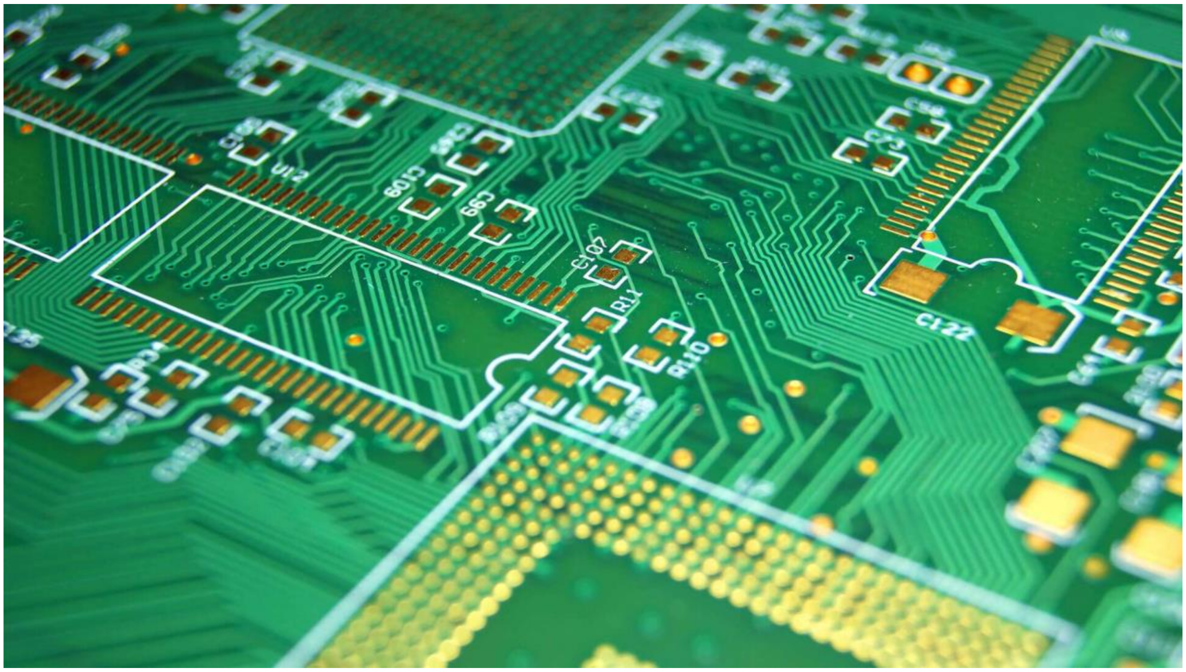


Figure 38

and to make the design of PCB we use the Easy EDA software at first, we choose the components and start to make the schematic and then we start to make the design of the PCB the PCB will be single layer the dim will be 300*200mm. Figure 39 showing the schematic of the electronics components, and figure 32 showing the PCB design.

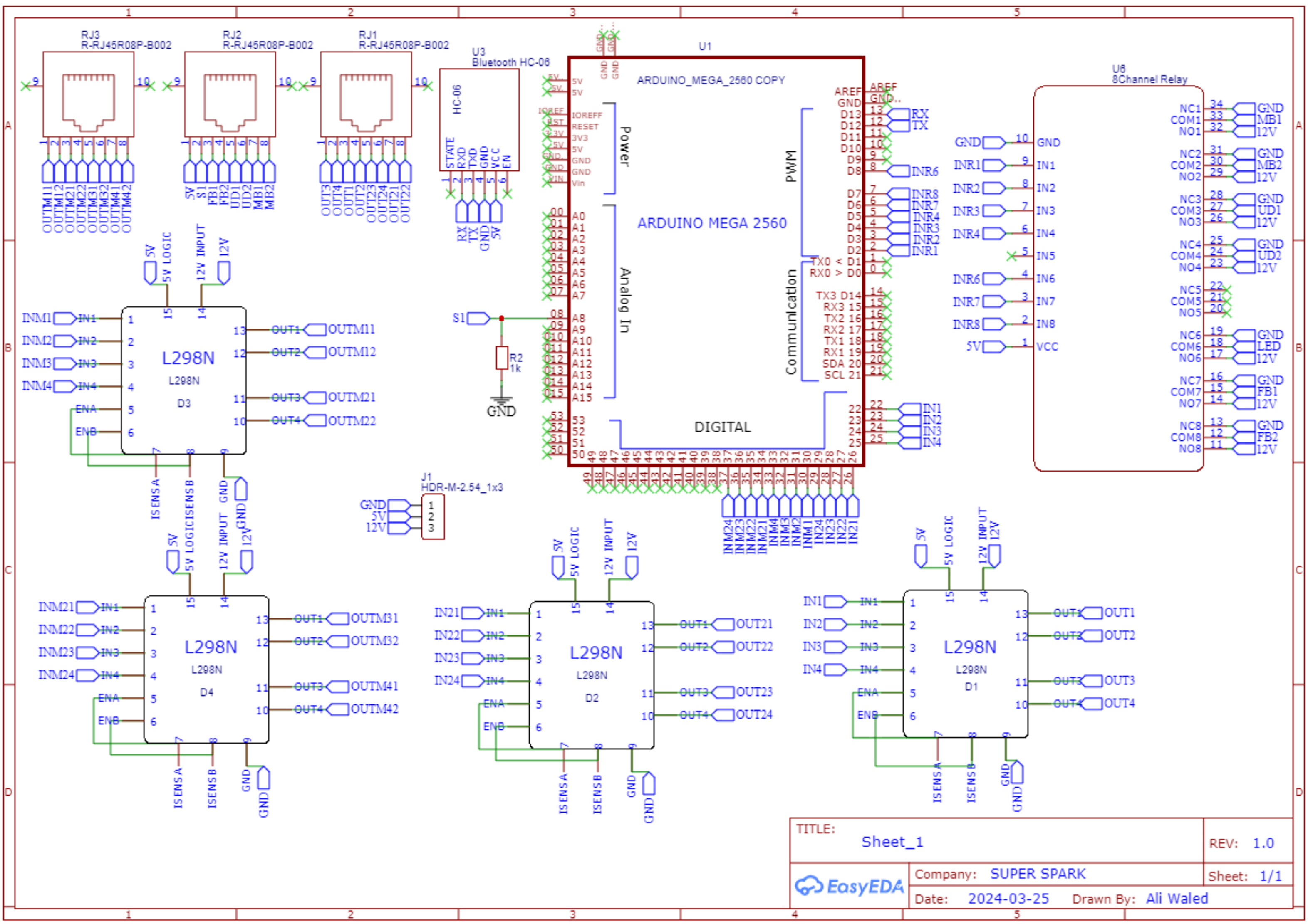


Figure 39

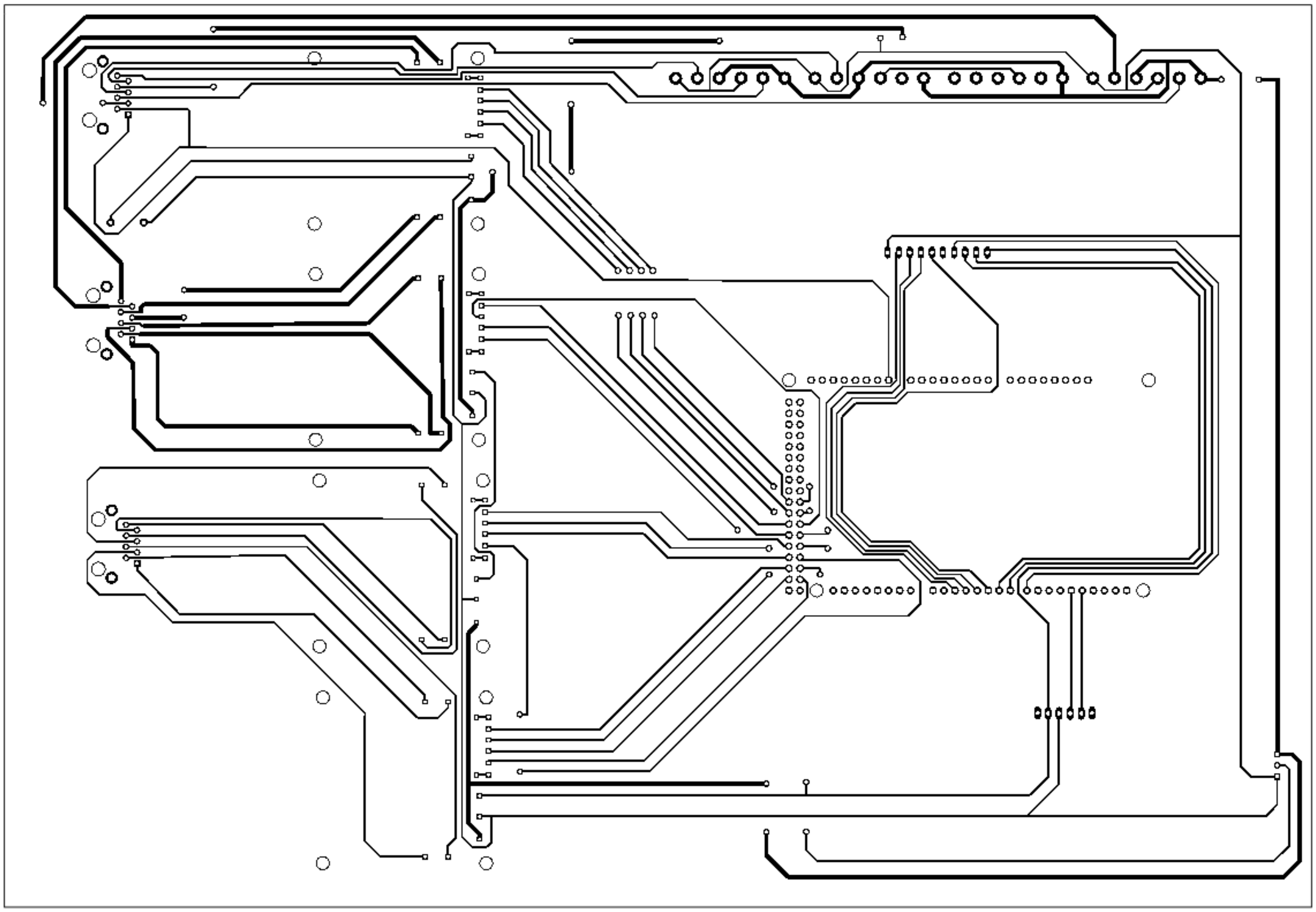


Figure 40

Figure 41 showing the PCB.

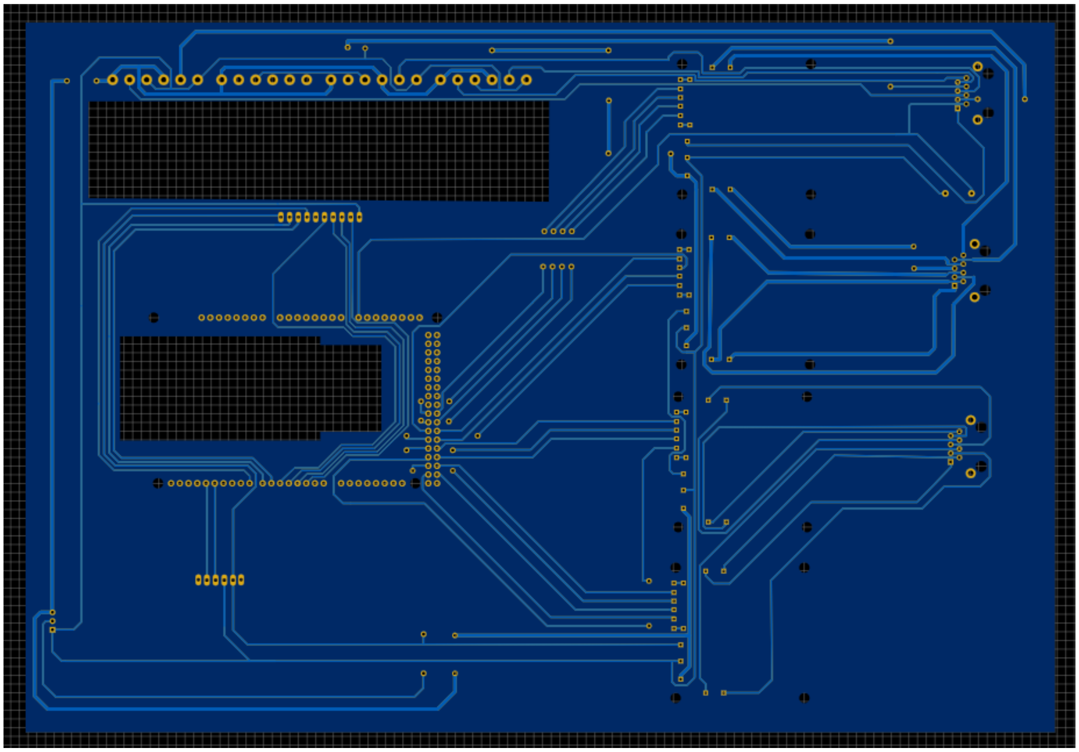


Figure 41

Programing and mobile applications

The robot will take a live photo from greenhouse and doing image processing to determining the position of tomatoes and to do that we will use a mobile application and use the phone camera, the application based on java programming language and use the ML kit library.

Machine learning for mobile developers

ML Kit brings Google's machine learning expertise to mobile developers in a powerful and easy-to-use package. Make your iOS and Android apps more engaging, personalized, and helpful with solutions that are optimized to run on device.

Optimized for mobile.

ML Kit's processing happens on-device. This makes it fast and unlocks real-time use cases like processing of camera input. It also works while offline and can be used for processing images and text that need to remain on the device.

Built with Google expertise.

Take advantage of the machine learning technologies that power Google's own experiences on mobile.

Easy to use.

We combine best-in-class machine learning models with advanced processing pipelines and offer these through easy-to-use APIs to enable powerful use cases in your apps.

Vision APIs

Video and image analysis APIs to label images and detect barcodes, text, faces, and objects.

Object detection and tracking

Localize and track in real time one or more objects in the live camera feed.

Object detection and tracking.

With ML Kit's on-device object detection and tracking API, you can detect and track objects in an image or live camera feed.

Optionally, you can classify detected objects, either by using the coarse classifier built into the API or using your own custom image classification model. See Using a custom TensorFlow Lite model for more information.

Because object detection and tracking happens on the device, it works well as the front end of the visual search pipeline. After you detect and filter objects, you can pass them to a cloud backend, such as Cloud Vision Product Search.

Key capabilities

- **Fast object detection and tracking** Detect objects and get their locations in the image. Track objects across successive image frames.
- **Optimized on-device model** The object detection and tracking model is optimized for mobile devices and intended for use in real-time applications, even on lower-end devices.
- **Prominent object detection** Automatically determine the most prominent object in an image.
- **Coarse classification** Classify objects into broad categories, which you can use to filter out objects you're not interested in. The following categories are supported: home goods, fashion goods, food, plants, and places.
- **Classification with a custom model** Use your own custom image classification model to identify or filter specific object categories. Make your custom model perform better by leaving out background of the image.

Using a custom TensorFlow Lite model

The default coarse classifier is built for five categories, providing limited information about the detected objects. You might need a more specialized classifier model that covers a narrower domain of concepts in more detail; for example, a model to distinguish between species of flowers or types of food.

This API lets you tailor to a particular use case by supporting custom image classification models from a wide range of sources. Please refer to Custom models with ML Kit to learn more. Custom models can be bundled with your app or dynamically downloaded from the cloud using Firebase Machine Learning's Model deployment service.

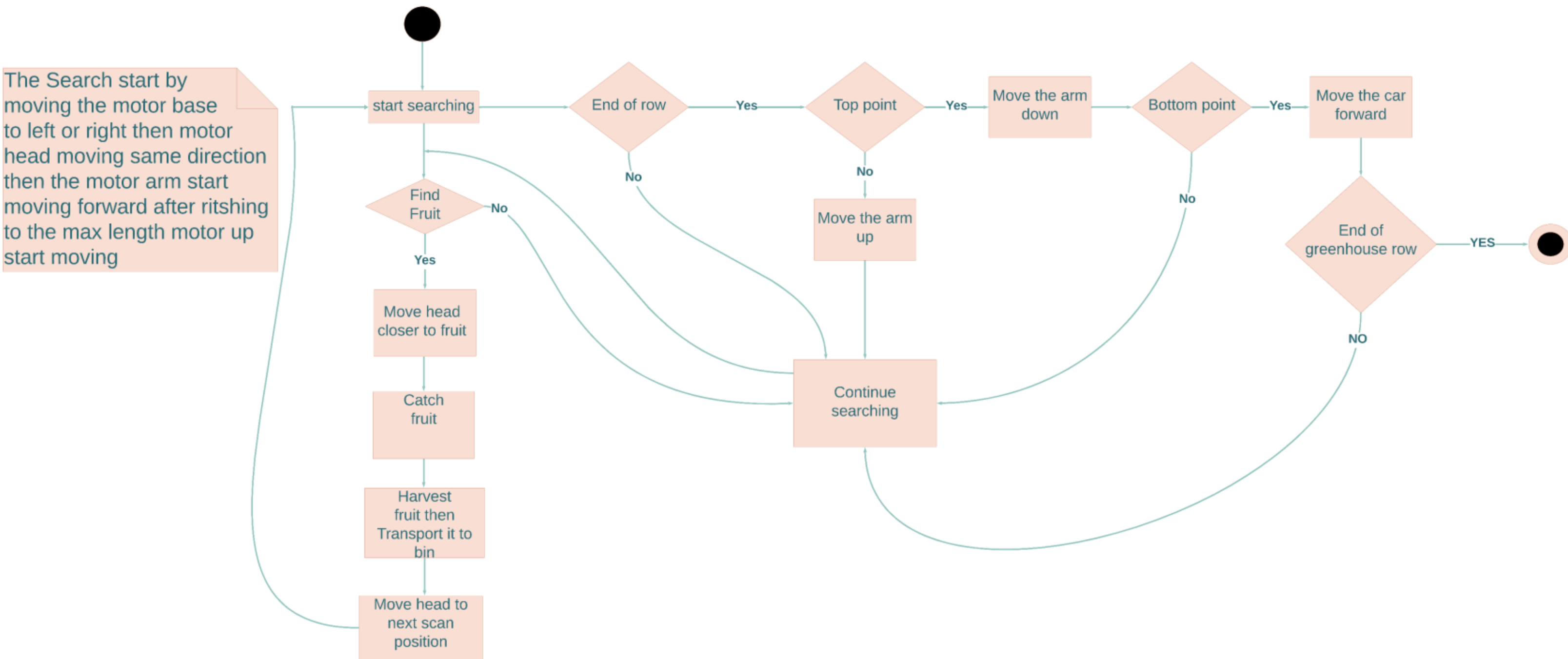


Figure 42

Figure 42 showing the flow chart of the code at first when the searching starts the motor base start move to the left or right to make the robot head facing the row of tomatoes planet after motor base finish moving motor head start moving in same direction of motor base then motor arm start moving forward after reaching to the max length motor up & down start moving will the searching is running if the robot found tomatoes the searching stop and start moving the arm closer to the tomato and hold it after hold the tomato and put it in the box the searching continue from the last position .

The mobile application is easy to use, the phone application is considered the robot's eyes and brain because it performs most of the work. Its mission is to search and analyze images captured by the phone camera and translated using machine learning libraries. When it finds the tomato, it sends the necessary commands and coordinates to the robot mechanics, allowing them to move, catch, and pick. The tomato.

Figure 43 showing the mobile application design, the application will have two mode the manual mode and the self-mode, in manual mode the application allows to user to control the motor of the arm or car, self-mode is the main function of application that’s make the application analyze images captured by the phone camera and translated using machine learning libraries the ML kit. When it finds the tomato, it sends the necessary commands and coordinates to the robot microcontroller, allowing them to move the arm, catch, and pick the tomato.

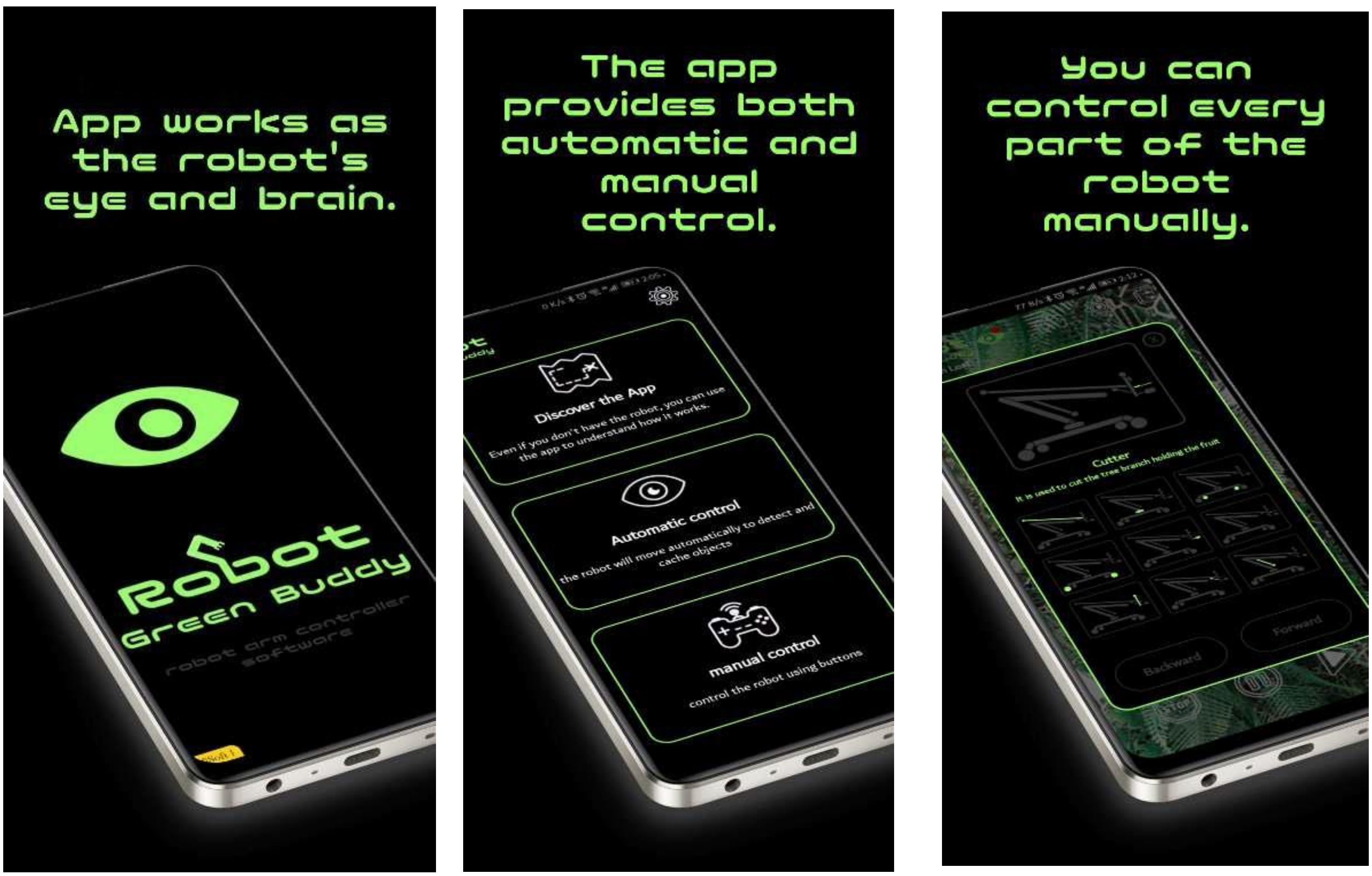


Figure 43

Figure 44 showing the mobile application will doing image processing and analyze images captured by the phone camera and translated using the ML kit and the application have the ability to find tomatoes behind the leaves not only the tomatoes front the camera as showing in figure 44.

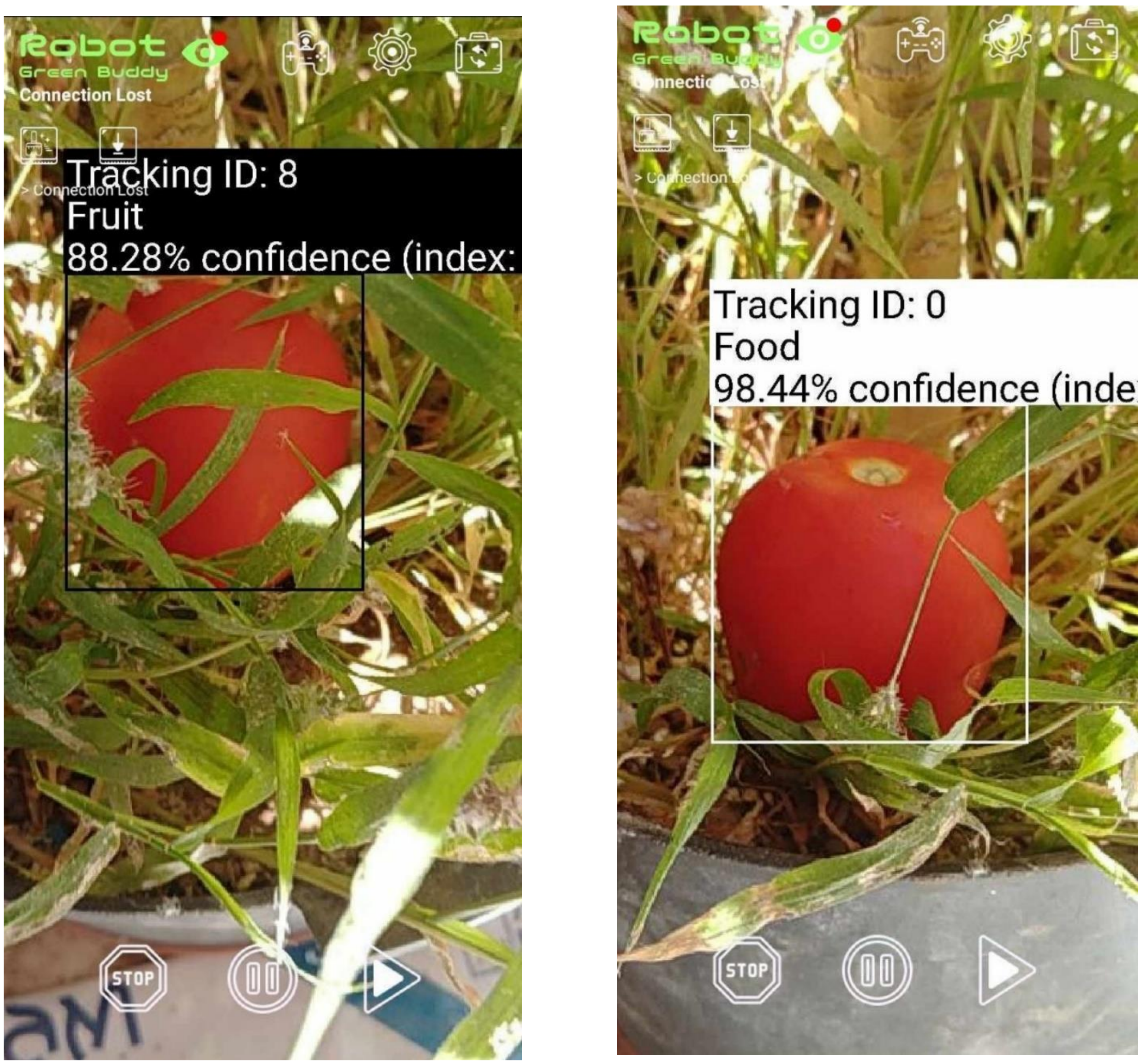


Figure 44

Figure 45 ,46 showing part of the code of mobile application and the Arduino you can find the rest of code on GitHub.

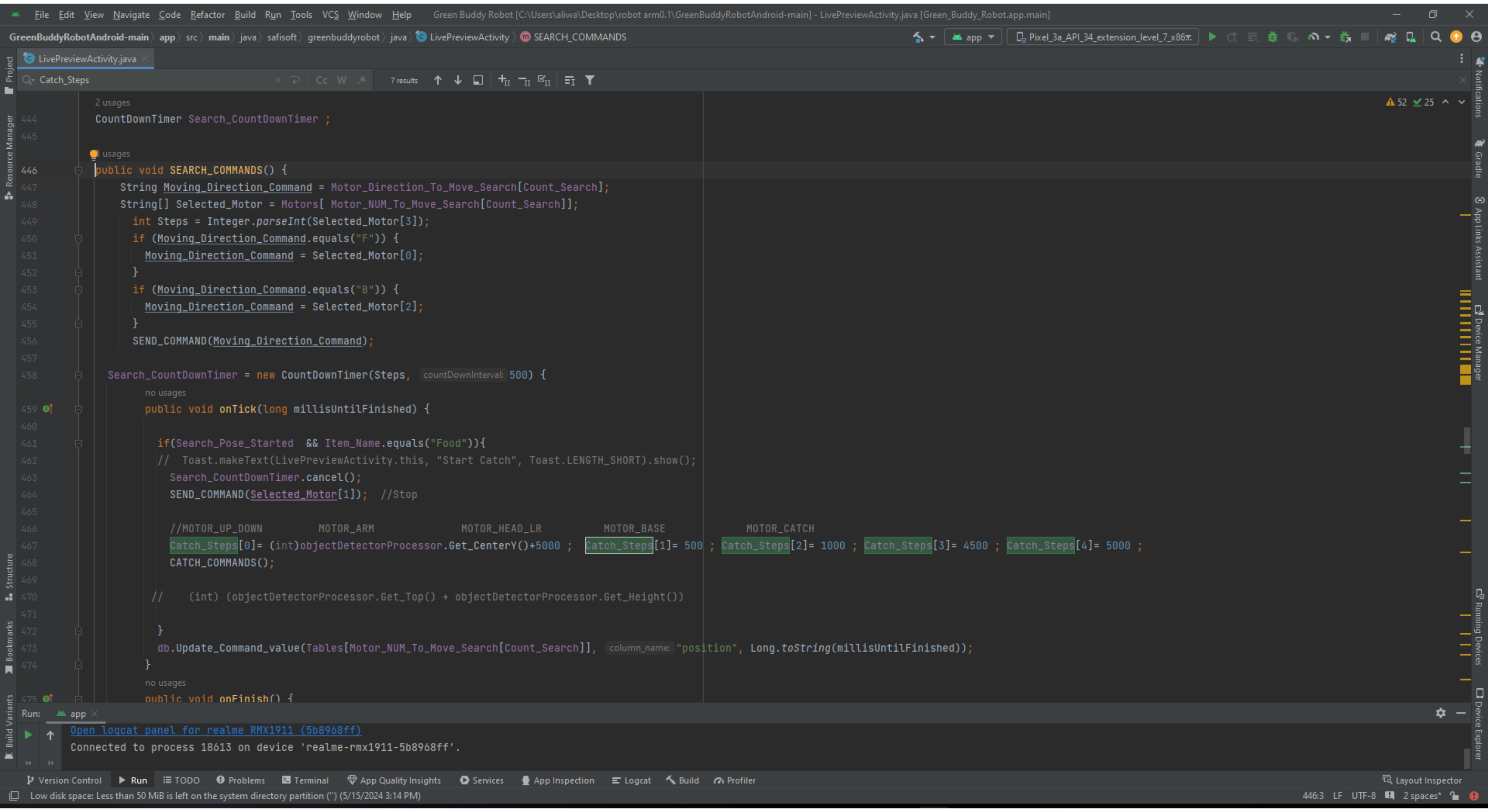


Figure 45

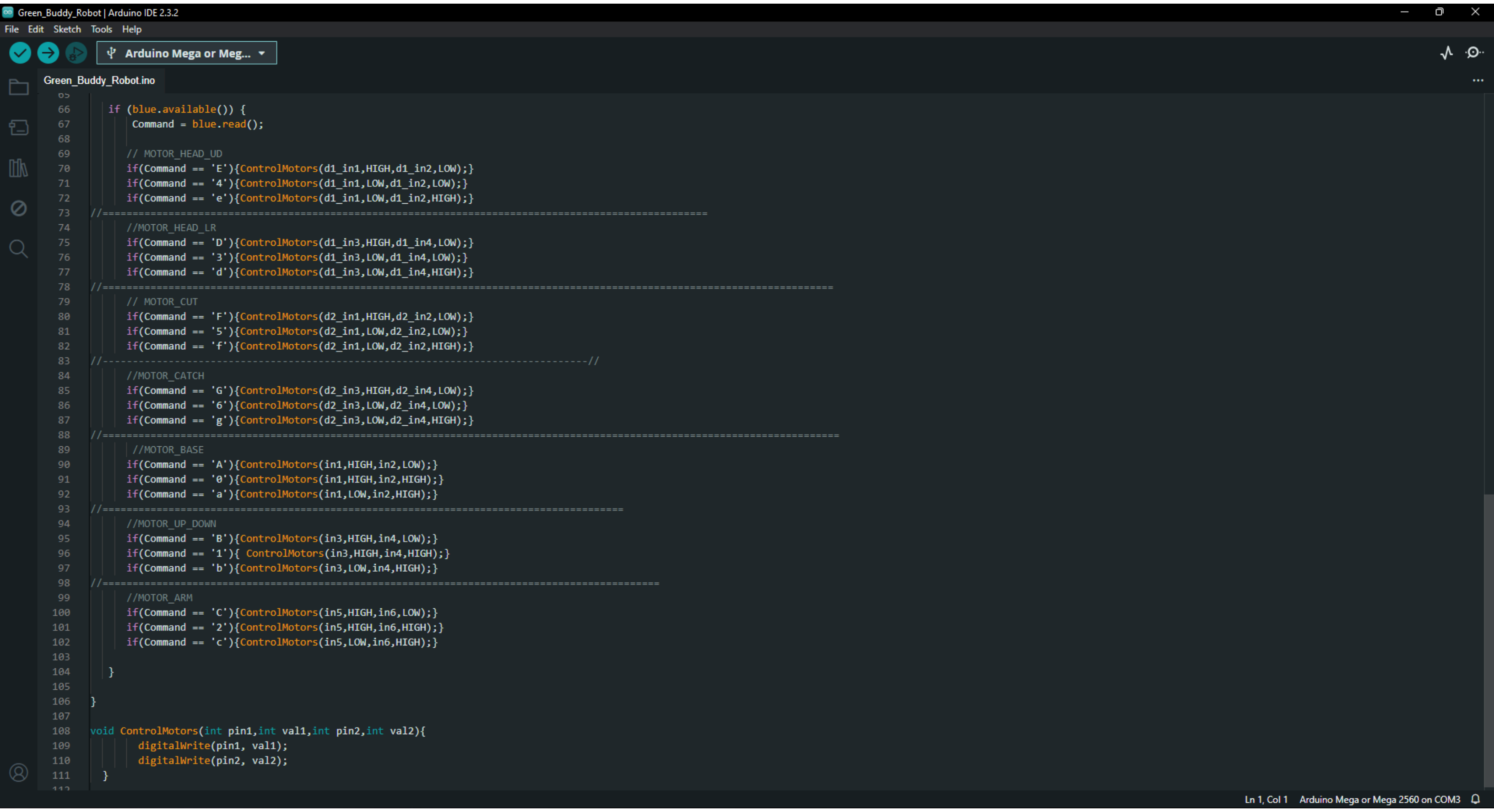


Figure 46

Conclusion

Our goal is to build a highly efficient and cost-effective robot arm for harvesting tomatoes in greenhouses. To achieve this, we conducted extensive research to find alternative materials, motors, drivers, and microcontrollers to reduce costs without compromising the robot's efficiency. Instead of using expensive aluminum, which requires specialized machinery like CNC for design, we opted for PVC pipes. For image processing, instead of using high-cost microcontrollers like NVIDIA Jetson or Raspberry Pi, which are priced around 15,000 EGP, we chose a more affordable Arduino Mega, costing approximately 850 EGP, and utilized a mobile phone for image processing, and the motor instate using linear actuator or nema 34 white gearbox the cost will be above 6,000 for motor instead of that we use a Dish Mover Motor the cost of single motor is 600 EGP, This approach significantly lowers costs while maintaining the robot's performance. The total cost of the robot is 11,500 EGP.

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