INTELLIGENT AGRICULTURE ROBOT FOR TEA PLANTATION PRESERVATION: TEABOT

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ABSTRACT

Crops are grown on a big scale in Sri Lanka. One of the most important export commodities that boosts Sri Lanka's GDP is tea production. In addition to other export commodities, tea has a long history, and Ceylon Tea is the most well-known brand worldwide. The world has a large market for Ceylon tea. The climate is mild, and the soil is fertile for growing tea in Sri Lanka. Because of this, Ceylon Tea has the same flavor that people in other nations adore. Sri Lanka had an abundance of people resources in previous decades to maintain expansive tea estates. As time passes, the nation is experiencing an industrial revolution. The population eventually began to disperse in search of new employment. Unlike other crops, tea requires proper maintenance and is more expensive. They were unable to keep up the tea estates as laborers declined. It affected to diminish the crops. Several estate owners began to switch to planting various crops with lower care costs. The export market was severely impacted. TeaBot is a highly developed autopilot robot that can irrigate and fertilize large-scale tea estates in place of human labor. The TeaBot is one of many robots that is specifically made to function in off-road environments without the requirement for well-defined, highly organized tracks. The robot primarily tends to the tea plants' watering and fertilization[1] needs. Because they require constant water and nutrients to produce the greatest crop, tea plants. The robot is improving productivity and reducing waste of fertilizer and water. The TeaBot can recognize the way to go, recognize the end of plant stems, and effectively water the plants.

Keywords – large-scale irrigation, Spraying, watering, fertilizing.

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PID	Proportional Integral Derivative
ROS	Robot Operating System
UI	User Interface
API	Application Programming Interface

1 INTRODUCTION

1.1 Background and Literature Survey

It has been challenging to maintain consistent irrigation and precise fertilization in massive plantations. Despite attempts to improve this process utilizing a number of different tactics, these efforts have fallen short as a result of issues like inefficient resource consumption, exorbitant pricing, and a labor shortage. The expense of hiring a huge crew is also much higher. Plantations cannot be accurately and timely watered or fertilized by hand, and in some situations, doing so is inefficient.

Most often, large-scale irrigation is not effectively monitored. If we contrast their effectiveness with small-scale production, it is also quite poor. Most countries perform big scale watering only by exploiting natural weather and rainfall seasons. In Sri Lanka, the wet season is used to cultivate plants, some of which are only native to certain areas. Although we can grow plants anywhere, large-scale plantations are only permitted in a few places due to environmental concerns.

There are a lot of factors to take into account before starting large-scale plantations in Sri Lanka.

1. **Climate**

Climate is defined as the condition of the atmosphere at a particular location over a long period of time (from one month to many millions of years, but generally 30 years).[2] These climate-related problems primarily affect regionalized and large-scale plantations. In Sri Lanka, there are primarily 4 climate seasons. Taking place in accordance with these climate seasons are large-scale plantations.

1. First Inter-monsoon Season (March - April)

   According to the distribution of rainfall over this time period, the hill country's entire south-western sector received 250 millimeters of rain, with some localized areas on the south-western slopes receiving more than 700 millimeters (Keragala 771 mm). Rainfall varied between 100 and 250 mm over much of the island, with the Northern

Jaffna Peninsula being the only notable exception (Jaffna- 78 mm, Elephant pass- 83 mm).[2]

2. Southwest -monsoon Season (May - September)

   This season sees rainfall ranging from roughly 100 mm to over 3000 mm. The western slops' mid-elevations saw the most precipitation (Ginigathhena- 3267 mm, Watawala- 3252 mm, Norton- 3121 mm) [2]

3. Second Inter-monsoon Season (October-November)

   Almost the entire island receives in excess of 400 mm of rain during this season[2]

4. Northeast -monsoon Season (December - February)

   At this time, Kobonella Estate experiences the most rainfall (1281 mm), whereas Chilaw, a region along the Western Coast near Puttalam, experiences the least (177 mm).[2]

most of the Sri Lankan large scale plants grow according to these climate seasons. Because we can water, fertilize, and take care of the plants, small-scale plantations may operate in every season. Nevertheless, in larger-scale production, it is impossible to take accurate care of each and every plant.

2. Topography

The central section of the island is mountainous and has heights of over 2.5 kilometers, as well as complex topographical features such ridges, peaks, plateaus, basins, valleys, and escarpments. These areas' farmers cultivate crops using a range of methods. Apart from a few little hills that rise abruptly in the lowlands, the rest of the island is generally level. These locations experienced various effects of climate change because of their terrain.[2]

3. Temperature

Altitude, not latitude, is the primary factor influencing regional variations in air temperature over Sri Lanka. The seasonal movement of the sun has a substantial impact on the mean monthly temperatures, even after adjusting for rainfall. While temperatures in Sri Lanka's highlands substantially decrease, they are largely uniform throughout the country's lowlands. Up to a height of 100 to 150 meters, the mean annual temperature in the lowlands varied from 26.5 °C to 28.5 °C, with 27.5 °C as the average. As altitude rises, the highlands endure rapid temperature drops.[2]

In addition to these, a number of other elements are taken into account while farming on a large scale, but rainfall is the key one because it directly affects plant cultivation differentiation and growing seasons. The majority of Sri Lankan farming is done utilizing the rainfed system due to these rainfall effects. The rain and water reservoirs directly irrigate a variety of crops around the county.

One of the main sources of foreign exchange earnings and a vital component of Sri Lanka's agricultural sector is the tea business. It has been extremely difficult to maintain the tea plantations amid expansive agricultural fields. According to recent statistics, the tea industry's economic impact is declining. There are a number of significant issues that have been found, including inefficient resource use, high labor costs, a labor shortage, high resource waste, and irregular watering and fertilization of the plantations[3].

There have been several methods developed to automate liquid fertilizing tea plants. such as drip irrigation, center pivot irrigation, utilizing intelligent robots, and so on. Large wheels are employed in the field during center pivot irrigation, and sprinklers and nozzles are used to water the plants[4]. The system must be implemented at a high initial cost, and it is challenging to water plants correctly with this technique. Additionally, certain plantations that are close to the wheels will receive enough water, but the other plantations won't get enough[4]. The installation of the pipes is expensive both initially and over time for drip irrigation systems[5].

It is useful and efficient to create an autopilot robot to irrigate and fertilize large-scale tea estates in place of human labor. The primary tasks performed by the robot are watering and fertilizing the tea plants. For the best production, tea plants require constant hydration and feeding. The robot is improving productivity and reducing waste of fertilizer and water. An automated irrigation system can be installed to overcome these problems[6].

Despite the fact that numerous agricultural robots have been created for a variety of uses [7][8]. The gap mentioned in the earlier issues has not been filled by those. Creating a robot for liquid fertilization of tea plantations is a difficult task since it is difficult to recognize the stems under various lighting conditions.

Robots need to be tuned accurately to detect the plant stem during the watering process and deliver a precise dose of water and nutrients. This will cut down on both water waste and irrigation expenses. Each farmer can generate crops with this autopilot robot with or without rain. Using this technique, we can grow crops anywhere in the nation, even in the arid regions.

Summary of prior studies.

1). Factors affecting large-scale agriculture: The majority of large-scale agriculture depends on a number of variables, including climate, topography, and temperature. Many large-scale farms rely on rainfall and rain-fed irrigation systems.

2). large-scale tea plantation management: Sri Lanka, emphasizing problems including uneven irrigation and fertilization, ineffective use of resources, labor shortages, and climate-related elements. It emphasizes how temperature differences, geography, and seasonal climate changes affect plantation cultivation. The primary issue is the tea industry's deteriorating economic effect as a result of these difficulties.

3). Automated irrigation methods: It is investigated how to automate fertilization and irrigation using techniques like drip irrigation and center pivot irrigation; however these have cost and effectiveness restrictions. To increase production and optimize resource use, the concept offers creating an autopilot robot for carefully and effectively fertilizing and watering tea plants.

4). Robotic approach for tea plantations: To replace human labor in the irrigation and fertilization of massive tea estates, it would be advantageous and efficient to develop an autopilot robot. The robot's main responsibilities are to water and fertilize the tea plants.

5). Key challenges in robotic approach: The main difficulty is delivering exact doses of water and nutrients to plant stems under various lighting conditions while minimizing waste and expenses. Also highlighted is the robot's ability to enable crop growing independent of rainfall, providing a remedy for parched places.

1.2 Research Gap

So, as was already indicated, there are many options available to enhance the watering and fertilizing of large-scale crops. The majority of automated systems are appropriate for plantations in greenhouses. There aren't many moving robots that can spray water precisely where the plants meet the ground. Also, the majority of robot systems lack a verifying device to determine whether water actually fell in the designated area. Most spraying systems waste lots of water and efficiency is low [9]. For tea plants, misting fertilizer is not recommended. Most of the systems do not have stabilizing water spraying nozzles. TeaBot will be able to precisely route the water nozzle component to the stem of the tea plant using the coordinates of the stem and the relative velocity of the robot with the watering arms.

Table 1:Comparison of former research related to water spraying.

Irrigation System	**Eligibility for tea field liquid fertilization**	**Watering scale**	**Issues**	**Mechanism**
Pressurized irrigation systems include sprinkler[9][10]	✗	Long	High cost	These systems spray pressurized water across the system and distribute water via pipelines.[9]
Solid set sprinkler systems[9][10]	✗	Long	Incorrect operating pressure reduce efficiency.[9]	Sprinklers are permanently fixed in well-designed solid set systems at spacings that produce the best consistency.[9]
Gun sprinkler systems[9][10]	✗	Very long	wind drift and evaporation losses lots of water.[9]	Large sprinklers known as "gun sprinklers" release water at high pressures and flow rates. [9]
Center pivot and lateral move systems[9][11][4]	✗	Medium	losses lots of water from the guns[9]	lateral move systems that increase the irrigated area by adding gun sprinklers to the extremities of the laterals [9]
Drip and line source	✓	Short	High maintenance	Apply water in tiny drops or streams from individual drip emitters to the

systems[9][12][5]			and management cost	soil's surface or just below it. [9]
Bubbler systems[9]	✓	Short	High maintenance and management cost	Using separate containers or basins, bubbler irrigation systems spray water around trees or other plants. [9]
Gravity flow irrigation Systems[9]	✓	Short	Losses of irrigation water due to lateral flow [9]	use gravity to irrigate[9]
Subirrigation systems[9]	✓	Short	Large installing cost and maintaining	A new water table is created over an existing one or one that is constrained by a layer of dirt. [9]
Surface (flood) irrigation Systems[9]	✓	Long	Large water wastage	water is distributed by flow across the soil surface[9]
TeaBot water spraying system	✓	Short	Solve lots of above-mentioned problems	water is fired from a sprinklers establish in robot

The TeaBot sprayer's capacity to navigate any terrain is the proposed solution. Compared to other systems, the cost is inexpensive, and maintenance is simple. Extremely little water is wasted, and there are no problems with the wind or wrong pressures. Spraying has a validation system and is accurate. If a pipeline system has a problem, it must check every pipeline to locate the exact location. In a TeaBot, checking the spraying arms makes finding problems quite simple.

1.3 Research Problem

Several research tests were conducted by some tea producers and researchers in an effort to create equipment that would allow them to irrigate and fertilize tea plantations while using fewer laborers. There are several irrigation techniques available, however the majority are not appropriate for tea. Most of them require large installment payments. A particular methodology will be used in this study challenge to close this gap. **How to create a spraying system that would effectively water and fertilize large-scale tea plantations** is the scientific challenge.

1. How to design the robot arm to control the water sprayers.
2. How to spray water to exact spot with the relative velocity of the robot.
3. How to build a stabilization mechanism in the sprayers reduce the shaking of the robot in off road conditions
4. How to build a system to track water spraying path and validate
5. How to regulate water pressure for different distances

2 OBJECTIVES

2.1 Main Objective

The TeaBot robot is suggested as a means of resolving the aforementioned issues. The development of the agricultural robot will focus on making it dependable and flexible so that the procedures of fertilizing and watering can be maintained. The TeaBot robot can also be described as flexible because it is capable of a variety of jobs. such as fertilizer to maintain soil fertility even during dry spells and irrigation to maintain growth and health. Water will be used during the fertilization process to increase efficiency.

Usually crops like tea and vegetables are grown according to a precise design. Like people, robots are able to recognize the rows of a plantation[13] in order to water and fertilize the appropriate plants. The robot will precisely detect the tea plantation rows and give the coordinates to the robot controller. With the coordinates of the stem the robot will be able to navigate the water nozzle component to the tea plants stem precisely with the relative motion of the robot with the watering arms. The camera is fixed to the platform and remains therefore fixed, regardless of the robotic arm's movements[14].The watering will be done in stream of water not by spraying mist because spraying van harm the tea plant leaves when fertilizers added to the water. After watering it will be verified if the plants are watered correctly or not.

Watering nozzles should be V-shaped, with two sprayers on one side of the robot and the other two on the other side. To water rapidly and correctly, 2 sprayers must be managed collectively. The two nozzles on either side must alternately move from one plant to another. It also contains a number of valves[15] to regulate the water flow and lessen water waste. The arms include many weight control functions, and all 2 nozzles may move both vertically and horizontally.

The majority of water spraying devices lack a way to determine whether water actually reached the desired location. That is not correctly validating. Yet, TeaBot Robot has a unique mechanism to capture a laser light inside the parabolic water beam that is sprayed from the nozzle. Robots can detect the water path and ensure it properly reaches its target by employing side cameras. After that, it can inform the robot controller.

Also, it offers a variety of off-roading functions, such as the capacity to maintain power utilization and find risks using computer vision coordinates (Obstacles on the navigating road).

2.2 Specific Objectives

These three objectives must be met to fulfil the above-mentioned main goal.

2.2.1 Development of the arm and hardware components

This is the most vital part of this proposed solution. Because this is the part it controls how the spraying nozzle moves and acts like a human hand. The arm of the sprayer is directly connected to water spraying nozzles. It may move to any side and shoot water in the direction specified by the coordinates. This has a total of 2 arms with identical hardware features. These dynamic arms can connect to any side of the robot and are flexible. The robot can be equipped with a variety of arms that can carry a range of weights depending on the various farming fields. These arms have the ability to control the pressure, spraying distance, and height in accordance with the field. The water spraying mechanisms on the robot arm must also be stabilized because the robot moves in off-road environments and its equipment can tremble at any time.

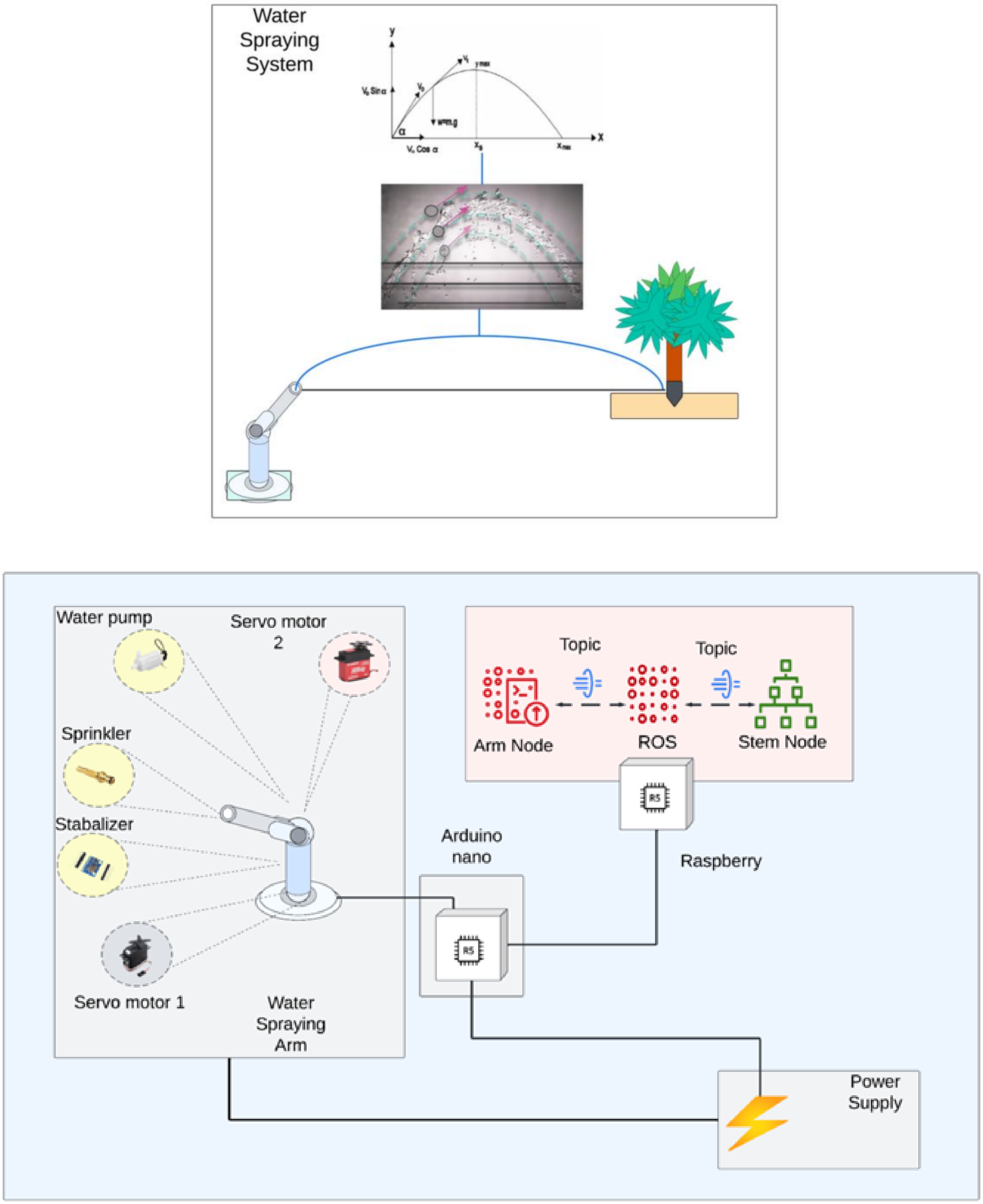

Figure 1: Development of arm and hardware parts

2.2.2 Development of the algorithm and software components

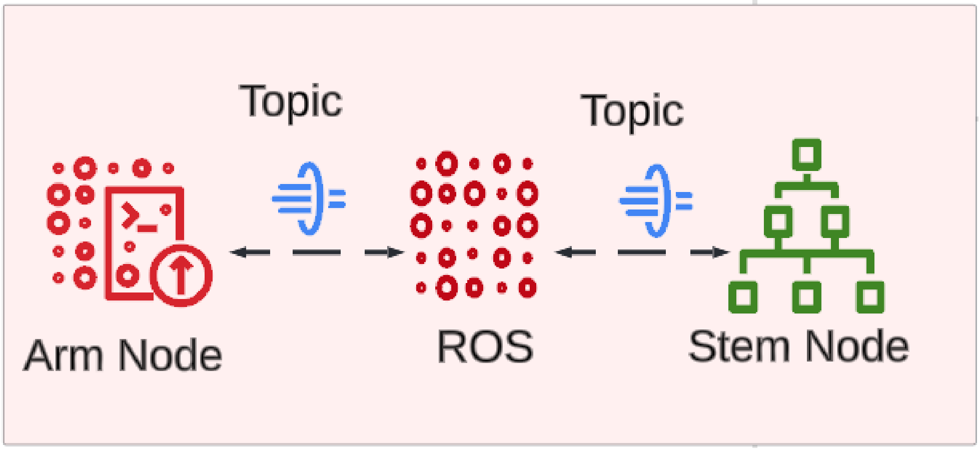

Figure 2 : Development of the algorithm and software

The primary area of research for the water spraying system is in this section. Servo motors, valves[15], and other mechanical components of the arm must be moved using the Python programming language. Nonetheless, every movement must be carried out in accordance with an algorithm. This algorithm should include multiple variables. the robot's speed, the density of the water mixture, the distance from the spraying nozzle to the stem, and the water pressure. The aforementioned variables are mostly calculated using physics, and in accordance with these results, the angle of the arm and the water pressure need to be adjusted in order to fire water onto the stems of the trees. The PID algorithm [16] also applied to stabilize the spraying nozzles of the Robot.

2.2.3 Laser light tracking mechanism.

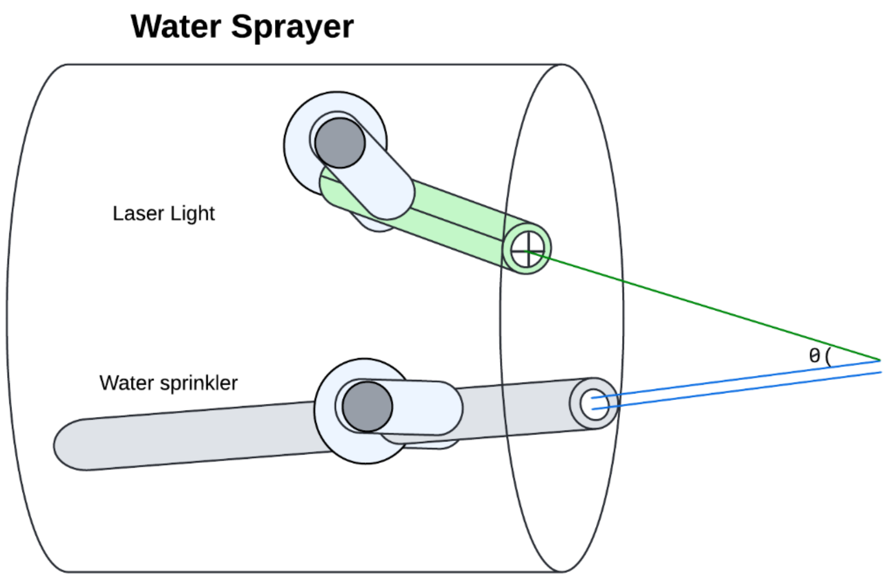

Figure 3: Water sprayer

This laser light system is the first one to be used for a robot spray validation system. It is challenging to determine the robot arm's current location using computer vision. mostly due to the robot arm not capturing the camera. A laser pointer can be used to confirm the precise location of the robot arm at any given time. If the camera detects the location of the laser pointer, it will be able to determine the arm's position. We can precisely move the arm to identified stems by lining up the laser's position with the detected stem's position.

3 METHODOLOGY

TeaBot, the proposed watering solution, would be developed in the following ways to deliver an efficient solution for large scale farmers.

3.1 Requirement Analysis

3.1.1 Requirement Gathering

Farmers that operate in locations with extensive farming provided the majority of the analyses for this study. Their domain knowledge and requirements for a large-scale irrigation solution in their farms were shared over one-on-one phone conversations and online chat platforms. To build a lasting solution for the objectives and goals that this provided for big scale watering system, the collected data was used to discover and investigate unmet needs, unsolved difficulties, and potential improvements in large scale farming[18].

- Functional Requirements
  - Water spraying to the stem.
  - Rotation of the water arm.
  - Water spraying angle control.
  - Water pressure control
- Non-Functional Requirements
  - Accuracy
  - Performance
  - Speed
  - Reusability

- System Requirements
    - Computational power to run the algorithm.
    - Continuous water flow
    - Rotation angles of the motor

- Personal Requirements
    - Farmers
    - Tea State owners
    - Agriculture field experts

3.1.2 Past research Analysis

When it comes to Past Research Analysis, there are quite a lot of research papers and publications under the topic of liquid fertilizing, robot arm controls and tea plantations. However, there was a smaller number of publications considering the dependency levels between spraying arms for robots, automation of water spraying and automated spraying arm for tea plantations. Key topics of interest included spraying systems, robotic approach to spraying system, robot arms, and tea plantations. During the past research analysis, the main focus was to identify the methodologies and the tools used to build the existing tools and platforms. Moreover, it helped to identify the problems that the past researchers faced.

3.1.3 Identify existing systems.

Few moving robots can spray water precisely where the plants and the ground converge. Additionally, most robot systems don't have a way to check if water truly fell at the intended spot. The majority of spraying systems waste a lot of water and perform poorly [9]. Misting fertilizer on tea plants is not advised. The majority of the devices lack stabilizing nozzles for water spraying.

3.2 Feasibility Study

3.2.1 Technical feasibility Study

In order to develop a robot arm solution for liquid fertilization should have basic knowledge of Robotics, Arduino and Computer vision. Members should be able to perform basic configuration and should have sufficient theoretical knowledge and practical experience in robotics.

Also, researchers should have a basic idea about algorithms, cloud computing, machine learning, and electronics. So, the members must be technically capable of using the technologies and completing the product's development to the specified elements in order to build the product in accordance with the aforementioned standards.

3.2.2 Knowledge on ROS

The modular architecture of ROS makes it possible for programmers to create individual software "nodes" that are capable of carrying out certain functions like processing sensor data, running control algorithms, or creating user interfaces. A highly adaptable and distributed system design is made possible by these nodes' ability to communicate with one another via a publish-subscribe messaging system. In order to provide hardware abstraction, ROS provides drivers and interfaces for a variety of robotic hardware devices as well as other peripherals. This abstraction makes it easier to include various components into a robotic system. To hasten the creation of robotic applications, this ecosystem offers a large selection of pre-built libraries and packages[19].

3.2.3 Knowledge on Twist library

A "twist" message type is frequently used in ROS (Robot Operating System) to describe linear and angular velocities. It is frequently used to describe how a robot, or any other item moves in 3D space[20]. It can be used to control robot arm movements.

Typically, the twist message has two key parts:

Linear Speeds:

- linear.x:
- linear.y:
- linear.z:

Angles of rotation:

- angular.x:
- Angular.y.
- angular.z:

3.2.4 Knowledge on Python

Python is renowned for being simple and readable. This makes it a fantastic option for both new and experienced programmers while working on ROS projects. Developers can communicate with the ROS framework and build ROS nodes using the Python client module rospy, which is provided by ROS. Access to ROS concepts like publishers, subscribers, services, and parameters is made possible via this library, making it simpler to operate inside the ROS ecosystem. Many of the many libraries available for Python, which serve a variety of functions, can be easily incorporated into ROS applications [21].

3.2.5 Knowledge on Arduino

A line of microcontroller boards and an open-source electronics platform called Arduino. It can be used to build a variety of projects, from straightforward prototypes to intricate electronic systems. The Arduino IDE (Integrated Development Environment), a user-friendly software development platform that makes it easier to write and upload code to the board, can be used to program Arduino board [22]. It uses its own programming language, which is based on C and C++. It is the main component used for robot arm control.

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3.3 Implementation

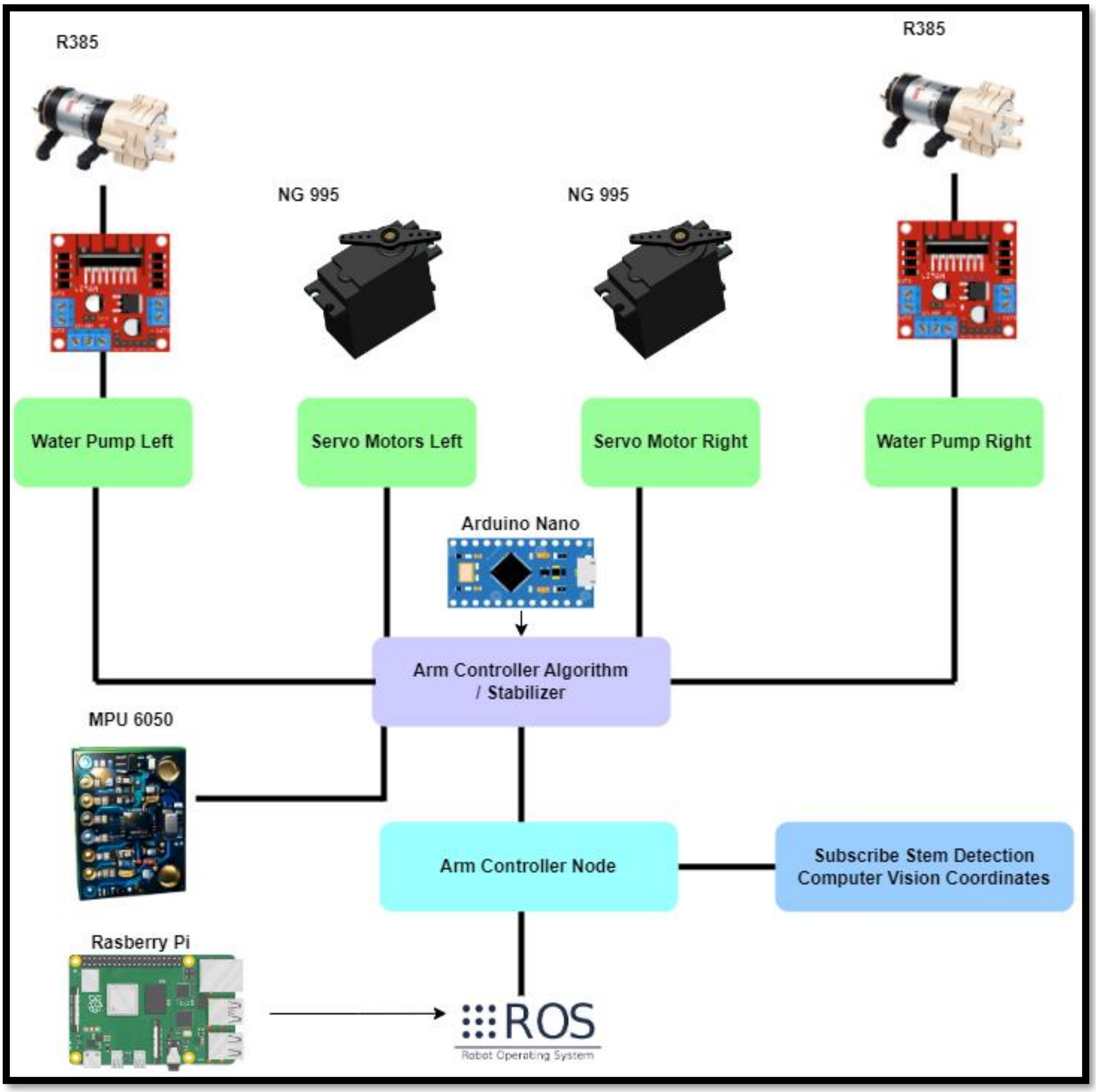


Figure 4 : System overview diagram of robot arm

The TeaBot's watering system is built using the most recent hardware and software. The two watering arms can be changed to fit different farming fields and share the same hardware functionality. The water spraying arm contains 180^0 liftable and 180^0 rotating motors. Power connections are attached to the battery used for the robot controlling feature, and an Arduino controller is mostly used to drive these motors. This 8Am 12V battery powers the entire robot-controlling system. If the current drawn by the motors is too great, the current must be reduced using a certain type of resistor. The weight of the arm and the weight of pipes including water determines which of these servo motors should be used, and each servo motor has a unique power supply need. A pressure monitoring system[23] is also necessary for water spraying from the nozzle to the stem. Water pressure decreases as the robot moves from one end to the other, so a pressure pump must be added to the system to maintain the pressure level precisely.

Solid works is used to design the robot arm and Python is used to control the electronic parts of the arm. The primary robot controller is a Raspberry Pi, device running Ubuntu Controller. This controller mostly uses the ROS framework[24] as a set of middleware. The other functions are all linked to this ROS system and communicate with one another. Many readings are necessary to spray water. Speed metrics are obtained from the accelerometer, distance parameters from the computer vision component, and the robot's tilting angle while traveling are gathered through the gyroscope sensor.

3.3.1 Overall system architecture diagram

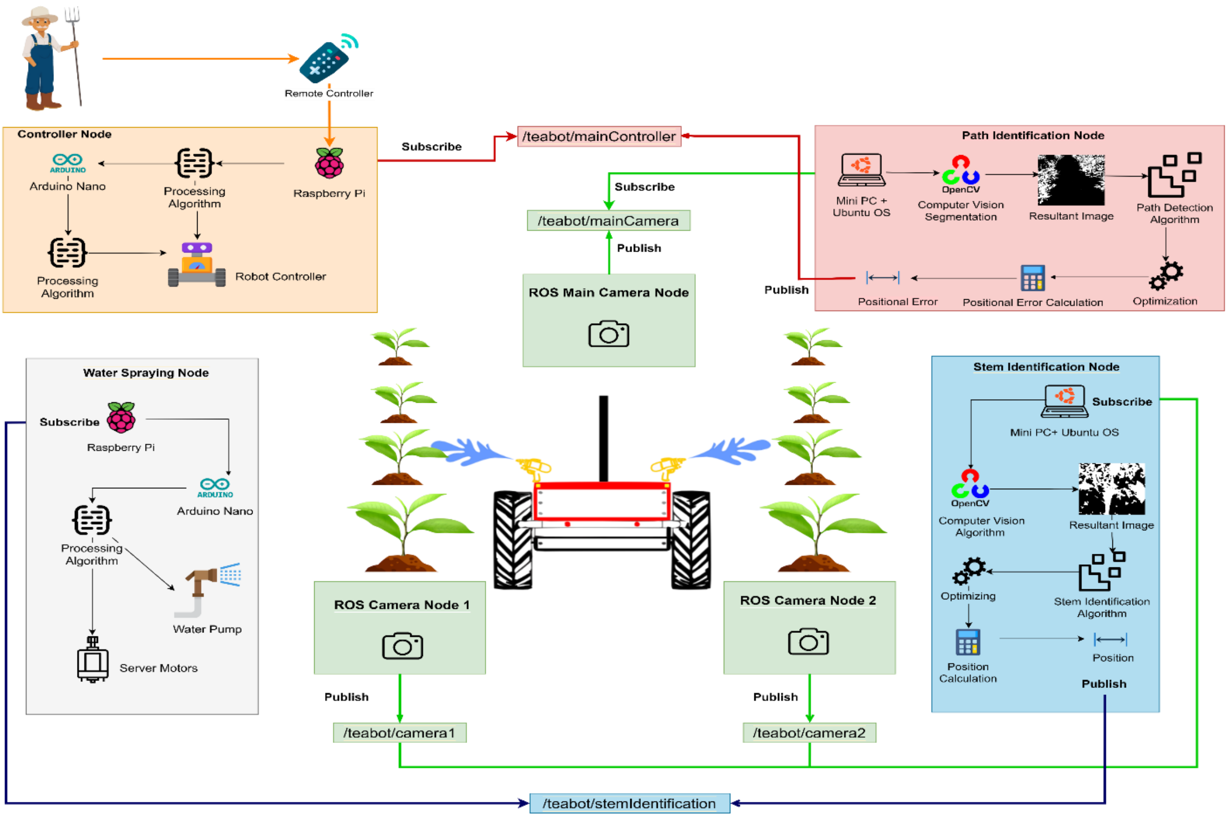


Figure 5: Overall system overview diagram

The robot wheels receive computer vision coordinates that are provided from the front camera. Robots navigate paths and move from one end to the other by using the coordinates. In order to irrigate the plants, side cameras are employed to locate the stem of the plants. These coordinates are then sent to the spraying arm.

3.3.2 Implementation of ROS Nodes

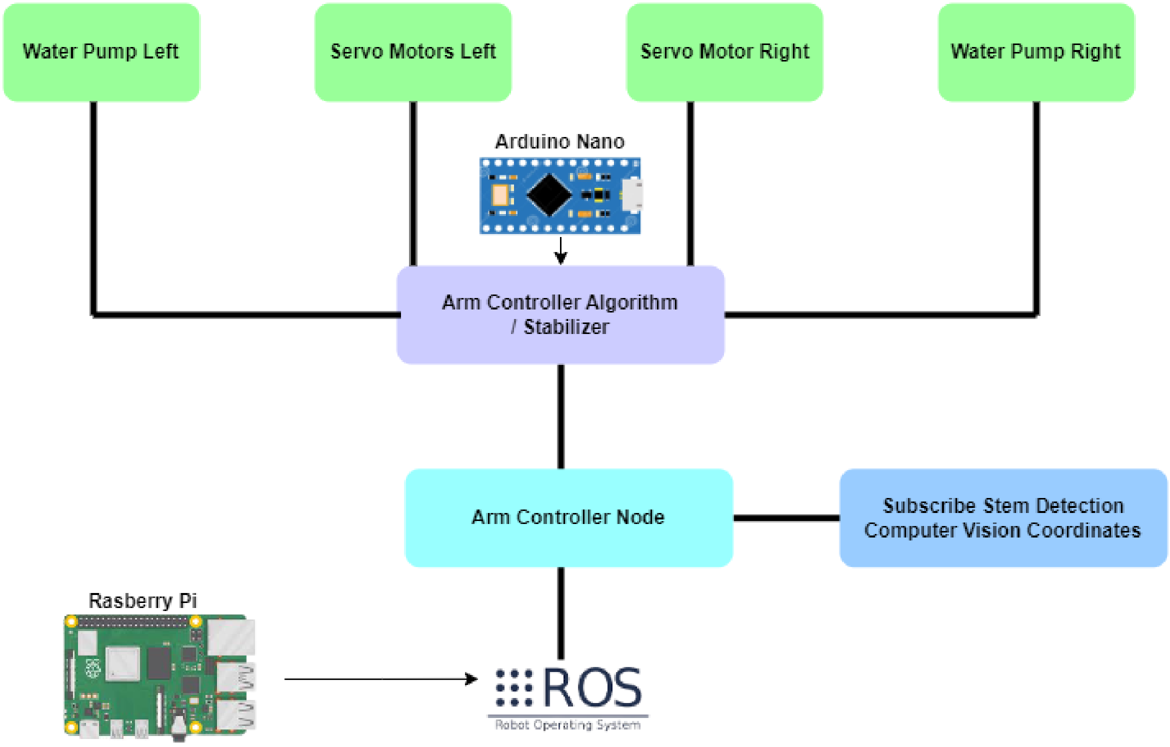


Figure 6: ROS Nodes

The Arm controller algorithm running on the Arduino Nano board manages the tea bot's watering mechanism. The left servo motors, left pump, right servo motor, and right pump were all connected to this Nano board. There are two servo motors working on the horizontal x axis and the vertical y axis on each side. The Raspberry Pi board is serially connected to a nano board. Arm controller ROS node runs on a Raspberry pi.

The coordinates for the pixel density value of a picture with a width of 0–700 pixels are sent by the stem detection algorithm. In that range, if a stem is detected for the first time, it starts at 700 and ends at 0 when the stem leaves the camera sight.

All of these coordinates are transmitted using the linear x of the Twist library from one node to another. There are numerous values that must be passed to the robot arm in place of these coordinates. Therefore, the best approach is to convert all of these values to an array, send the array via only one parameter, split the array, and separate each variable.

The servo motors have a scale of 0-180, whereas the stem's coordinate has a scale of 0-700. Each coordinate must be converted from 700 to 180 scales, but in a real-world application, the robot arm must be tuned from 0-140 scales to spray at an angle like a cone. If we raise it to 180, though, the robot's wheel will likewise be watered. The algorithm for converting scales is shown below.

- Servo coordinates = (Stem coordinates*140)/700

When the arm is first detected by the camera, the distance is greatest, thus the pump requires more power. When it reaches the center of the detection, the motor's power is low. When the detection ends, the pump requires more power once more. To achieve this, the voltage's analog signal must periodically be controlled. To transform that scale, the bellow method is employed.

If pixel value is > 350

Pump voltage = ((Stem coordinates-350) *155)/300+100

If pixel value is < 350

Pump voltage = ((350-Stem coordinates) *155)/300+100

Pump speed varies between 280 and 100 volts, with 280 being the highest and 100 being the lowest at any given time. Each coordinate is broken down into 300 parts. and each of them is then multiplied by 155 to give each coordinate difference a weight.

3.3.3 Implementation of Arduino controller

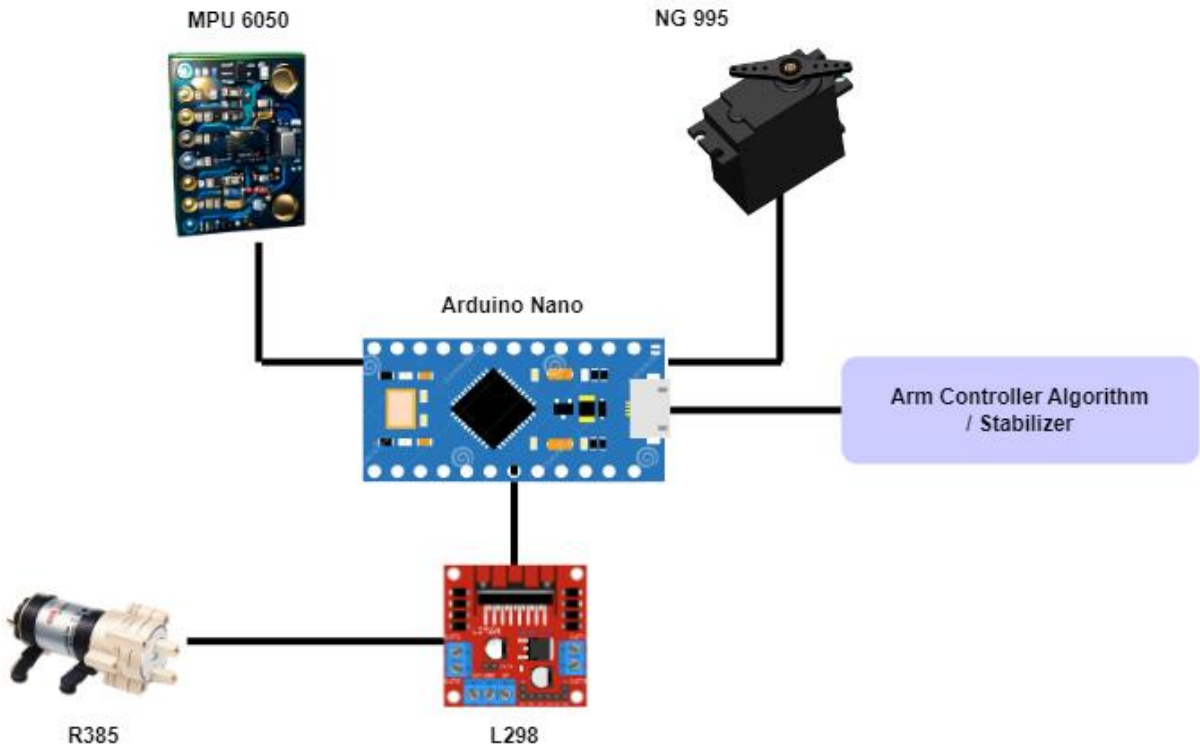


Figure 7: Arduino controller

Robot arm controllers are controlled using Arduino nano. It has 1 gyroscope sensor (MPU 6050), 4 servo motors (NG995), a motor driver (L298), and 2 water pumps (R385). The best and most affordable way to control all of these components is with nano, which is also simple to repair if it burns or breaks while the arm is being controlled. Due to the expansion of the pins, the entire system is not directly connected to the Raspberry Pi.

By using serial USB pins, coordinates sent from the raspberry board are transferred to the nano board, where they are fed directly to the servo motors. The similar system is employed by water pumps as well. Arms that spray water are stabilized using a gyroscope module.

3.3.4 Implementation of Hardware parts

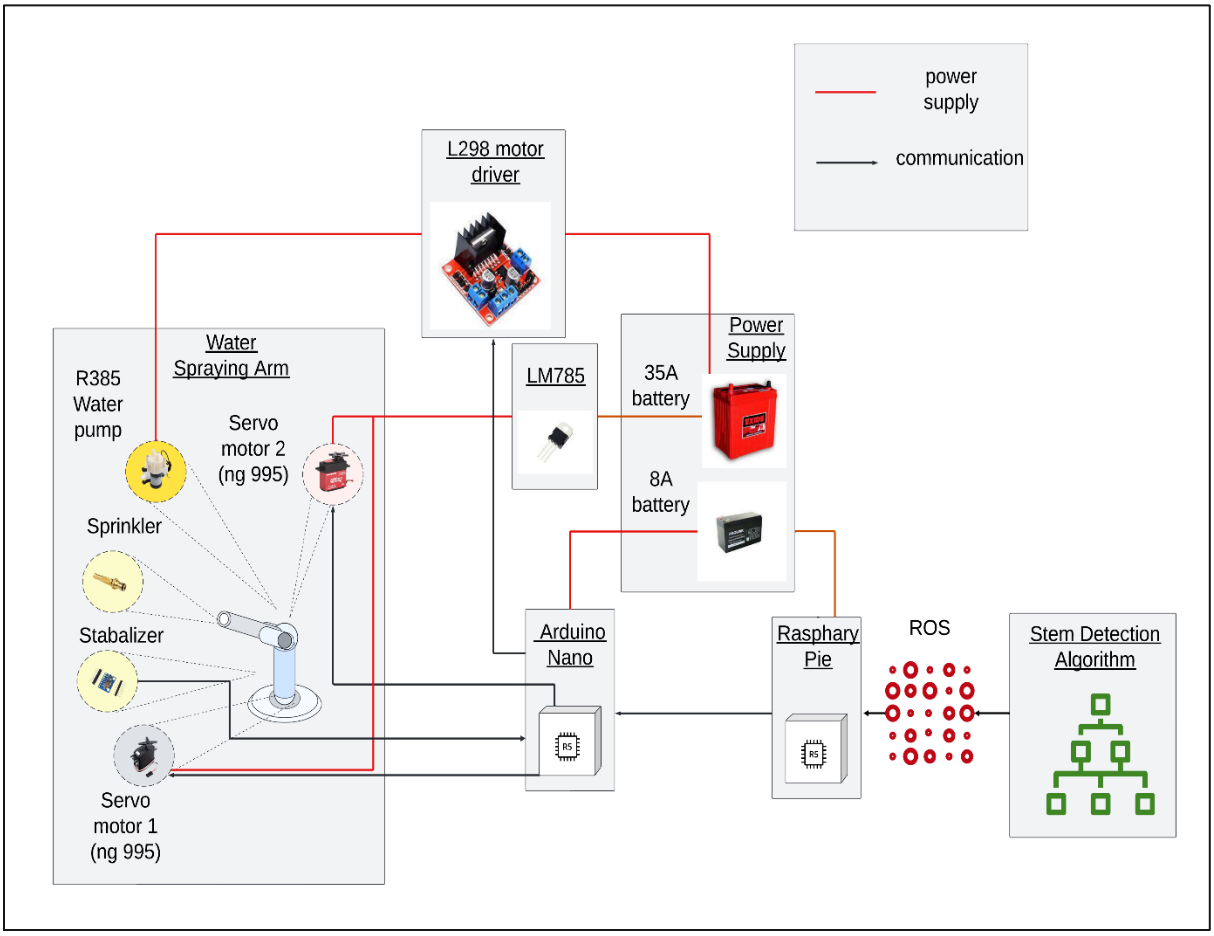


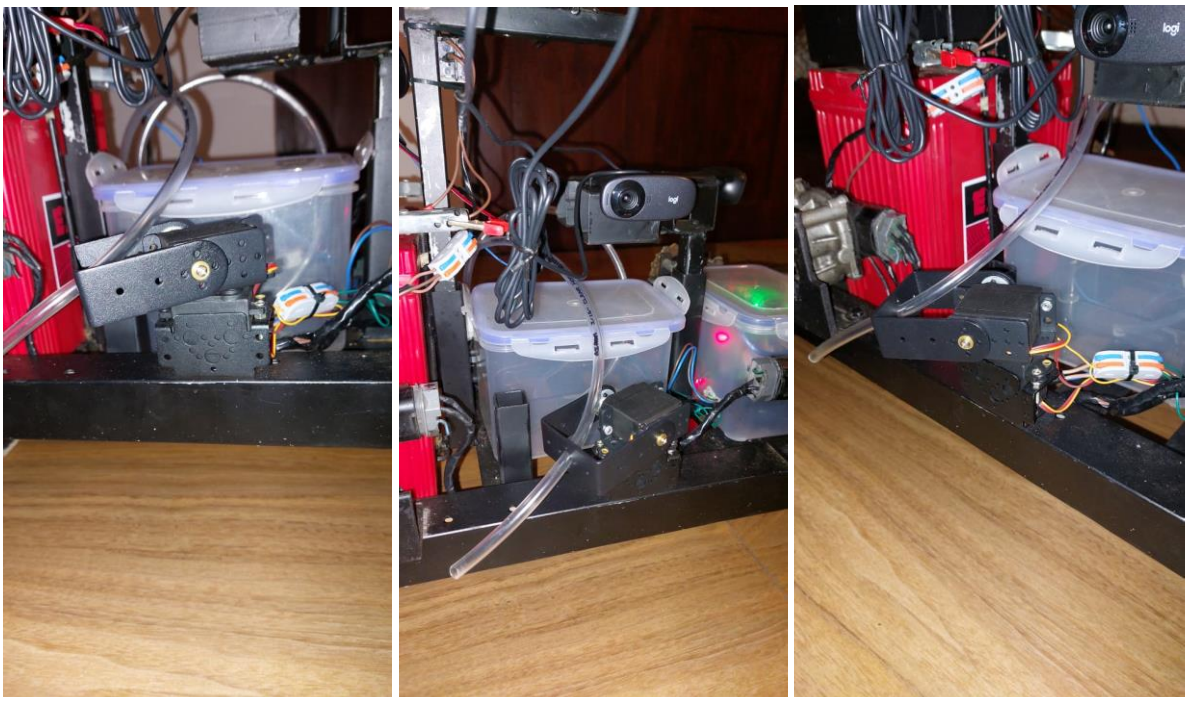
Figure 8: Hardware integration

The hardware connections for a robot arm are depicted in this diagram. Two batteries were employed for the power supply: a 35A, 12V battery, and an 8A, 12V battery. In order to continuously power the chips and shield them from electrical noise generated by water pumps, Arduino and Raspberry Pi chips are connected to an 8A battery. The Robot arm is powered by a 35A battery. This comprises the two water pumps (R385) and all four servo (ng 995) motors. LM785 IC is used to convert 8A to 2.5 A. Lots of heat is produced during this power conversion. Thermal tapes were used to wrap it and affix it to the robot's steel surface in order to lessen the heat.

The output from the computer vision system is transmitted over Wi-Fi to the Raspberry Pi-based arm controller node. The coordinates provided by the stem detection process are transmitted via ROS nodes, and inside the Raspberry Pi, they are translated from a scale of 0 to 700 to a scale of 0 to 140 before being sent to the nano board. Then, for appropriate operation, those values are fed to the servo motors.

The stem detection algorithm's coordinates are used by the Raspberry Pi to determine the PWM voltage of the pump, which is then sent to nano. The motor driver (L298) is used to regulate the pump's speed using PWM values that range from 100 to 280.

Figure 9: Robot Arm physical design



3.3.5 Implementation of Laser module

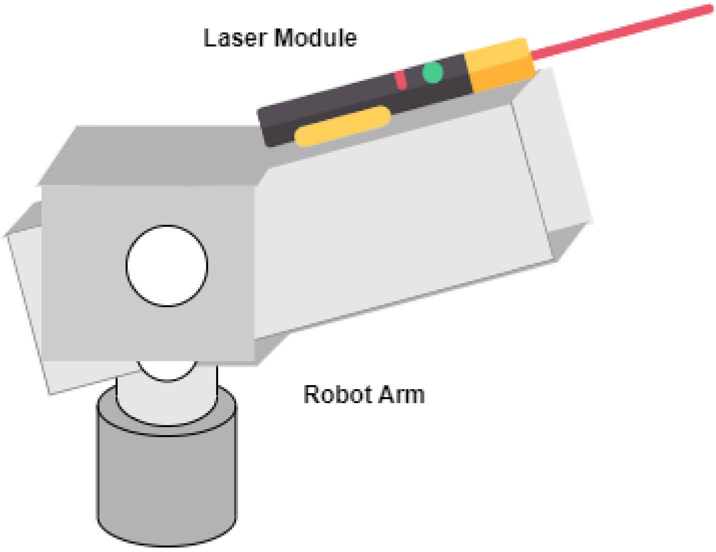


Figure 10: Laser module

By applying the graph's median values and the values obtained from the Sobel filter, the coordinates of the stem may be computed. However, to determine the current position of the arm is a challenging part. The best way to determine the arm's current position is to use a laser module or a laser dot. The color range of the laser dot may be filtered using computer vision, and by using the pointer, we can determine where the arm is. The y axis of the robot arm can be properly adjusted if the laser pointer fits into the stem's location.

Figure 11: The tree stem with the laser pointer

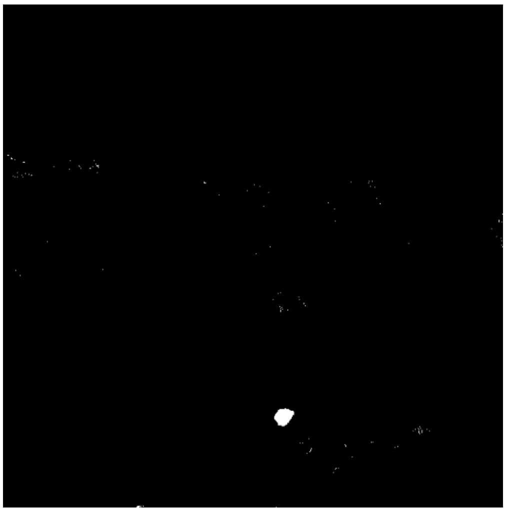


Figure 12: After the picture has been mask-applied

The laser beam in Image 11 is focused on the tree. The laser pointer can be separated by using a red color mask with lower range = 0,50,50 and upper range = 0,255,255 (fig 12). This allows us to determine the robot arm's present position..

Figure 13: Following stem detection

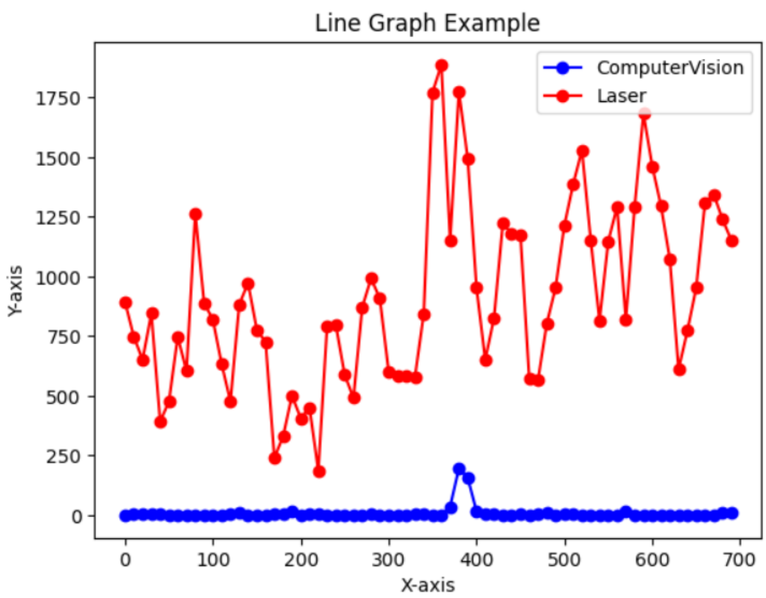


Figure 14: Stem location vs Laser position

Figure 14's blue color graph displays the laser module's current position, while the red color graph displays the location of the stem that computer vision detected. Arm's actual location is defined by the laser module's current position. The laser dot position must be brought to the stem location, which means there should be as little difference between these two graphs as possible in order to accurately water the plant. The position of the arms is incorrect otherwise.

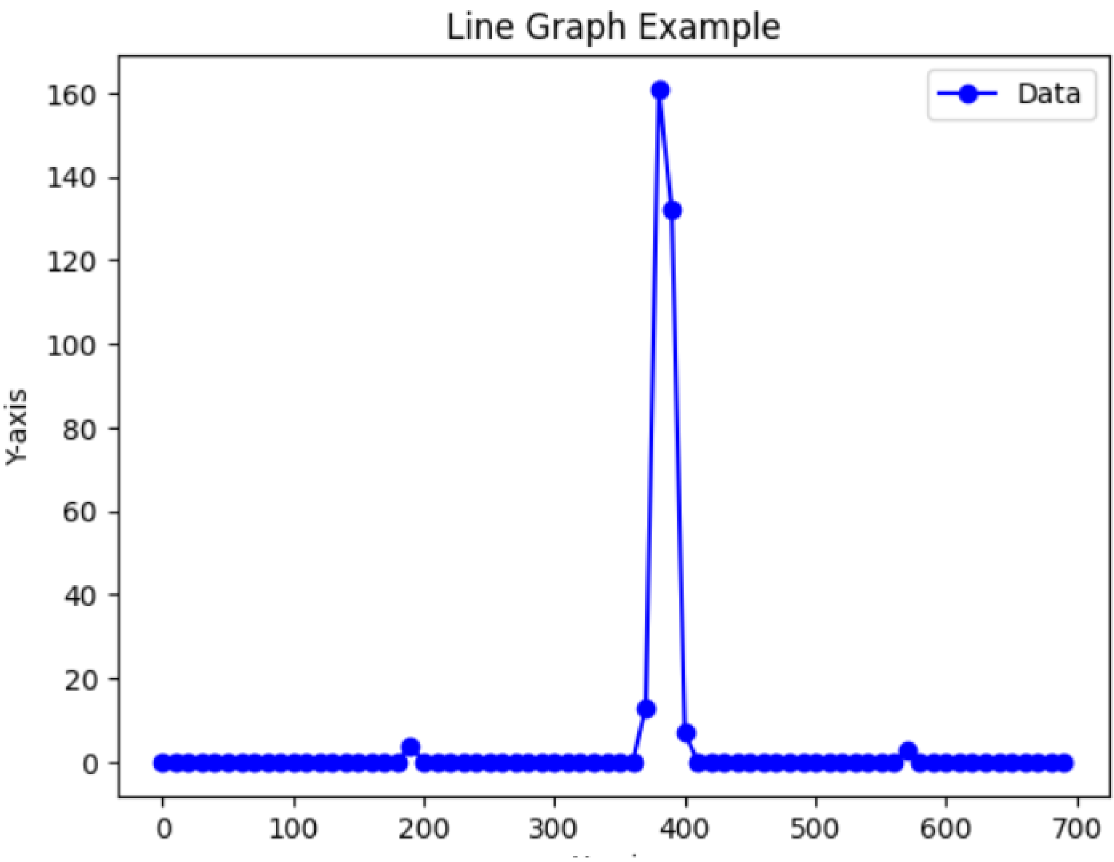


Figure 15: Laser dot position graph

3.4 Commercialization

In particular, the accurate and effective irrigation of crops is one of the major difficulties in agriculture that the TeaBot water spraying robot is designed to answer. Tea plantations and other crop farming businesses are largely the target market for this novel agricultural solution. This commercialization strategy describes the methods for making TeaBot available to its target audience, with an emphasis on adaptation, flexibility, and user-friendliness.

TeaBot is made up of both software and hardware elements. While the software can be periodically updated to improve functionality and adapt to changing agricultural needs, the hardware is unchangeable once sold. TeaBot is a dynamic and constantly changing solution thanks to its software-driven methodology, which enables the addition of new features and enhancements.

Subscription-Based Model:

To facilitate the widespread adoption of TeaBot, we propose a subscription-based model that caters to the diverse needs of our customers. This model offers various subscription tiers to choose from, ensuring that users can select the plan that aligns with their requirements.

- Hardware Pricing and Subscriptions: The TeaBot hardware component is available for purchase online through the TeaBot website and other online and local marketplaces. The price starts at US$960 for one Robot.

- Individual Plan for software updates: Under the Individual plan, TeaBot offers three subscription tiers: Basic, Standard, and Pro.

    - Basic: This tier is free for a lifetime and includes access to essential spraying functions.
    - Standard: Priced at US$2.99 per month, this tier includes additional spraying features and access to new features and updates.

    - Pro: Priced at US$3.49 per month, the Pro tier offers the most comprehensive set of spraying features, access to new activities and updates, and the ability to view user learning analytics.

- Organizational Plan for software updates: For organizations such as tea plantations and farming enterprises that require multiple TeaBot units, we offer three subscription tiers: Micro, Medium, and Mega.

    - Micro: Suitable for 1 to 5 TeaBot units, this plan costs US$39.99 per user per year and provides access to essential spraying features, new activities, and learning analytics.
    - Medium: Designed for 5 to 10 TeaBot units, this plan costs US$34.99 per user per year and includes all essential features, access to new activities, and learning analytics.
    - Mega: Tailored for organizations with more than 10 TeaBot units, this plan costs US$24.99 per user per year and offers comprehensive features, access to new activities, and learning analytics.

Once a user buys a robot, it comes with a one-year hardware warranty and a two-year software warranty.

4 Testing, Result and Discussion

4.1 Testing

Verify that the system's subcomponent is operating correctly. Throughout the development process, this will be done concurrently. This will be done to find bugs in the system as the functionalities are implemented. Here, testing will be carried out on the Arduino model to ensure that it produces the desired results. Examples include test cases for mathematical algorithms to ensure that it produces the right results for the input results and properly classifies the problem. Ensure sure the algorithm functions flawlessly and produces the right results in off-road scenarios.

4.1.1 Lab Testing

Laboratory testing is utilized to examine the arm’s movements in accordance with the arm's codes and restrictions. A During lab testing, the interaction of ROS nodes is mostly examined. Hardware components and ROS nodes' relationship. How to optimize the nodes based on the time between each communication node. In laboratory testing, values passing from the stem algorithm are turned into a string array to shorten the delay between communication channels. Since the prototype arm is lightweight, it should be necessary to continuously adjust each motor's speed individually; nevertheless, this problem is resolved in the field robot. Before going on a field trip, all potential outcomes are examined in a lab setting before being evaluated.

Figure 16: Lab tested prototype.

4.1.2 Field Testing

We don't expect what happens when things are being tested in the field. The arm mostly tries to wobble here and there and does not function effectively in accordance with the desired level of the lab testing. These things occur as a result of the camera's erroneous and flawed readings. Sobel filter is mostly used by the camera to locate the stem's borders. Sometimes a plant's shadow is also seen as a component of the stem, and as a result, the arm tries to water the shadow of the plant. We had to switch to an HD camera in order to lessen the shadow impact. Sometimes, if it grabs the edge of another object other than a stem, it tries to abruptly transfer the arm to a different place. Therefore, we had to disregard such incorrect coordinates. We had to keep track of the most precise coordinate range, and which coordinates to ignore in various circumstances. Occasionally, during field testing, we see electric noise coming from a water pump trying to activate an arm without any signals. It is reduced using capacitors.

Figure 17: Field tested arm

4.2 Results

4.2.1 Test results

- Delay in stem identification: The Raspberry processor is not powerful enough to execute two computer vision programs. They are stem detection and path navigation. To provide outputs, these delays are more than 30 milliseconds. This delay makes the arm's motion less than ideal. We hook in a laptop to process the output, and a raspberry pi is used to regulate the electronics to eliminate the latency. Only the output that has been processed inside the laptop is sent to the raspberry. So, the arm functions perfectly.
- Laser light vision: Strong sunlight makes laser light vision invisible. Therefore, some of the arm's coordinates cannot be precisely recorded. It functions well in dimly lit areas and with shadows. The laser light that is focused to directly hit the sun is difficult to photograph.
- Electrical Noises: The water pump motor might make electrical noise when it is on or off. As the motor begins or stops, the current varies quickly, which produces this noise. The other parts of the system may be impacted by the noise as it spreads through the power supply. If the operation of the water pump produces electromagnetic radiation, EMI and radio-frequency interference (RFI) may take place. The servo motors on the Arduino and other components of the circuit may be affected by this radiation. To reduce the effect, use capacitors and separate power supply for chips.
- Accuracy in different tea plants: The water spraying arm performs flawlessly for large tea plants, but it performs inaccurately for small tea plants. More tiny tea plants in the field would mean that they would go unnoticed and receive inadequate watering. Variables in the stem detection algorithm must be adjusted to lessen the aforementioned issue.
- Avoid incorrect detections: During the computer vision data collection in the tea field, numerous incorrect values can be found. We need to compare the present values with the stem's past accurate values in order to chop off those values. If the discrepancy is significant, we must exclude that area and lessen the arm oscillation that results from

incorrect coordinates. The below table shows accuracy of the arm according to the time gap VS Pixel count difference.

Table 2: Accuracy of the robot arm

Time Gap (s)	Pixel count difference	Accuracy
1	**100**	**Accurate**
1	**200**	**Accurate**
1	300	Not-Accurate
1	400	Not-Accurate
1	500	Not-Accurate
2	**100**	**Accurate**
2	**200**	**Accurate**
2	300	Not-Accurate
2	400	Not-Accurate
2	500	Not-Accurate
3	100	Not-Accurate
3	200	Not-Accurate
3	300	Not-Accurate
3	400	Not-Accurate
3	500	Not-Accurate
4	100	Not-Accurate
4	200	Not-Accurate
4	300	Not-Accurate
4	400	Not-Accurate
4	500	Not-Accurate

This table allows us to create a graph of the arm's accuracy in relation to the time delay vs the difference in pixel count.

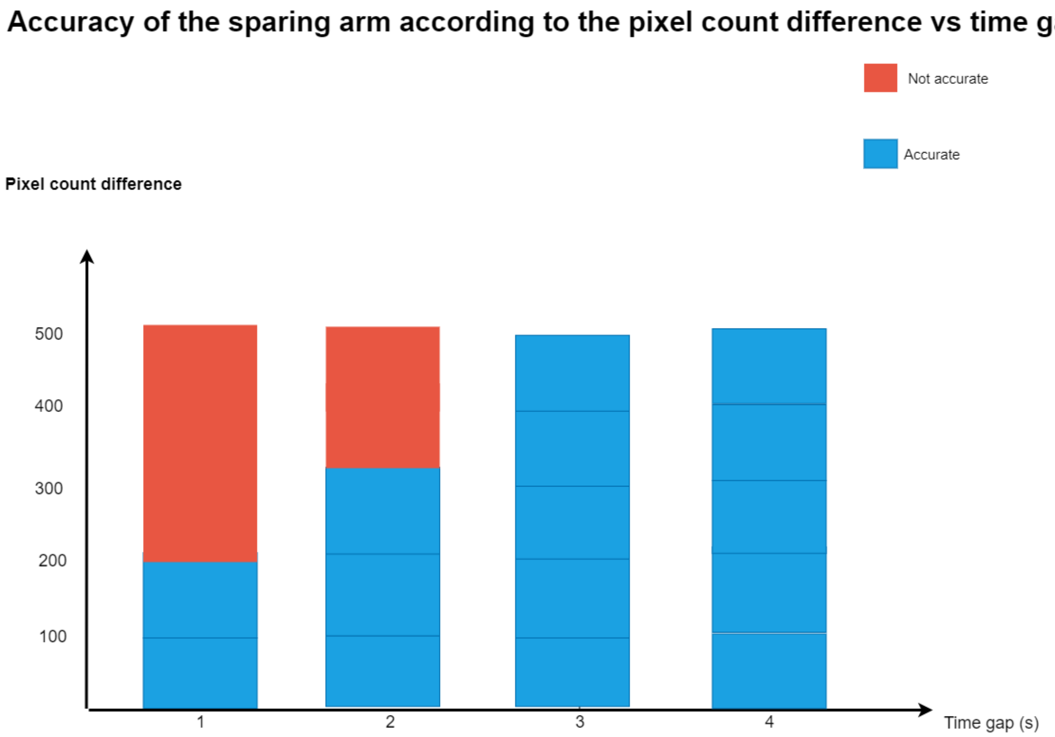


Figure 18: Accuracy Graph

4.2.2 Research Findings

This section discusses the individual research finding of the TeaBot spraying arm. These research findings were derived from the literature review and test results mentioned earlier in this document.

- One key finding suggests the importance of using a high-power mini-PC, such as the Intel NUC, instead of a Raspberry Pi, to minimize the overall system's latency. This choice is crucial for ensuring that the algorithms operate seamlessly and without any delays. A lower-latency system is essential for real-time responsiveness and precise coordination of the robot's spraying arm.
- Another significant finding is the recommendation to use brushless water pumps to reduce electrical noise generated by the pumps. This noise can potentially interfere with the operation of the servo motors in the robot's arm. The use of brushless water pumps eliminates the need for shielding and additional filtration capacitors, providing a quieter and more reliable solution for watering.
- Adjust the robot for tea plant nurseries so that its arm doesn't miss any little plants and can accurately water every plant. After that, a robot arm can correctly water both large and small plants.
- To prevent erroneous detections and ensure accurate coordination, a specific criterion regarding pixel count differentials and time intervals has been established. The finding suggests that the difference in pixels between the previous and current pixel counts should not exceed 200 within a second or 350 if measured over two seconds. These threshold values have been determined through field testing, during which pixel count differentials and time intervals were systematically varied and analyzed. The resulting graph demonstrates the relationship between these parameters and accuracy. When incorrect coordinates are detected, they should be discarded, and only the correct values should be sent to the servo motors for precise control of the spraying arm.

4.3 Discussion

The tea industry is a significant contributor to Sri Lanka's agricultural sector and one of the country's primary sources of foreign exchange profits. The tea plantations have been incredibly challenging to maintain amidst the vast agricultural areas. Recent studies show a decreasing economic impact of the tea sector. Numerous serious problems have been identified, including poor resource utilization, high labor expenses, a labor shortage, excessive resource waste, and inconsistent fertilization and watering of the farms.

"TeaBot" water-spraying robot to effectively and practically meet a variety of demands. TeaBot was developed with the goal of bridging the gap between conventional manual watering techniques and cutting-edge automated technologies, offering a practical and affordable watering solution.

Current watering techniques frequently lack adaptability and effectiveness. When compared to some automated solutions, manual watering can be labor- and time-intensive and lack the flexibility required for various plants and landscapes. TeaBot offers a cutting-edge watering solution by combining the best aspects of both worlds.

Owners of tea plants are TeaBot's major target market as a commercial product. Users can considerably increase their watering efficiency compared to manual methods or current automated systems by incorporating TeaBot to their gardens and farms.

The ROS communication system that connects all of TeaBot's components and is in charge of coordinating its operations forms the basis of its functionality. We investigated numerous methodologies and technologies to construct this component in order to achieve our goals. Reducing hardware costs while upholding high performance standards was our main objective.

TeaBot is made to be adaptable, allowing it to change its watering pattern in response to human preferences and real-time data. This cutting-edge method of automatic watering optimizes plant health while minimizing water waste.

To be a dependable and flexible tool for agricultural activities, TeaBot was created. Fertilization and irrigation are two crucial processes that are at the center of its basic functions. TeaBot can successfully maintain soil fertility and support the healthy growth of crops even in difficult situations like drought spells by combining these functions into a single robot. The effectiveness of agricultural activities as a whole is increased by this multidimensional strategy.

Instead of using mist or spray, TeaBot uses a stream of water for irrigation. This decision was carefully considered because sprinkling tea plants with nutrients in the water has the potential to damage their delicate leaves. Specialized watering nozzles on the robot have two sprayers on each side in a V-shaped layout. To ensure effective and even watering, these nozzles are timed to alternately travel from one plant to another. The system's incorporation of valves enables precise control of water flow, significantly minimizing water waste.

TeaBot offers a variety of off-roading capabilities in addition to its basic functions. It has the ability to effectively manage power consumption, maximizing its energy effectiveness for prolonged operations. The robot also employs computer vision coordinates to recognize and avoid obstacles in its path, boosting its capacity to function autonomously in challenging conditions.

In conclusion, the TeaBot robot is an important development in agricultural technology that addresses the demand for crop management that is precise, effective, and resource-conserving. It is a useful tool for modern agriculture since it can walk rows, deliver accurate irrigation, and verify watering accuracy. TeaBot is positioned as a promising option for boosting crop yields and sustainability in the agricultural industry thanks to its cutting-edge features and off-roading skills.

5 Conclusion

In summary, the creation and potential of the TeaBot robot presents a game-changing answer to the complex problems faced in contemporary agriculture, notably in the production of crops like tea and vegetables. The goal of this project was to address several important difficulties with agricultural practices, such as fertilization and watering, and to develop a flexible and dependable robot capable of carrying out these activities efficiently.

The TeaBot robot is unique in that it is adaptable to a variety of agricultural tasks, from ensuring the healthy growth and vitality of crops through irrigation to preserving soil fertility during dry spells. Its capability to successfully integrate water into the fertilization process and so expedite the process underlines its dedication to increasing agricultural efficiency.

In reality, products like tea and vegetables are painstakingly farmed according to exact guidelines. In order to effectively target and care for the right plants, TeaBot must be able to detect rows of plantations, a critical ability that mirrors human perception. TeaBot navigates its water nozzle component to each tea plant's stem with amazing precision by precisely recognizing tea plantation rows and delivering coordinates to the robot controller, maximizing the delivery of water and nutrients. During these procedures, the stationary camera, unaffected by the robotic arm's movements, provides precise positioning. Importantly, TeaBot's choice to use a stream of water rather than a mist spray reduces the possibility of damaging the leaves of tea plants when fertilizers are added to the water.

To ensure quick and accurate watering, TeaBot's revolutionary design also includes V-shaped watering nozzles with two sprayers on each side that are strategically coordinated. The efficiency of the entire irrigation process is increased by the coordinated movement of these nozzles and the addition of valves to control water flow and reduce waste. Since the two nozzles on the robot may move both vertically and horizontally, the weight control mechanisms on its arms give it versatility and adaptability.

TeaBot also demonstrates its dedication to seamless and autonomous operation in a variety of agricultural contexts through its off-roading capabilities, which include power utilization management and obstacle recognition by computer vision coordinates.

In conclusion, the TeaBot robot is an innovative example of agricultural technology that combines adaptability, precision, and resource efficiency. It is positioned as a possible option for increasing crop yields and improving agricultural practices because to its novel features, methodical approach to addressing agricultural difficulties, and commitment to sustainability. The promise of TeaBot goes beyond tea production, providing useful knowledge and resources for enhancing agriculture as a whole.

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7 APPENDICES

7.1 Plagiarism Report

APPENDICES 1:Playgiarism report

test

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

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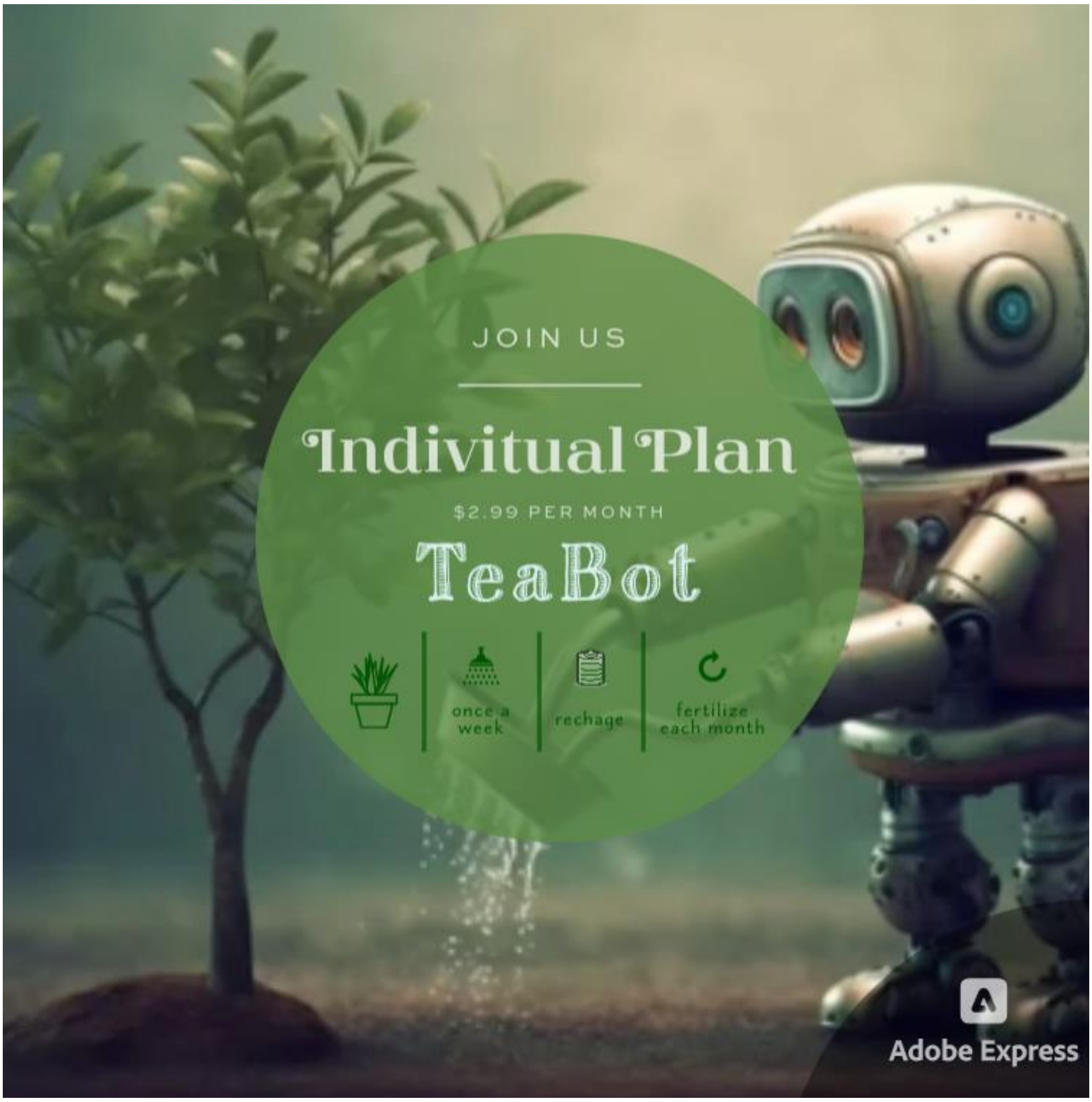
7.2 TeaBot Commercialization

APPENDICES 2: Hardware commercialization


JOIN US
Indivitual Plan
$2.99 PER MONTH
TeaBot
once a week
rechage
fertilize each month
Adobe Express

APPENDICES 4: Budget and justification

Item	Quantity	Amount (LKR)
Rubber wheels	4	4,000
Sprocket, chain and wheel (gear system)	4	10,800
Iron frame	1	15,500
Motors	4	14,000
43A Motor drivers	4	5,400
Raspberry Pi	1	90,000
12V 65Ah battery	1	45,000
12V 8Ah battery	1	5,000
Camera	3	15,000
Liquid nozzles	2	3,000
Servo motors	8	9,600
Total		**220,000**