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Abstract: *This paper presents the design and development of automatic planter of tree sapling specifically designed for tree planting on a remote and hazardous area. Traditional planting is labor-intensive, time-consuming, and inconsistent, while existing semi-automated planters still require human intervention. The machine integrates pneumatic actuators, stepper motors, and sensors to fully automate the planting process, from soil excavation to sapling placement with precise depth and spacing control. The machine demonstrates an application of embedded systems in agriculture include real-time monitoring, enhancing operational reliability in harsh environments.*

Keywords: *Agriculture, Automatic planter, tree sapling, Embedded system; Automation.*

1. INTRODUCTION

1.1 Background of the Study

The tree planting industry in Caraga Region is a significant part of the region's agricultural sector. While overall agricultural production in the region has experienced a slight decrease in recent years. Caraga remains a key player, particularly in the farming of coconut trees and falcata trees. Traditional planting is labor-intensive, time-consuming, and inconsistent, while existing semi-automated planters still require human intervention for tasks such as sapling separation, orientation, and placement, which negatively impacts profitability and productivity.

The evolution of agricultural machinery from early tractors to compact, versatile models like the Allis-Chalmers Model "B" 1937[1], demonstrates how mechanization can transform labor-intensive processes. Current automated planters offer substantial benefits, including 300-500% faster planting speeds and 20-30% higher sapling survival rates, but their designs are often optimized for uniform crops like rice, which benefit from consistent seedling morphology and predictable soil conditions. These systems struggle with the variability of tree saplings, which differ in size, root structure, and terrain requirements. This study bridges that gap by developing a fully autonomous tree planter that adapts proven mechanization principles while introducing innovations to handle irregular saplings and diverse environments. By integrating adaptive gripping mechanisms, terrain-compensating digging systems, and advanced sensors, the proposed system eliminates human dependency while ensuring precise, efficient planting addressing a critical need in global reforestation and sustainable land management efforts.

1.2. Objectives

With the statement of the problem in mind, this study aims to address the gap by designing and fabricating an automatic planter of tree sapling machine capable of enhancing tree-planting efficiency, timesaving and supporting environmental sustainability. The study also seeks to evaluate the machine's performance, particularly its accuracy, to determine it as a solution for tree planting in farming operations. Specifically, this study aims to:

1. Design and fabricate one (1) prototype automatic planter of tree sapling machine that plants up to 20 tree saplings.
2. To design a machine that can excavate the desired depth of the soil.
3. Evaluate and validate the performance of the automatic planter machine.

2. REVIEW OF RELATED LITERATURES

This chapter discusses the contents of the researcher's study, which may help to understand and broaden the definition of the entire system. It also comprises the framework of the system, block diagram, flow chart, hardware and software to be used.

2.1 Hand Planting Tree Sapling

The traditional method of hand-planting tree saplings involves several critical steps that remain labor-intensive and time-consuming. Workers first dig planting holes using basic tools like dibber bars or shovels, carefully ensuring proper depth and width to accommodate the root system. The sapling is then positioned vertically in the hole, taking care to avoid root bending or twisting that could stunt growth. After placement, soil is firmly packed around the roots to eliminate air pockets while maintaining adequate soil porosity for root development. The process concludes with immediate watering to reduce transplant shock and sometimes the application of mulch to retain soil moisture. While this method allows for careful individual attention to each sapling and adaptability to challenging terrains, its manual nature results in low productivity, inconsistent planting quality, and significant physical strain on laborers.

These limitations become particularly apparent in large-scale reforestation projects, where the manual approach struggles to meet planting targets efficiently, highlighting the growing need for mechanized alternatives that can maintain planting precision while dramatically increasing output. The physical demands and time constraints of manual planting underscore why agricultural mechanization has become essential for meeting global reforestation and climate mitigation goals.

2.2 Rice Transplanter

Rice transplanters were first developed in Japan in the 1960s, whereas the earliest attempt to mechanize rice transplanting dates to the late 19th century. In Japan, the development and spread of rice transplanters progressed rapidly during the 1970s and 1980s[2]. The rice transplanter consists of a seedling tray seedling, seedling tray shifter, pickup fork, and pickup fork mover. It will transplant the seedling uniformly without damaging them, and the planting depth and hill-to-hill spacing can be adjusted.

Either direct seeding or transplanting normally establishes experimental plots; when it is transplanter, it is either done manually or mechanized transplanting. Manual transplanting is labor intensive, and plant population and density are normally inconsistent; seedling are normally prone to transplanting shock because they must be uprooted from the nursery. Either direct seeding or transplanting normally establishes experimental plots; when it is transplanter, it is either done manually or mechanized transplanting. Manual transplanting is labor intensive, and plant population and density are normally inconsistent; seedling are normally prone to transplanting shock because they must be uprooted from the nursery[3]. Self-Propelled Rice Transplanting Mechanism has a diesel engine coupled with a single wheel. The diesel engine is the source to drive the wheel connected to it. It is a riding-type machine that transplants seedlings.

2.3 Sapling Planter Machine

Machine planting is best suited for level terrain that is not rocky or steep and free from many stumps and the tops and branches of recently harvested trees. The planter cuts roughly a ten-inch-deep furrow in the ground and then packs the soil around the seedling. One or two people will be seated in the planter placing seedlings in the furrow, so it needs to be pulled by a tractor. Machine planting is less labor-intensive than hand planting. It allows more seedlings to be planted per unit of time and can produce a higher survival rate of seedlings. It also permits precise spacing and planting depths.

2.4 GPS-guided Autonomous Robot Machine

Automating One example is the automatic navigation of agricultural machines, including tractors and combine harvesters. The development of electronics and the resulting decrease in the size of computers, and the simultaneous development of smarter chips and microprocessors, have greatly affected the agricultural industry [4]. The potential benefits of automated agricultural vehicles include increased productivity and accuracy, together with enhanced operational safety.

Improvements in data acquisition and transfer and the processing power of computers, as well as their ability to process huge quantities of data in very little time, have contributed to the increase in autonomous vehicle research[5].

2.5 Automatic Minisett Yam Planter

In Nigeria, yam minisetts are planted manually on mounds, beds, or ridges at distances of 25 cm apart. This gives about 40 000 stands/ha. Thus, manual planting of the minisetts entails very heavy back-breaking and time-consuming work, coupled with the very high labor intensity in yam production[6], [7].

2.6 Multi-mode Community precision seeder

Aiming at the sowing problem of low seeding efficiency, poor consistency and low level of machine intelligence in the seeding process of traditional community planter [8]. The rows in the community are simultaneously sown, the operation efficiency is high, and the difference in the external environment is brought to the breeding experiment. The beidou seeding mode in this system is based on the high-precision positioning technology of beidou [9].

2.7 Differentiate Between Pneumatic Actuator and Electric Actuator

Electric actuator systems can incorporate more delicate components like motors, encoders, and sensors, making them less suitable for hazardous environments. In contrast, pneumatic actuators are better suited for such environments, but it is essential to consider the ingress protection (IP) rating and specifications to understand the specific environment they can handle. Pneumatic actuators generally have a broader range of ambient temperature tolerance (-20~350°F) compared to electric actuators (40~150°F). However, when operating in high ambient temperatures, pneumatic actuators may experience air seal failures and sluggish performance. Similarly, high heat can impact the bearing grease life of an electric motor and affect the expansion properties of metal, leading to increased friction and wear in an electric actuator. Pneumatic actuators are known to produce more noise than electric actuators due to the use of compressed air. Nevertheless, advancements over the years have led to improvements in reducing noise levels.[10].

3. MATERIALS AND METHODS

The methods for gathering and analyzing data that are relevant to the research will be explained in this chapter. This includes outlining the general study framework, illustrating the system architecture, and setting out the data analysis procedures.

3.1 Framework with block diagram

Figure 1 below shows the block diagram of the machine. The microcontroller board processes the data received from the microswitch, the stepper motor driver that controls the stepper motors which controls the movement of the linear motion system and the conveyor, the air compressor for the pneumatic system. A data logger, GSM and RTC for monitoring the system.

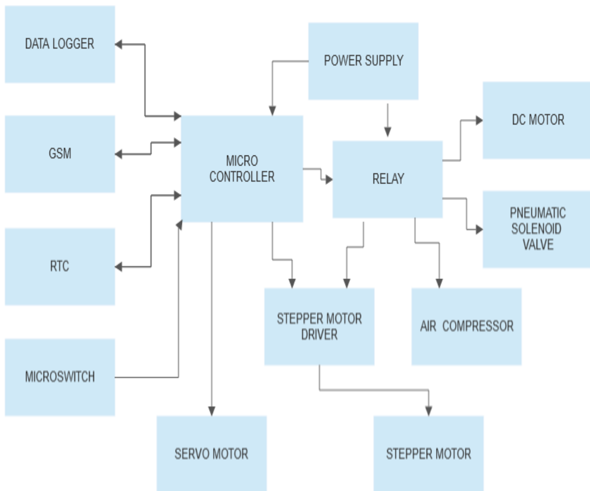

Figure 1. Block diagram of the Overall System

3.2 Schematic Diagram

The schematic diagram of the machine is shown in the figure 2. It shows the detailed connection of the components used in the system. The Arduino Mega 2560 as the main controller of the system. The stepper motors for the linear motion system and conveyor are each connected to a stepper motor driver. Switches for the position indicator of the linear motion system and pneumatic system.

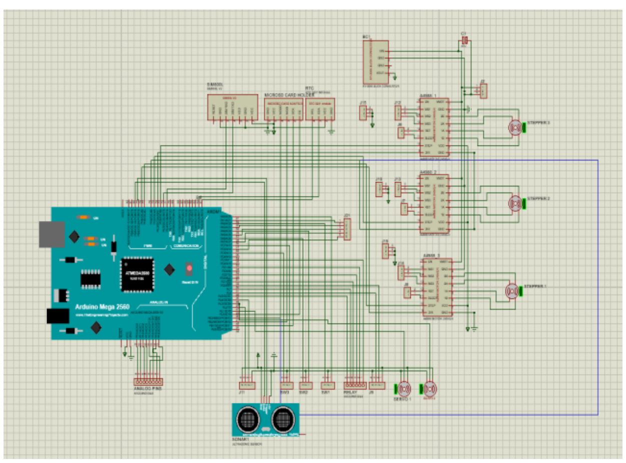
Figure 2. System Schematic Diagram

3.3 System Flowchart

In Figure 3, the loading area must be occupied and an input data from a separate machine must be read to start the system operation. Once the input data is read, the SD card initiates, and the planting mechanism starts. At the digging operation, the ultrasonic sensor initiates its operation, and the SD card records the ultrasonic sensors findings. At the planting operation, the system will count its row position, and the linear motion system moves the grabber according to its row count. If the row count is in row four, the first row will have no more plant saplings, and the conveyor will move forward one column. After the grabber has taken hold of the tree sapling, the linear motion moves backward, and the pneumatic system will propel the grabber downward and the grabber will release the tree sapling. After the planting operation is done, the linear motion and pneumatic system will reset its position to their origins.

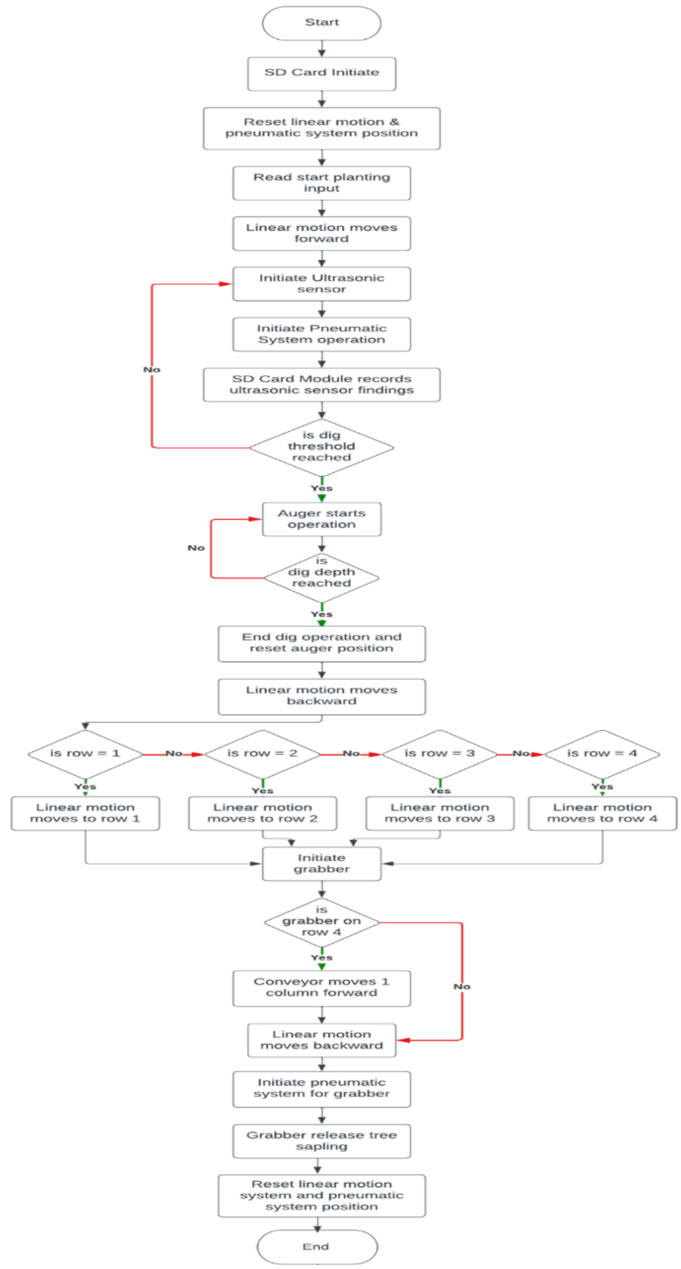

Figure 3. Flow Chart of the System

3.4 Software Aided Machine Design

Figure 4 shown are different perspectives of the software designed automatic tree sapling planter. The researchers used the software SketchUp in designing the 3D model of the machine. The isometric view of the overall design of the proposed automatic planter of tree sapling and its components that consists of a digger, tree sapling grabber, electronic component box, conveyor, tree sapling divider, chassis, and linear motion system. The researchers will use a rectangular steel tube as the chassis of the machine. The conveyor uses a plastic screen mesh with stepper motor to control its movement. The conveyor will occupy half a portion of the chassis. The other half will contain the linear motion system that will include the pneumatic system and the tree sapling grabber. The designed dimension of the automatic planter of tree sapling will have an overall width of 580mm and height of 522.82mm. The chassis will have a height of 80mm.

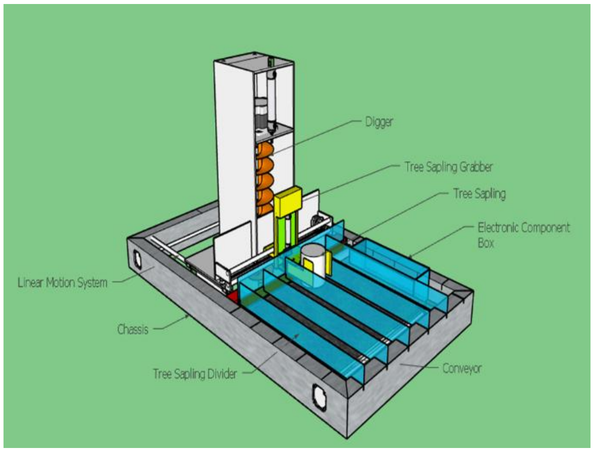

Figure 4. Isometric View of the System

3.5 Overall Proposed Design of Physical Construction

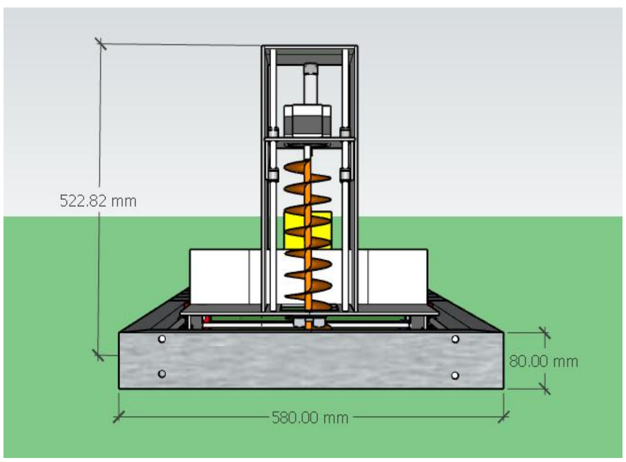

Figure 5. Propose Technical Drawing for the Machine's Design. (Front View)

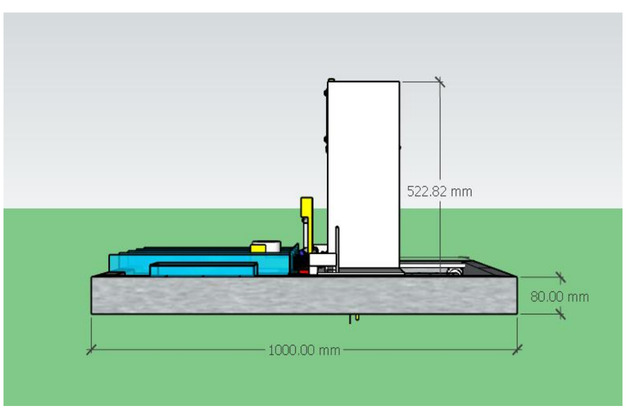

Figure 6. Propose Technical Drawing for the Machine's Design. (Side View)

4. RESULTS AND DISCUSSIONS

This chapter presents the results of the design, development, and evaluation of the automatic planter of tree sapling machine for small-scale agricultural farming. The actual figure of the constructed tree sapling planter device was presented first. The effectiveness of the prototype was measured through the data gathered from the series of trials conducted.To evaluate the performance of the machine, the researchers tested digging and grabbing accuracy, planting speed of tree sapling, and sensors detection precision. As well as with emphasis on its ability to offer mobility for small-scale operations.

4.1 Evaluation of System Design and Development
The automatic planter of tree sapling machine was designed and developed to operate effectively within the limitations of small-scale agricultural tree planting environments.

4.2 Hardware Components of Tree Planter Machine
The system was made up of mechanical, electrical devices and electronic components: LiFePO4 Battery [10], serves to as a power supply to the machine; an Arduino Mega 2560 [11], serves as a microcontroller, a Brushless DC Electric Motor (BLDC) [12] is an electric motor powered by a direct current voltage supply and commutated electronically instead of by brushes like in conventional DC motors, this serves to drive the digger and bore a hole. Micro SD Card [13] is used for storing data from the information taken from the data logger. Micro SDHC Mini TF Card Adapter Reader Module for Arduino, serves as card reader module for reading and writing through the file system and the SPI interface driver.
The ACS712 is a current sensor that can work in both AC and DC environments. This sensor runs on 5V and outputs an analog voltage proportionate to the current recorded. A collection of precision Hall sensors with copper lines make up this gadget [14]. A Real-Time Clock (RTC) is a computer clock that keeps track of the current time. A clock module is used to provide timing reference seconds, dates, and years to any microcontroller or computer[15]; NEMA 17 Stepper Motor [16], serves an incremental step rather than continuous rotation for the movement of the machine; an A4988 stepper motor driver is a microstepping driver with built-in translator that is designed to control and drive bipolar stepper motors [17]. The buck converter is a type of DC-DC converter that steps down the input voltage to a lower, regulated voltage. It can cover voltage from 9V to 36V and create an output to 5V, it gives low voltage supply to other electronic components[18].
The HC-SR04 Ultrasonic sensor is a device that uses sound waves to measure distance. It consists of two main components: a transmitter and a receiver. The transmitter emits high-frequency sound waves that bounce off objects in front of it, and the receiver detects the echoes of those sound waves. By measuring the time, it takes for the sound waves to travel to an object and back, the sensor can calculate the distance to that object[19].
On mechanical parts, A double-acting pneumatic cylinder is a device that converts compressed air energy into linear motion. It consists of a cylinder, a piston, and two ports for compressed air to enter and exit. Unlike a single-acting pneumatic cylinder, which uses air pressure to move in one direction and a spring to return to its original position, a double-acting cylinder uses compressed air to move in both directions. When air is supplied to one port, it pushes the piston in one direction,

and when air is supplied to the other port, it pushes the piston in the opposite direction [20]. A pneumatic solenoid valve is a device that controls the flow of compressed air in a pneumatic system. It consists of a valve body, a solenoid coil, and a plunger or spool that moves inside the valve body to open or close the valve [21].
This study uses an air compressor to supply compressed air to the pneumatic cylinder. This air compressor uses 12V as a supply and has a max pressure output of 140psi/ 10bar [22]. A micro switch, also known as a snap action switch, is a type of switch that is activated by a small force. It consists of a small lever that is actuated by a mechanical force, such as the opening or closing of a door, or the movement of a machine part. When the lever is actuated, it snaps into a new position, opening or closing a set of contacts that allow or interrupt the flow of electrical current[23].
This study uses a linear bearing platform for free motion in one direction. This linear bearing is designed for use of 8mm rod and contains a standard LM8UU bearing. The block has four tapped holes to attach to other hardware's used in the study[24]. A high-precision GT2 timing belt designed for use in linear motion systems was used. The belt has a width of 6mm [25]. a GT2 Timing pulley for precise motion control. This pulley is meant for use with the GT2 belt with 6mm width. This pulley has 36 teeth, and an 8mm inner bore. Two sets of screws used to attach firmly to an 8mm rod [26].
The design focused on making the system portable. Small-scale fish farmers often face challenges, such as limited access to equipment, small working spaces, the need to move equipment between locations, and the risk of manual errors. To address these issues, the machine was created with portability in mind, making it easy to transport. Additionally, the design allows for quick assembly and disassembly, ensuring that the machine can be easily set up and moved from one location to another.
The machine's portability is not just limited to being physical, but it is also functional. It is powered through a 12V battery, enabling it to function in locations without a source of power supply. This battery option is essential for remote fish farming operations where access to electricity may be limited. The machine's design also prioritizes minimizing setup time. With a keypad for adjusting thresholds and an LCD display for real-time feedback, operators can quickly customize the system to meet their specific needs. This easy-to-use setup requires minimal training, making it accessible to anyone. The straightforward design makes sure that even farmers with little technical knowledge can operate the system feasibly.

4.3 Construction of Automatic Tree Sapling Planter Prototype

The construction of the automatic tree sapling planter is shown in the following figures shown below. The automatic tree sapling planter shown in Figure 7 is fixed to a rectangular metal tube which is used as the chassis of the prototype by the researchers. The tree sapling conveyor is controlled by a stepper motor and acrylic sheet is used by the researchers as the tree sapling dividers. The linear movement system is also includes the pneumatic system for the digger and the tree sapling grabber of the prototype. The air pump that supplies pressurized air for the pneumatic system is fixed near the pneumatic cylinders.
Figure 7 below shows the finished construction of the automatic tree sapling planter. The researchers cut and welded a rectangular steel tube together to create a rectangular chassis. Construction of the linear motion system is done after the chassis. Steel rods are fitted into pillow block and mounted ball bearings. Aluminum plates that hold the grabber and pneumatic system is fixed to the steel rod by a linear bearing platform.

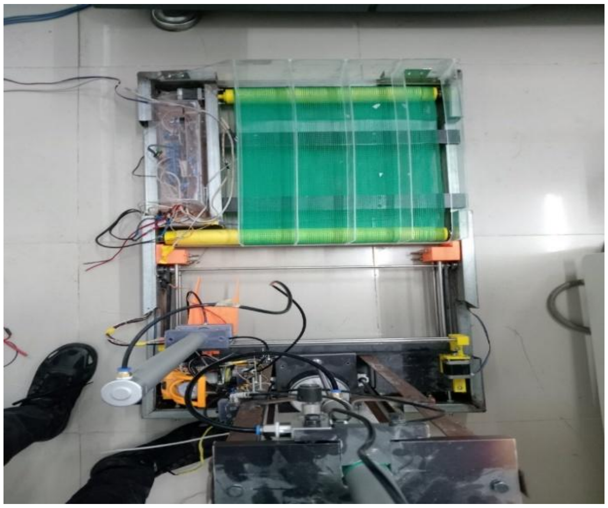

Figure 7. Automatic Tree Sapling Planter Prototype

The conveyor is then constructed, and the material used is a PVC pipe enclosed by a rubber mat and a plastic screen mesh. Acrylic sheet is then cut for the divider of the tree saplings. The conveyor has a dimension of 40 cm in width and 45 cm in length. The dividers are 10 cm apart from each other. The researchers have set aside a space next to the conveyor for the electrical component. The material used for the casing of the electrical component is a cut acrylic sheet. Researchers used steel rods and linear bearing platforms for guides of the aluminum plate. The aluminum plate holds the air pump on the right side and a stepper motor on the left side as shown on Figure 7. Angle bars stand on the aluminum plate serves as holder for auger for the digger and the pneumatic cylinder that thrusts the auger downward.

4.4 Testing and Calibration of Ultrasonic Sensor

In this study the ultrasonic sensor is being used to measure the distance of the auger drill to the ground. The ultrasonic sensor is attached to the plate for the DC motor for the digger and the device is connected via USB cable to monitor the measurement. The sensor measurement results will be compared with the measurement measured manually the distance of the sensor to the ground surface by using the meter.
Ultrasonic sensor test results as a height meter can be seen in the table 1. From the table 1 can, be seen that the difference between the measurement of the sensor with manually measurement results by comparing the actual measure of height and the measured value from the ultrasonic sensor.

Table 1. Test Result of Ultrasonic Sensor

Test #	Distance Measured by Meter Tape	Distance Measured by Ultrasonic Sensor	Accuracy
1	107	103	96.26%
2	100	97	97%
3	95	92	96.84%
4	90	87	96.66%
5	85	81	95.29%
6	80	76	95%

4.5 Device Setup and Testing for Linear Movement System Test

The linear movement of this study was tested. The test was conducted with the system on operation in repeated cycles. The system was observed if the repeated cycles had consistency and if the mechanism was stable. In those repeated tests, the grabber was observed if it would insert consistently on the tree sapling dividers with a constant distance between the dividers and the grabber. The conveyor was to move forward one column after each cycle has reached the fourth row.

4.6 Testing of Linear Movement System Accuracy

A test was done on the accuracy of the linear movement system. The researchers set the parameters and to observe the grabber of the system and found out that it positions itself precisely to the position in between the tree sapling dividers. The grabber and divider have a distance of 5~7-millimeter clearance.

5 . CONCLUSION AND RECOMMENDATIONS

This part of the study includes the conclusion and recommendations of the researchers with regards to the current study. The conclusions and recommendations made were based on the results of the experiments conducted and the previous studies established related to the current study.

5.1 Conclusion

In addition to the aforementioned features, the researchers also implemented Data logging to monitor the tree sapling planter. The data provide planting depth. The construction of the automatic tree sapling planter involved careful consideration of the available resources and manufacturing capabilities. The researchers utilized milling machines, welding equipment, and basic shop tools to fabricate various components of the device. These capabilities enabled them to create components from bars, sheets, and cylinders, as well as perform simple machining processes. However, due to limitations in complex machining, the design of the prototype relied on fasteners to join parts together. This design choice facilitated quick assembly times compared to welding and offered the advantage of easy repair and adjustment during testing. Certain components such as frame components, gears, and bearings were sourced from off-the-shelf suppliers for the prototype. This approach aligns with the potential commercial application of the device, as these components are typically readily available in the market. By incorporating commercially available parts, the researchers ensured that the prototype's construction and functionality mirrored what would likely be done in a commercial setting. This further supports the scalability and feasibility of the automatic tree sapling planter for wider implementation in the future.

5.2 Recommendations

Based The researchers strongly recommend the implementation of an improved grabber mechanism and the utilization of superior materials to enhance the effectiveness of holding and dropping the tree sapling into the excavated hole. By focusing on the design and material aspects, the overall tree planting process can be significantly enhanced, leading to improved success rates and ecological restoration outcomes.

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