DESIGN AND DEVELOPMENT OF AUTONOMOUS SAPLINGS PLANTATION ROBOT FOR AFFORESTATION

[1]G Dorababu, [2] R Ashok Kumar Reddy, [3]Sunkesula Apsar, [4]devireddy Jayaprakash Reddy [5] Madhu B P
[1,2,3,4]Student, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India
[5]Assistant Professor, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India

Abstract — The main objective of our project is to minimize human involvement in tree planting. With the rapid increase in human population, dependency on the environment has grown significantly, leading to large-scale deforestation and a decline in green cover. At the same time, labor shortages and the urgent need to increase forest density have created a strong demand for innovative planting solutions. To address this, we propose the development of an automatic tree planting machine that can efficiently transplant seedlings with minimal human effort. Tree planting typically involves transplanting seedlings for purposes such as forestry, land reclamation, and landscaping. Unlike conventional manual planting methods, our machine is designed to plant seedlings continuously without halting, thereby improving speed, reliability, and large-scale forestation efforts.

This project aims to support environmental sustainability by reducing deforestation and enabling large-scale reforestation with greater efficiency.

Keywords – Tree planting, forestry, route planning, regeneration, Auto plant.

I. INTRODUCTION

Rising global temperatures, deforestation, and the degradation of natural ecosystems have pushed humanity to the brink of ecological instability. Forests are one of the most vital natural resources, serving as carbon sinks, preserving biodiversity, stabilizing the water cycle, and protecting the soil. However, with millions of hectares of forest lost annually due to urbanization, industrialization, and agriculture, afforestation has become a vital strategy for restoring ecological balance.

Traditional methods of plantation often involve manual labor, are time-consuming, and can be inefficient, especially in regions with difficult terrain or limited accessibility. Moreover, largescale afforestation campaigns require immense manpower and planning. Considering these challenges, automation presents itself as an innovative and scalable solution. The integration of technology in the field of environmental restoration can dramatically increase efficiency, consistency, and effectiveness in planting trees.

The increasing urgency to address climate change, biodiversity loss, and deforestation has led to a growing emphasis on large-scale afforestation and reforestation programs across the globe. Forests not only serve as the lungs of our planet, absorbing carbon dioxide and releasing oxygen, but also play a pivotal role in preserving ecological balance, conserving water bodies, maintaining soil health, and supporting biodiversity. In recent years, the degradation of natural forests due to industrialization, urbanization, and unsustainable agricultural practices has resulted in a significant decline in forest cover. Governments, environmental organizations, and international agencies have recognized the importance of reversing this trend by implementing afforestation initiatives aimed at restoring degraded lands and enhancing green cover. However, the traditional methods of planting trees, which are heavily reliant on manual labor, have proven to be increasingly inefficient, expensive, and unscalable, especially when it comes to achieving the vast reforestation targets set by various environmental bodies. These traditional processes involve digging individual pits, planting saplings by hand, and manually covering the roots with soil a time-consuming and labour-intensive approach that is often impractical for large- scale applications.

Tree plantations, often referred to as forest plantations or tree farms, have emerged as a solution to meet the growing demand for timber, biomass, and ecological restoration. These plantations are generally monocultures, where one or two selected species are planted and maintained in a systematic and controlled manner. While plantation forestry has its share of ecological limitations, it remains a vital strategy for increasing forest area, particularly in regions with severely depleted natural forests. Plantation forests are commonly cultivated by both government agencies and private entities, including paper, wood, and pulp industries. In several countries, industrial plantations have replaced natural forests for the sake of commercial timber production. These plantations can be highly productive, with genetically modified or selectively bred species designed for fast growth, disease resistance, and optimal wood yield. Despite these benefits, the actual act of planting trees in these systems still suffers from the inefficiencies of manual labour and poor mechanization, particularly in developing countries where advanced equipment is often inaccessible or cost prohibitive.

To address this gap, the idea of an autonomous or semi-autonomous sapling plantation machine has emerged as a viable and innovative solution. The primary objective behind designing and developing such a machine is to automate the most labor-intensive tasks involved in the tree planting process. This includes digging the pit, placing the sapling, and covering the roots with soil, all executed in a continuous, consistent, and precise manner. The autonomous plantation machine is envisioned to work on rough terrains, under diverse environmental conditions, and with minimal human supervision. Such a system holds the potential to drastically transform how tree planting operations are conducted, especially in remote or difficult-to-access areas, where mobilizing manual labor is a challenge.

Figure 1: Deforestation vs Afforestation

Figure 2: Tree Plantation Machine

Modern automation technologies like robotics and embedded systems are paving the way for a new generation of agricultural and environmental machinery. Inspired by the same principles, the autonomous sapling plantation machine utilizes a combination of hardware and software to mimic human functions as shown in figure 1 and 2, but with greater speed, accuracy, and endurance. For instance, the use of Arduino or Rely microcontrollers enables real-time decision-making based on preprogrammed instructions and sensor feedback. This allows the machine to detect soil consistency, maintain fixed planting intervals, and ensure correct planting dept all of which are essential for the healthy growth of saplings. The mechanical setup, which includes digging arms, soil hoppers, and sapling dispensers, works in coordination with the control system to perform each step in the plantation process. The machine may also include solar panels or rechargeable batteries, further enhancing its sustainability and reducing reliance on fossil fuels.

II. PROBLEM IDENTIFICATION

- The conventional manual methods of tree plantation are often labour-intensive, time-consuming, and prone to inconsistencies, which can result in reduced efficiency and less-than-optimal planting outcomes.
- This project seeks to overcome these limitations through the design and development of an automated tree plantation machine that streamlines and enhances the planting process.
- The system is intended to accurately plant saplings at predetermined locations, considering critical factors such as soil conditions and environmental sustainability.
- By integrating automation into afforestation efforts, the project aims to significantly improve the speed, precision, and effectiveness of tree planting activities, thereby supporting environmental conservation and promoting sustainable land management practices.

III. LITERATURE REVIEW

A literature review is a survey of scholarly sources on a specific topic. It provides an overview of current knowledge, allowing us to identify relevant theories, methods, and gaps in the existing research.

We have surveyed the following papers in context to our Project,

Veerabhadra Ronad et, al (2024): Tree planting involves transplanting seedlings, primarily for purposes such as forestry, land reclamation, or landscaping. This method is distinct from arboriculture, which focuses on transplanting larger trees, and from seed distribution, which is more affordable but less efficient and slower in establishing tree cover. This concept includes several integrated subsystems: regeneration and route planning, autonomous navigation (path planning), eco-friendly planting technology, automated seedling handling, crane motion planning, planting spot detection, and post-planting monitoring. Each subsystem was initially tested independently and later brought together for integrated field testing on a clear-cut site. The results are highly promising, especially in terms of environmental impact. The new system significantly reduces soil disturbance—from about 50% with traditional disc trenching methods to under 3% using the autonomous approach. The Auto Plant project also sheds light on the challenges and future possibilities in this field, such as balancing machine cost with operational efficiency, improving sensor durability against vibrations and weather conditions, and enhancing the precision of obstacle detection during autonomous movement and planting activities [1].

Linnea J. Hansson (2024): Sustainable forestry depends on effective regeneration methods to ensure rapid establishment of new forests. In Sweden, 99% of tree planting is still done manually, but recruiting labour for this physically demanding work is increasingly challenging. An autonomous machine capable of scarifying and planting with high precision, minimal environmental impact, and improved working conditions would greatly benefit the forest industry. Over the past two years, a collaborative team of researchers, manufacturers, and forestry companies has been developing and testing a new concept for autonomous forest regeneration, known as Auto plant. This system includes several integrated subsystems: regeneration and route planning, autonomous navigation (path planning), environmentally friendly regeneration technology, automated seedling handling, crane motion planning, planting spot detection, and post-operation monitoring. Each subsystem was initially tested independently and later integrated for a full-scale field test on a clear-cut area. The concept demonstrated strong potential, particularly in terms of environmental benefits. Soil disturbance was significantly reduced from about 50% with traditional disc trenching methods to less than 3% using the Auto plant system. The project also shed light on both the challenges and opportunities ahead, such as balancing machine cost with operational speed, ensuring sensor reliability under harsh conditions like vibration and weather, and enhancing the accuracy of obstacle detection during autonomous navigation and planting [2].

Ola Lindroos (2023): autonomous forwarding tasks. By integrating advanced computer vision, autonomous navigation, and manipulator control algorithms, the machine can identify and collecting logs from the forest floor and navigating various types of terrain all without human input. Initial testing demonstrated promising results, showcasing both the safety and efficiency of the machine in the cut-to-length timber harvesting process. The computer vision system delivered high accuracy in log detection, while the navigation system performed reliably across different environmental conditions. This research marks a major advancement in autonomous outdoor robotics and suggests a transformative future for the forestry sector. Autonomous machines like this could significantly boost productivity, lower labour costs, and reduce the environmental footprint of timber extraction. The success of this project underlines the potential for continued innovation and refinement of autonomous solutions in forestry operations [3].

Paweł Tylek (2023): The objective of the project was to design an autonomous robot and develop an innovative technology for planting forest crops and afforesting reclaimed and former agricultural land. As part of the project, the machine's functionality and operational constraints were defined, enabling the creation of a virtual 3D CAD model of the platform and its working modules. Simulation tests were conducted, computational models were created, and engineering analyses of the machine's structure were performed. Based on these results, technical documentation for the prototype of the mobile automated device was developed. Research models of the platform and its working units were then constructed and subjected to operational testing in both laboratory settings and real-world conditions [4].

Morgan Rossander [2023]: Reforestation, typically carried out after final felling, is a critical and often legally required step to ensure the sustainability of wood production. In Sweden alone, more than 400 million seedlings are planted each year. This task is physically demanding, and the resulting quality can vary. As a result, research and development efforts are underway to create automated planting systems. This paper presents one such effort: the development and evaluation of a mission supervisor designed to control the tasks and behaviour of a full- scale autonomous forest regeneration machine operating in realistic field conditions. The mission supervisor is built using the Robot Operating System (ROS) framework, leveraging a finite state machine package known as SMACH. The system is deployed on a terrain-capable research platform equipped with a full-scale forwarder crane. We begin by outlining the planting scenario and defining the composite tasks required, each represented as a state. A simplified simulator provides an intermediate testing phase before moving to field trials. The mission supervisor is then implemented and run in real time on the full-scale machine [5].

Marek Szychta (October 2022): Forest regeneration using seedlings grown in container nurseries is typically carried out manually, employing standard tools such as the dibble bar or tube dibble. This process, involving the manual placement of numerous seedlings into the soil, is labor-intensive. Under average conditions, manually clearing the soil surface and digging planting spots with a 0.4-meter diameter requires approximately 38 man-hours per hectare. Planting with a dibble bar takes around 34 man-hours per hectare, not including the additional time needed to transport seedlings across the afforestation site. Currently, forestry lacks automated planters capable of efficiently establishing forest plantations. This paper introduces the concept of an autonomous robot, and an innovative technology designed for forest regeneration and the afforestation of former agricultural and reclaimed lands. It also outlines the design of a key working component a universal, openable dibble integrated with a threetoothed shaft that prepares planting spots. This proposed solution allows for continuous machine operation, eliminating the need for the base vehicle to stop during planting [6].

Mohammed Amer, et al. (2020): The agricultural sector contributes over 25% to Palestine's total gross domestic product and employs more than 15.2% of the population in the West Bank and Gaza Strip. With more than 1.854 million dunums of cultivated land, agriculture remains a vital part of the national economy. Despite its importance, traditional planting methods are still widely used, resulting in significant time, effort, high costs, and frequent transplant losses. This study presents the development of an automated planting machine designed to support and modernize Palestine's agricultural sector. The machine aims to improve the efficiency and accuracy of planting operations by automating the key steps of cultivation and gently placing transplants into the soil. The design of the machine considers the types of crops commonly grown in Palestine, factoring in plant dimensions and the required spacing between seedlings. Simulation and experimental tests of the prototype demonstrated that the machine operates accurately and smoothly. It effectively completes the full planting process from ploughing to planting and soil covering with precision and consistency. This innovation addresses critical challenges in the sector by reducing labour demands, cutting costs, and saving time, ultimately helping meet the practical and economic needs of local farmers [7].

Olimpia PANDIA et al. (2014): The section is equipped with a mechanism that enables the transmission of movement to several components, including potholders. These holders maintain a consistent vertical position relative to the soil surface, regardless of the terrain slope. Movement is transmitted via a Gall chain from a soil- tracing wheel, and the system allows for adjustment of the spacing between plants within a row. This section can be integrated into a seedling planting machine capable of planting in 1–2 rows on terrain covered with foil mulch, or in 1 to 6 rows on uncovered ground. Additionally, it can serve as part of a multifunctional agricultural unit used for soil preparation, laying foil mulch, or installing irrigation hoses during soil treatment. The motion transmitted from the soil-copying wheel includes the capability to adjust the rotation rate, which in turn allows for customizable spacing between rows. Furthermore, the components supporting the potholders can be adjusted in length to help achieve the desired plant spacing [8].

IV. SUMMARY OF LITERATURE REVIEW:

Tree Plantation drives combat many environmental issues like deforestation, erosion of soil, desertification in semi-arid areas, global warming and hence enhancing the beauty and balance of the environment. Trees absorb harmful gases and emit oxygen resulting in an increase in oxygen supply. On average, a single tree emits 260 pounds of oxygen annually. Similarly, a fully-grown tree is sufficient for 18 human beings in one acre of land in one year stressing the importance of tree plantation for mankind. Machine planting is another common planting method in India. Equipment and transportation costs are such that machine planting is generally used for larger acreages where reduced labour cost and high planting productivity are desired.

V. RESEARCH GAP:

1. Lack of Region-Specific Plantation Strategies as There is insufficient research on selecting the most suitable tree species for dry and eroded areas to optimize food production, environmental impact, and economic value.
2. Limited Validation of Water-Saving Technologies like Grouses Ecological Water Saving claim high efficiency, but lack independent, long-term studies across different soil and climate conditions to confirm their effectiveness.
3. Insufficient Socioeconomic and Scalability While tree planting is linked to job creation and rural development, there's a lack of detailed research on actual economic impact, technology adoption challenges, and scalability in low-income regions.
4. Weak Integration Between Afforestation and Food Security Goals as this current research lacks comprehensive models connecting tree planting, food production, and long-term food security, especially in the context of growing populations and climate change.

VI. OBJECTIVES OF THE PROJECT:

In the literature review, it is found that there is a scope for automated tree plantation machines. This research gap found in the literature review can be solved with the following objectives:

- To design and fabricate an autonomous machine capable of efficient and precise sapling plantation for afforestation in diverse terrains.
- Carry out frontline demonstrations of innovative farm implements and machinery in real farming environments. These demonstrations will assess their performance, promote adoption, and support widespread usage under local conditions to close existing mechanization gaps.
- To evaluate the performance of the developed system in terms of planting accuracy, efficiency, and adaptability to real-world afforestation scenarios.

VII. METHODOLOGY:

The methodology of this project begins with a clear definition of objectives, outlining specific goals, performance benchmarks, and expected outcomes. This foundational step establishes a strategic roadmap for the entire design and development process. Next, a comprehensive literature review is conducted to gather valuable insights from existing research, technologies, and best practices related to tree plantation machinery, automation techniques, and sustainable afforestation efforts. This phase acts as a knowledge foundation, informing subsequent decisions and strategies. Following the literature review, brainstorming sessions are held to encourage creativity and generate innovative concepts. These sessions prioritize design ideas that enhance efficiency, support automation, and align with environmental sustainability. With conceptual ideas in place, detailed engineering designs are developed using CAD tools. These technical blueprints outline mechanical specifications, system layouts, and component structures. Simultaneously, careful consideration is given to material selection, focusing on options that provide strength, durability, light weight, and eco-friendly characteristics to support sustainability objectives. The fabrication phase then follows, where the prototype is built using techniques such as welding, machining, and assembly in accordance with the finalized design. Finally, rigorous testing and validation are carried out to assess the prototype's performance, safety, and compliance with design standards. This critical evaluation phase supports iterative refinement and optimization, ensuring enhanced functionality, reliability, and effectiveness of the tree plantation machine.

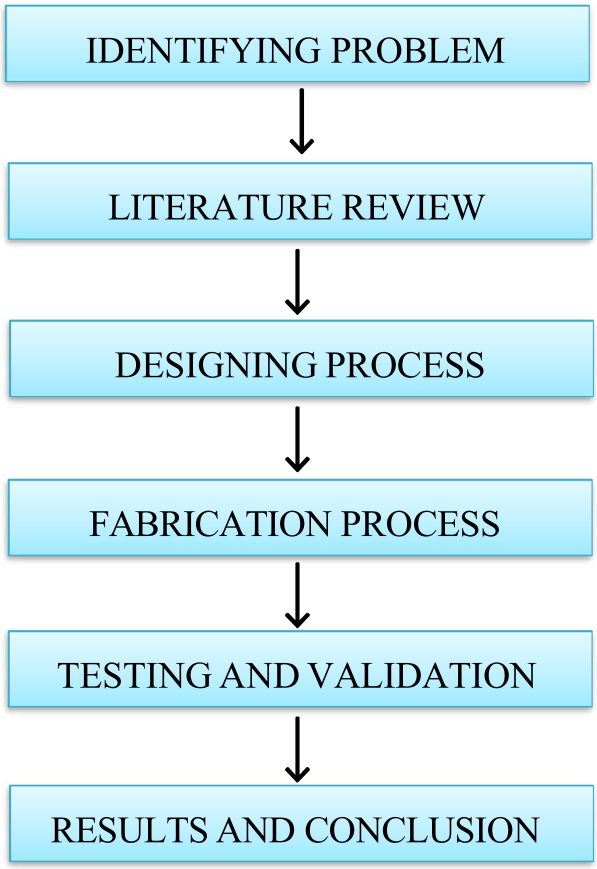

Figure 3: Methodology Flow Chart

Figure 3: shows the methodology followed to carry out project work.

- Identifying Problem: Clearly define the project objectives, including goals, performance expectations, and desired outcomes. This step sets the direction for the entire project.

- Literature Review: Conduct in-depth research on existing technologies, automation techniques, and sustainable practices related to tree plantation. This helps build a strong knowledge base to guide the design.
- Designing Process: Generate innovative ideas through brainstorming. Develop detailed CAD models and engineering drawings. Choose materials that are durable, lightweight, and eco-friendly.
- Fabrication Process: Build the prototype using processes like welding, machining, and assembly, based on the finalized design and selected materials.
- Testing and Validation: Test the prototype to ensure functionality, safety, and performance standards are met. Refine and improve the design based on test results.

- Results and Conclusion: Analyse the testing outcomes, summarize the results, and draw conclusions about the machine's effectiveness, reliability, and impact on afforestation efforts. Figure 3 shows the methodology of the project work carried out.

VIII. LINE DIAGRAM

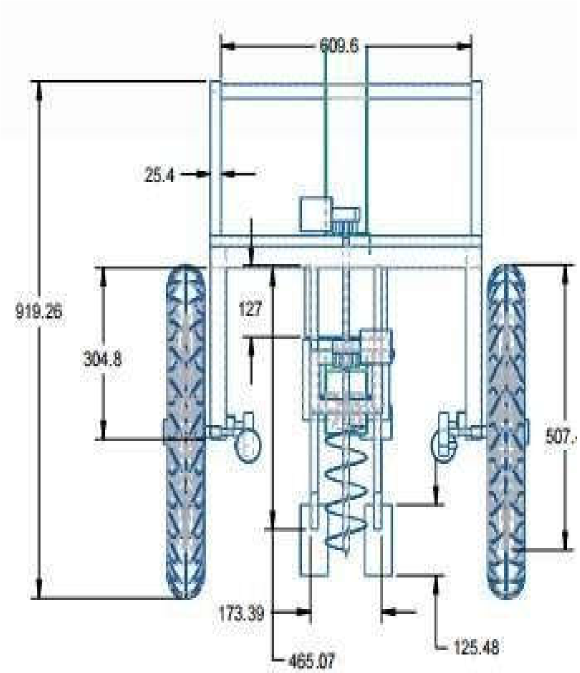

Figure 4: Front View Line diagram of the Machine

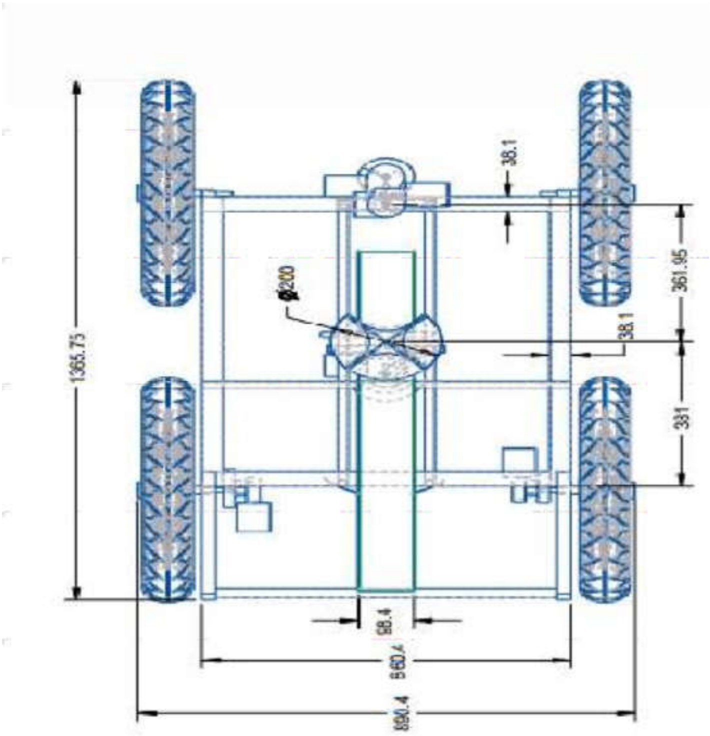

Figure 5: Top View Line diagram of the Machine

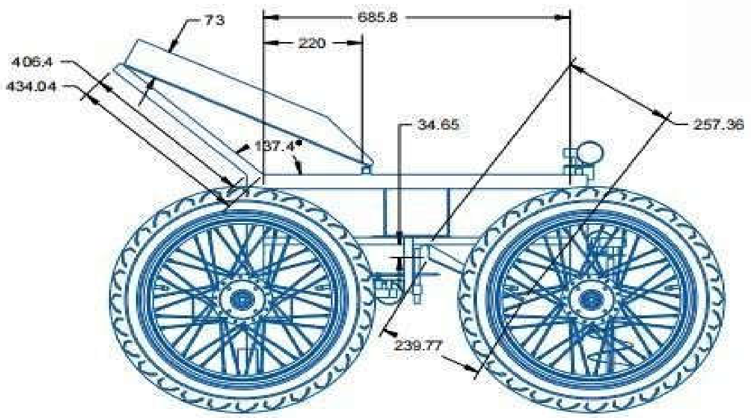

Figure 6: Side View Line diagram of the Machine

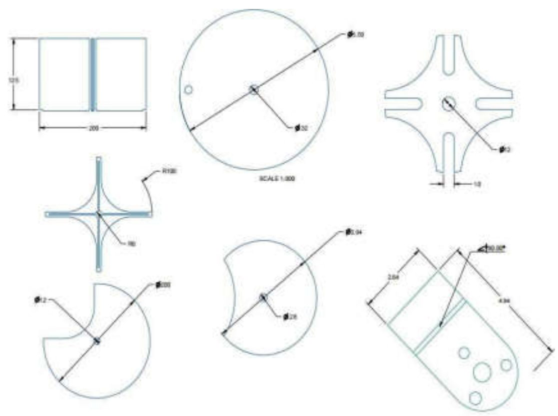

Figure 7: Assembly Parts of the Machine

IX. Results and Discussion

The principal operation of the developed tree plantation machine prototype, as shown in Figure 8, revolves around optimizing manual efforts through mechanical and electronic automation. The process begins with land preparation, which is critical to ensure healthy plant growth. It involves clearing debris, leveling the soil, and ensuring adequate ventilation—steps that greatly affect sapling survival rates.

Figure 8: Tree plantation machine prototype

In the modified version of the machine, we have mechanically enhanced the planting system by integrating a rotating drill bit, which eliminates the need for traditional plowing mechanisms. This drill bit autonomously creates uniform holes in the soil to a fixed depth, ensuring consistency across all planting spots.

The machine operates in a semi-automatic manner manual initiation is required, but once the process starts, it runs in an automated cycle. A key enhancement in this prototype is the integration of Arduino microcontroller logic with relay-based timing circuits. These allow for the precise control of the planting sequence, including time delays between steps to ensure synchronized operations. This not only simplifies the user's role but also reduces human error and increases operational consistency.

In contrast to previous prototypes which relied on manual timing or simple switches, this version utilizes Arduino-controlled logic to manage seedling release, drill operation, and the timing of the entire planting cycle. While a PWM controller still regulates motor speed, the inclusion of automation components such as relays ensures the process follows a programmed sequence without requiring operator input after initiation.

During initial testing, the prototype took approximately 2 to 3 minutes to plant a single sapling. While this duration is longer compared to earlier versions which focused more on seeding, our version is designed for planting live saplings, which requires precision and care in hole formation and placement. These tests also demonstrated smooth motor coordination, efficient drill performance, and accurate sapling deployment.

The overall cost of the complete machine stands at around ₹35,000, including approximately ₹2,000–₹3,000 for the Arduino and automation module. Despite the limited number of trial runs, the initial performance suggests that the machine is technically feasible, cost-effective, and highly adaptable for future enhancements.

The mechanical simplicity, combined with Arduino-based automation, makes this model an excellent solution for small to medium-scale tree plantation projects. Moreover, the use of common components and low-cost electronics makes it suitable for rural implementation without requiring expert maintenance or programming knowledge.

In the broader context, this machine bridges a crucial gap in existing solutions which are either seed-oriented or manually intensive. Compared to conventional methods that require approximately 5minutes or more per sapling and multiple laborers, this machine provides an autonomous option that minimizes workforce dependency and can operate efficiently with just one operator.

Looking forward, additional upgrades such as real-time monitoring using sensors, solar charging systems, and automated sapling feeders can be considered to further reduce operational time and improve efficiency.

The cost analysis for the tree plantation machine project encompasses various aspects, including material costs, labour costs, equipment costs, and operational expenses. A detailed breakdown of these costs is essential for assessing the project's financial feasibility and budgeting effectively.

On an average labour cost of 100 rupees for planting 1 sapling and 100 saplings per day including food and transportation charges:

1. Time Saved per Tree: Time saved per tree = 1800 sec (30 minutes) (manual labor time) – 300 sec (5 minutes) (machine time)
2. Time Saved for 400 Saplings:

Time saved for 400 saplings = Time saved per tree * Number of saplings = 30 minutes/tree * 400 trees = 720,000 seconds/day = 200 hours

3. Cost Savings per Day:

Total time saved per tree = 1500 seconds = 25 min per tree

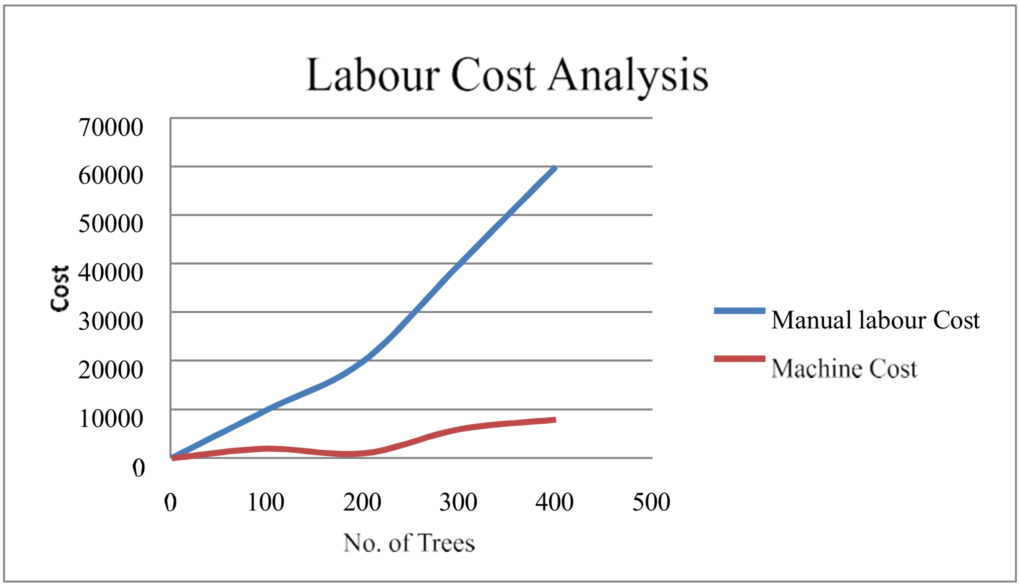

Figure. 9: Labor cost estimation of tree plantation

Labor cost per day = 500 rupees Cost savings per day = Labor cost per day * Total time saved = 500 rupees per day * 25 minutes= 12,500/- rupees/day

Manual labour per plants is estimated as Rs 100 and using machine cost of plant planted is Rs 20. By this calculation it is notice that cost of each plants saves Rs 80 and 80% of amount will be saved using tree plantation machine.

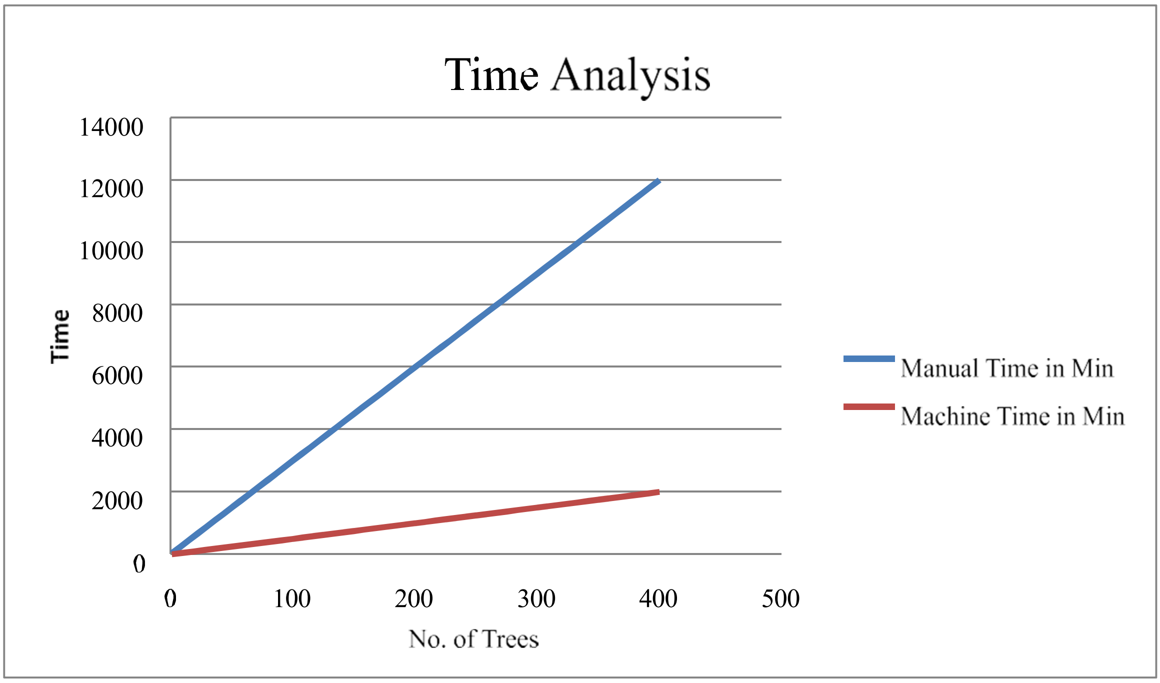

Figure 10: Labor Time estimation of tree plantation

Figure 10 shows time estimation of tree plantation time taken by this calculation it is notice that time taken of each plant 5 min in the machine and 30 min time was taken by manual labour to plant per tree.

Table 1: Plantation time calculations

No. of Plants	Manual Time in Min	Machine Time in Min
1	30	5
100	3000	500
200	6000	1000
300	9000	1500
400	12000	2000

X. CONCLUSION

The presented project showcases a semi-automatic tree plantation machine designed to bring innovation and efficiency to modern agricultural practices. Building upon prior research and prototypes, the current version introduces a mechanical drill bit for precise hole creation and an Arduino-based automation system that regulates the planting cycle through timed relay controls. These advancements allow for consistent, accurate planting with minimal human intervention once the process begins.

1. The modified machine, equipped with a motorized drill bit and time-controlled planting system, ensures accurate and efficient sapling placement in prepared soil beds.

2. Compared to manual methods, this prototype shows notable improvements in labour savings and operational consistency, though current planting time (3–4 minutes per sapling) is still being optimized.

3. The system remains user-friendly, initiated by simple DPDT switches, after which the Arduino microcontroller manages the planting sequence without requiring further input.

4. Initial tests demonstrated stable performance and mechanical reliability, with no significant faults observed during short trial runs.

5. By promoting precise planting with minimal soil disruption, the machine contributes to environmentally conscious afforestation and reforestation practices.

6. Future development will focus on reducing planting time, increasing automation through additional sensors, and enhancing sapling feeding mechanisms for improved scalability.

7. This project also emphasizes the importance of integrated engineering disciplines, including mechanical design, embedded systems, and agricultural science, in addressing climate and ecological concerns.

8. Ultimately, this machine has the potential to transform traditional tree plantation practices, making large- scale afforestation more affordable, consistent, and less labor dependent—thus aligning with global sustainability and reforestation goals.

9. The use of low-cost, easily available components such as Arduino, relays, and mild steel makes the machine accessible and financially viable for small-scale farmers and NGOs working on plantation drives.

10. The modular design of the machine allows for easy maintenance and upgradability, enabling future adaptations such as solar power integration or GPS-based navigation for autonomous field mapping.

11. By reducing dependency on skilled labour and enabling consistent planting operations, the machine supports community-driven reforestation programs, particularly in regions facing labour shortages or challenging terrains.

XI. FUTURE WORK

1. It can be developed for forest plantation, enabling mass afforestation in remote or inaccessible terrains with minimal human intervention.

2. It can be developed into a fully automated plantation machine using IoT for remote control, monitoring, and real-time data logging.

3. Integration of GPS and GIS technologies can help in mapping large agricultural lands and ensuring precision-based planting along predefined paths.

4. A sapling feeder mechanism can be introduced for automatic loading of saplings into the planting system, further reducing manual effort.

5. Solar-powered operation can be introduced to enhance energy efficiency and make the machine sustainable for use in off-grid areas.

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