Design and Development of an Automated Multi-Vegetable Transplanter for Precision Agriculture

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Abstract- **The increasing demand for efficiency in agriculture has emphasized the need for automation in transplanting operations. This research presents the design and development of an** automated multi-vegetable transplanter **capable of planting various saplings with uniform spacing and depth. The machine integrates a precision pick-up mechanism, Geneva drive conveyor, digging and soil covering systems, and a programmable logic controller (PLC) to automate sapling transfer from tray to soil. The system is tractor-mounted and powered partially by ground wheel motion, with electronic control systems driven by a lead-acid battery. Key innovations include adaptability for various crop types, a modular framework, and integrated sapling irrigation. The prototype demonstrated promising performance in reducing labor costs, improving planting consistency, and supporting sustainable farming practices.**

Keywords-**Automated transplanter, agricultural mechanization, sapling pick-up, Geneva mechanism, vegetable transplanting, PLC, smart farming**

I.INTRODUCTION

Manual transplanting of vegetable saplings is time-consuming, labor-intensive, and often imprecise, resulting in yield loss and higher operational costs. The Automated Multi-Vegetable Transplanter addresses these issues by combining automation, mechanical precision, and ergonomic design. Designed for small to medium-sized farms, the system ensures consistent planting of a variety of crops such as tomato, brinjal, chili, and cabbage, accommodating diverse tray and root sizes. This project aims to replace inefficient manual processes with a user-friendly, cost-effective, and scalable machine suitable for Indian agricultural conditions.

II.LITERATURE REVIEW

The automation of transplanting systems has evolved as a solution to the labor-intensive nature of manual sapling planting, particularly in vegetable farming. This literature review synthesizes research on automated vegetable transplanters, focusing on their technological advancements, impact on efficiency, and remaining challenges in the context of agricultural mechanization

1.Manual vs Mechanical transplanting
Manual transplanting has traditionally been labor-intensive and prone to inconsistency. *Jain and Rai (2008)* in their book "Farm.

Machinery and Power" discuss how traditional methods often result in poor spacing and planting depth, which affect crop yields. Early mechanized transplanters improved efficiency, but they lacked precision in planting, as highlighted by *Guo and Sun (2014)* in the *Journal of Agricultural Engineering Research*

2. Early Development of Mechanized Transplanters
Mechanized transplanters evolved to reduce labor requirements but struggled with handling delicate seedlings. *Michael and Ojha (2014)* in "Principles of Agricultural Engineering" describe how these early machines mechanized sapling transfer but often failed to provide uniform planting, limiting their effectiveness in diverse crop types and soil conditions.

3. Advancements in Automation Technology
Modern transplanters use sensors, robotics, and precision mechanisms to improve planting accuracy. *Choi et al. (2017)*, in *Computers and Electronics in Agriculture*, introduced artificial vision systems that allow machines to pick up and plant saplings more accurately. *Liu and Lu (2018)* demonstrated how pneumatic control systems reduce sapling damage and improve spacing accuracy, making transplanting faster and more reliable.
Zhang (2016) in "Precision Agriculture Technology" discusses how these machines integrate AI and sensor technologies to adapt to various crops and soil conditions, optimizing plant health and yield.

4. Labor Efficiency and Cost-Effectiveness
Automated transplanters significantly reduce labor needs. *Geng et al. (2020)* found that labor requirements could drop by 70% with automated systems, a key benefit for farms facing labor shortages. Although initial costs can be high, *Sharma and Singh (2016)* in "Mechanized Sowing and Planting Technology" argue that the long-term savings in labor make these machines cost-effective. However, *Cheein and Carelli (2013)* caution that the high upfront investment may limit accessibility for small-scale farmers, suggesting modular systems as a solution.

5. Precision and Versatility Challenges
One key challenge is creating machines that can handle various crop types. *Wang and Zhang (2020)* highlighted that machines need to be adaptable for different sapling sizes and planting depths. *Kondo and Noguchi (2021)* in "Agricultural Robotics" emphasized that AI and robotics are improving adaptability, allowing machines to adjust in real-time to soil and environmental conditions.

6. Future Directions
Future research aims to make these machines more affordable and adaptable. Peng et al. (2019) explored AI-driven transplanting systems that can adjust planting operations in real-time, enhancing precision further. Auat Cheein and Kaya (2022) suggest that modular designs could reduce costs and increase adoption, especially for small-scale farms.

III. RESEARCH GAP

Limited Versatility Most automated transplanters are designed for specific crops, limiting their use for diverse vegetable types. There's a need for adaptable systems that can handle multiple crops with varying planting requirements.

Inadequate Use of Smart Technologies Few systems integrate advanced technologies like IoT or sensor-based monitoring. These could optimize transplanting based on real-time data (soil moisture, weather), improving planting accuracy and resource use.
Insufficient Real-World Validation Many studies focus on theoretical designs or controlled environments. Extensive field testing under varying conditions (soil types, weather) is necessary to confirm the practical effectiveness of transplanters.

Overlooked Environmental Impact Current research neglects the environmental effects of transplanting machines, such as soil compaction and ecological harm. Sustainable design improvements are needed to minimize these impacts.

Neglect of User Needs and Ergonomics Transplanters often lack user-friendly features, making them difficult for farmers to operate. Research should focus on incorporating ergonomics and user feedback to improve ease of use in the field.

Lack of Cost-Benefit Analyses Few studies provide comprehensive cost-benefit analysis. Clear data on economic feasibility, including ROI and long-term savings, is needed to help farmers assess the value of these machines.

Inadequate Training and Support Many farmers struggle to use advanced machines due to insufficient training and support. Research should focus on creating effective educational resources to optimize the use of these technologies

Focus on Smallholder Farmers Research largely targets large-scale farms, leaving smallholder farmers without affordable, adaptable solutions. There is a need for affordable, modular transplanters specifically designed for small-scale farming

IV. PROBLEM DEFINATION

Now days, The agricultural sector is facing increasing challenges, including:

Labor Shortages Manual transplanting is a labor-intensive process, and with increasing labor shortages in agriculture, there is a need for automated solutions to reduce dependency on manual labor.

Inconsistent Planting Manual planting often results in inconsistent spacing, depth, and alignment of saplings, which can negatively affect crop growth and yield. The need exists for a system that can ensure uniform planting.

Inefficiency in Time and Costs Traditional transplanting methods are slow and costly due to the time and labor required. There is a need for faster, more cost-effective alternatives that improve efficiency and reduce operational expenses.

Damage to Saplings Handling and transplanting delicate saplings manually can lead to damage, affecting their survival rates and growth. A machine that ensures gentle handling is essential to improve crop health and yield.

Adaptability Issues Most transplanters are designed for specific crops and are not adaptable to different vegetables or field conditions. A versatile system is required to handle a variety of crops with varying sizes and planting depths.

High Initial Investment Existing automated transplanters often have high upfront costs, which can be prohibitive for small and medium-scale farmers. Affordable, cost-effective solutions need to be developed.

Therefore, there is a clear need for an affordable, efficient, adaptable, and environmentally sustainable automated vegetable transplanter that addresses these issues.

V. CALCULATION

Appendix A: Digging Cup Design Calculation

A.1 Design Parameters

Parameter	Value	Unit
Sapling Diameter	3.5×1.5=5.25	cm
Depth of Tray	4	cm
Sapling Size (Height)	10 to 25	cm
Density of Soil	1.7	kg/m³ (approx)
Depth of Digging Cup	15	cm
Width of Digging Cup	10	cm

A.2 Cup Volume Estimation

To ensure the cup can accommodate the sapling's root mass, we estimate the cup as a cylindrical volume:

$$\text{Volume} = \pi \times \left(\frac{d}{2}\right)^2 \times h$$

Where:

- d=0.10 m (width = diameter)
- h=0.15m (depth of cup)

$$\text{Volume} = \pi \times \left(\frac{0.10}{2}\right)^2 \times 0.15 = 0.00118\ m^3$$

A.3 Soil Mass Displacement

Using estimated soil density:

Mass of soil displaced = Volume × Density = 0.00118 × 1700 = 2.006 kg

Appendix B: Ground Wheel and Planting Rate Calculations

B.1 Tractor Speed and Planting Time

- Speed of Tractor:

v=1.5 m/s=1500 mm/sv = 1.5

- Planting Frequency:

5 plants in 2 seconds⇒1 plant every 0.4 sec

Required Shaft RPM:

$$\text{RPM} = \left(\frac{60}{0.4}\right) = 150 \text{ rpm}$$

B.2 Ground Wheel Diameter Calculation

We know:

$$\text{Ground wheel RPM} = \left(\frac{\text{Tractor speed(m/min)}}{\pi \times D}\right)$$

Where:

- Tractor speed = 1.5 m/s=90 m/min
- Required ground wheel RPM = 150

$$150 = \frac{90}{\pi \times D} \qquad \pi \times D = \frac{90}{150}\ D = 0.1909 \text{ m} = 190.9 \text{ mm}$$

B.3 Ground Wheel Circumference

C= π × D = π × 190.9 ≈ 600mm

This means the ground wheel covers 600 mm per rotation.

B.4 Planting Distance and Gear Ratios

- At 600 mm spacing:

1 plant per 600 mm⇒1 plant per ground wheel rotati on

Sprocket Ratio: 1:3

- At 450 mm spacing:

600 mm circumference / 450 mm spacing=1.33 plants per rotation

Approximated using Sprocket Ratio: 1:4

This means:

- For larger spacing (600 mm), use 1:3 sprocket
- For denser spacing (450 mm), use 1:4 sprocket
- Ground wheel diameter: 190.9 mm
- Circumference: 600 mm
- Planting controlled by sprocket ratios
  - 1:3 for 600 mm spacing
  - 1:4 for 450 mm spacing
- Shaft RPM synchronized with ground speed for precise planting

Appendix C: Geneva Mechanism Design Calculations

The Geneva mechanism is used in the transplanter to convert continuous rotational motion into intermittent motion, enabling precise sapling delivery with controlled angular indexing.

C.1 Given Parameters

Symbol	Description	Value	Unit
a	Drive crank radius	38.21	mm
n	Number of driven slots	8	-
P	Drive pin diameter	5	mm
t	Allowed clearance	2	mm

C.2 Calculated Values

1. Center Distance (C)

$C = \frac{a}{\sin\left(\frac{180}{n}\right)} = \frac{38.21}{\sin(22.5)} = 99.94$ mm

2. Geneva Wheel Radius (b)

$b = \sqrt{c^2 - a^2} = \sqrt{(99.94)^2 - (38.21)^2} = 92.34$ mm

3. Slot Center Length (S)

S = (a + b) − C = (38.21 + 92.34)− 99.94 = 30.7 1mm

4. Slot Width (W)

W = P + t = 5 + 2 = 7mm

5. Stop Arc Radius (y)

Y =a − (P × 1.5) = 38.21 − (5 × 1.5) =3 0.71mm

6. Stop Disc Radius (Z)

Z = y +t = 30.71 +2 = 32.71mm

7. Clearance Arc (V)

$V = \frac{b \times Z}{a} = \frac{92.34 \times 32.71}{38.21} = 79.04$ mm

- Drive crank radius (a): 38.21 mm
- Geneva wheel radius (b): 92.34 mm
- Clearance arc (V): 79.04 mm
- Slot width (W): 7 mm
- The calculated parameters ensure precise indexing and smooth operation for sapling spacing in the transplanting process.

VI. SYSTEM DESIGN

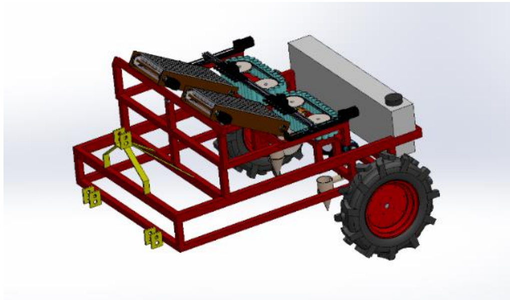

Fig 1: Overall Design

7.1 Pick-Up System:

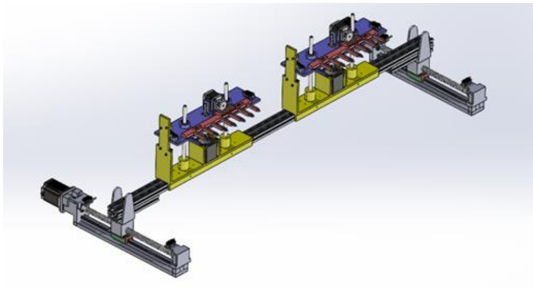

Fig 2: Pick up System

- Stepper motor-driven aluminum arms
- Uses sensors for tray detection and sapling position
- Powered by 24V lead-acid battery
- Tray conveyor for continuous feeding

7.2 Conveyor System:

- Geneva mechanism driven by ground wheel
- Precisely places saplings into digging cup

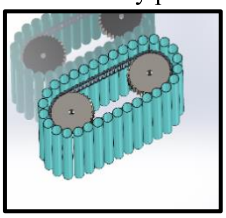

Fig 3: Conveying System Fig 4: Geneva Mechanism

7.3 Digging & Planting System:

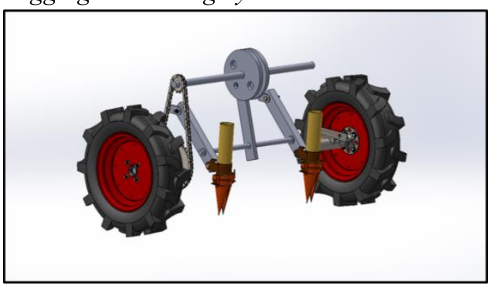

Fig 5: Digging & Planting System

- Chain and gear-driven digger for hole formation
- Ensures uniform depth based on crop requirements

7.4 Soil Covering System:

- Mild steel wheels press soil over roots
- Prevents exposure and supports root development

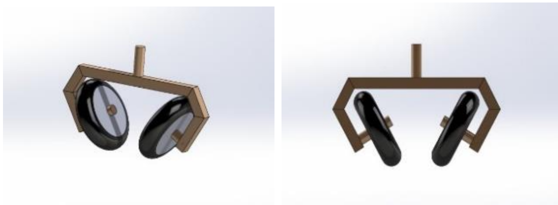

Fig 6: Soil Covering System

7.5 Additional Features:

- IR & Ultrasonic sensors for tray and sapling monitoring
- Buzzer + LED alert for low tray warning
- 70L water tank with pump and relay-based sprinkler system
- Alternator for in-motion battery charging

VII. RESULTS AND DISCUSSION

The prototype showed:

- Consistent sapling spacing (~300 mm) and depth (50 mm)
- Gentle handling with <5% sapling damage
- Productivity of over 800 saplings/hour
- Up to 60% labor cost reduction
- Field adaptability with kerb weight ~380 kg
- Improved ergonomics with safety covers and fillets
- Alternator ensured battery operation throughout field tasks

The testing confirmed that the design is scalable and suitable for diverse crops and smallholder settings.

REFERENCES

[1] Khadatkar, A., & Mathur, S. M. (2022). Design and development of an automatic vegetable transplanter using a novel rotating finger device with push-type mechanism for plug seedlings. *International Journal of Vegetable Science*, *28*(2), 121-131

[2] Tech, M. Specialization: Farm Machinery and Power Engineering

[3] Michael, A. M., & Ojha, T. P. (1966). *Principles of Agricultural Engineering: Farm power, farm machinery, and farm buildings* (Vol. 1). Jain Brothers..

[4] Zhang, Q. (2016). *Precision agriculture technology for crop farming* (p. 374). Taylor & Francis.

[5] Kumari, A., Singh, S., VP, A., Joshi, P., Chauhan, A. K., Singh, M., & Hemalatha, S. (2023). Mechanization in Pre-harvest Technology to Improve Quality and Safety. In *Engineering Aspects of Food Quality and Safety* (pp. 93-114). Cham: Springer International Publishing.

[6] Kondo, N., & Noguchi, H. (2021). Agricultural Robotics.

[7] Michael, A.M., & Ojha, T.P. (2014). Principles of Agricultural Engineering

[8] Jain, R. & Rai, R. (2008). *Farm Machinery and Power*. Jain Brothers.

[9] Choi et al. (2017). *Computers and Electronics in Agriculture*.

[10] Cheein, G.O., & Carelli, R. (2013). *Agricultural Robotics*.

[11] Geng, Y. et al. (2020). *Automation in Vegetable Farming*.

[12] Liu, Y., & Lu, C. (2018). *Pneumatic Control for Sapling Handling*.