Robot combine harvester for paddy harvesting

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***Abstract*—Currently, the number of farmers in Sri Lanka is decreasing because of It seems that the young generation in Sri Lanka is not interested in agriculture. In this trend, after a few decades, Sri Lanka's rate of self-sufficiency in agricultural production will drop sharply.The young generation in Sri Lanka is more interested in technical fields.So by using these facts, this problem can be solved by introducing robots in agriculture. Recognizing the importance and urgency of developing such agricultural robots, this study proposed and developed a robotic combine harvester.[quick summery about machine system]**

***Index Terms*—Robotic,harvesting**

I. Introduction

The combination of technological innovation and agricultural practices has become increasingly important in modern agriculture. With the growing global population and increasing demand for food production, agriculture faces many challenges. Under the stress of increasing population, changing climate, and changing infrastructure, traditional farming methods are not sufficient to meet the increasing demand, consequently, an alternative solution is urgently needed to reduce labor shortages and inefficiencies in agricultural practices and increase productivity. Worldwide, farmers face countless challenges to meet the ever-increasing food demands of the people. The rapidly expanding population has put tremendous pressure on agricultural production, creating the need to produce more from less agricultural land. At the same time, labor shortages in agriculture create major constraints, affecting productivity and efficiency. Labor-intensive harvesting methods are often unable to meet the growing demand for efficient and productive operations in today's agricultural environment.

Robotic harvesting emerges as a strategy for these urgent and demanding situations. Designed to function autonomously or semi-autonomously, those robot structures are geared up with ultra-modern technology that redefines conventional cutting techniques and the usage of specialized mechanical equipment that is blended on, like a rotating wheel that cuts at a precise attitude of 120 ranges as the robotic is moved forward The key function of those robot structures is their movable robotic arm, which may circulate exactly vertically and horizontally. This application allows robots to transport plants quickly via fields and attain plants at specific heights and locations. The horizontal and vertical movements of the robotic arm bypass limitations and alter to exclusive area layouts to facilitate unique harvesting It strives to transform the agricultural panorama by supplying powerful, reliable, and accurate answers to the demanding situations faced by farmers. Incorporating modern-day technologies and innovative guidelines, these applications are trying to boom agricultural productivity, lessen exertion shortages, and make certain sustainable meal manufacturing and human consumption meet rapidly growing demands.

Identify applicable funding agency here. If none, delete this.

Fig. 1. Paddy Field

II. Literature

In the realm of paddy harvesting, the necessity for efficient food production looms large. Presently, the sector faces challenges marked by a shortage of farmers and insufficient time for manual labor. Robotics emerges as a promising solution, capable of rapid harvesting to meet the escalating food demand while mitigating the manpower shortage and minimizing food prices.

Existing technologies showcase diverse approaches. For instance, the Sunami harvesting machine employs a mechanical process.The RT was YANMAR half-crawler tractor. The HRHC system was developed in the laboratory of vehicle robotics at Hokkaido University – Japan. It can manoeuvre in a real field.The CS was based on a programmable logic controller (PLC) system. Meanwhile, some robotic models operate within a fixed position, executing plant cutting within circular areas but lack autonomous movement. A recent study highlighted a new approach—utilizing GPS trackers and predefined paths to enable robots to autonomously navigate and harvest fields.

Fig. 2. Sunami Machine

However, challenges persist. The issue of collecting harvested crops poses a hurdle. Single robotic units struggle with collection, necessitating additional machinery, a complex and costly endeavor. Moreover, water levels in paddy fields present hardware problems for robots. While waterproofing solutions exist, their implementation substantially raises costs.

The scale of paddy fields amplifies the urgency for robotic intervention. Large expanses demand mechanization for timely and efficient harvesting, an endeavor impractical through manual labor. By deploying robotic systems, the potential to expedite the harvesting process and meet burgeoning food requirements becomes plausible.

As the demand for food surges, driven by a growing population, the implementation of robotic systems in paddy harvesting emerges as a strategic imperative. Overcoming technical barriers and cost implications, these systems possess the capability to revolutionize the agricultural landscape, ensuring swift and effective food supply to meet the burgeoning global needs.

III. Solution

A. *System Architecture of an Automatic Harvester*

The system architecture of this automatic harvester is designed to integrate various hardware and software components, ensuring seamless coordination and efficient operation. The architecture encompasses both on-board and off-board systems, incorporating advanced technologies to enable autonomous harvesting.

1) On-Board System: The on-board system of an automatic harvester is a crucial component responsible for the physical operation and real-time decision-making within the field.

1) **Hardware Component**
   The hardware components of the on-board system are carefully selected to enable efficient harvesting, navigation, and data processing. Here is an overview of the key hardware components. These hardware components work in synergy to enable the automatic harvester to navigate through the field, identify and classify crops, and perform precise harvesting maneuvers. The integration of advanced sensors, cameras, and a powerful processing unit allows the harvester to operate autonomously, making real-time decisions based on environmental data and enhancing overall harvesting efficiency. Ongoing advancements in hardware technology continue to contribute to the evolution of automatic harvesters, improving their capabilities and adaptability in different agricultural settings.

   - Robotic Arm

     Description: The robotic arm is the primary harvesting tool that mimics the human arm's dexterity. It is equipped with specialized end-effectors or tools designed for precision crop cutting.
     Function: Performs the actual harvesting by reaching and cutting the ripe crops.

   - Sensors and Cameras
     a) LiDAR (Light Detection and Ranging)

        Description: LiDAR sensors use laser light to measure distances and create detailed 3D maps of the environment.
        Function: Provides accurate terrain mapping, obstacle detection, and navigation assistance.

     b) Infrared Cameras

        Description: Infrared cameras capture infrared radiation, allowing the harvester to identify temperature differences in crops.
        Function: Assists in detecting ripe crops by analyzing thermal signatures.

     c) RGB Cameras

        Description:Traditional cameras capture color information in the visible spectrum.
        Function: Used for visual recognition of crops, distinguishing between various crop types, and identifying ripeness based on color.

   - Processing Unit

     Description: A high-performance onboard computer equipped with CPUs and GPUs.
     Function: Processes data from sensors and cameras, runs computer vision algorithms, executes machine learning models for real-time decision-making, and controls the robotic arm.

- GPS Navigation System

  Description: A global navigation satellite system (GNSS) receiver.
  Function:Provides accurate positioning and navigation data, enabling precise path planning, mapping, and field traversal.

- Power Management System

  Description:Manages the energy supply and distribution throughout the harvester.
  Function: optimizes power consumption for extended operation, monitors battery levels, and ensures efficient utilization of energy resources.

2) **Software Components**
   - Control System Software

     Description: The software responsible for coordinating the movement of the robotic arm, actuators, and other mechanical components.
     Function:Translates high-level commands from higher-level software components into low-level control signals for precise harvesting maneuvers.

   - Computer Vision Algorithms

     Description: Algorithms designed to process visual data from cameras and sensors.
     Function: identifies and recognizes crops, distinguishes between crops and weeds, and assesses crop ripeness based on color, shape, and other visual characteristics.

   - Navigation and Path Planning Software

     Description: Algorithms responsible for determining the most efficient path through the field, considering obstacles, and optimizing harvesting routes.
     Function: guides the harvester to navigate autonomously, avoiding obstacles and ensuring optimal harvesting efficiency.

   - Communication Software

     Description: Software responsible for establishing and managing communication with the off-board system and potentially other connected devices.
     Function: Facilitates real-time data exchange, remote monitoring, and control.

   These software components work collaboratively to enable the automatic harvester to operate autonomously, make intelligent decisions, and perform precise harvesting. The integration of computer vision, machine learning, and control algorithms ensures that the harvester can adapt to varying field conditions, optimize harvesting strategies, and enhance overall efficiency in agricultural operations. Ongoing advancements in software development continue to contribute to the capabilities and sophistication of automatic harvester systems.

2) Off board System: The off-board system of an automatic harvester plays a critical role in data analytics, remote monitoring, and overall management of the harvester's performance. This system is typically located on a remote server and is responsible for tasks such as predictive maintenance, machine learning model training, and providing a user interface for farmers.

1) **Hardware Component**
   These hardware components work together to provide centralized data processing, analytics, and management capabilities for the automatic harvester. The off-board system is essential for extracting insights from the data collected by the on-board system, allowing for informed decision-making, predictive maintenance, and remote monitoring. Additionally, it serves as the interface through which farmers can interact with and control the harvester, ensuring user-friendly management and customization based on specific agricultural needs. Advances in cloud computing technologies and high-speed wireless communication continue to enhance the capabilities of the off-board system in supporting the optimal performance of automatic harvesters.
   - Remote Server

     Description: A centralized server located off-site, often in a cloud environment or a dedicated data center. ***Function***:Stores and processes data received from multiple harvesters, hosts machine learning models, and facilitates remote management and monitoring.

   - Communication Modules(Wireless Communication)

     Description: Enables high-speed, reliable communication between the on-board system of the harvester and the remote server.
     Function: Facilitates real-time data transfer, remote control, and continuous monitoring of harvester operations.

   - Storage System

     Description: High-capacity storage devices or

cloud-based storage solutions.
Function: Stores historical data, sensor readings, and other relevant information for analytics, reporting, and future reference.

- Processing Unit

  Description: Powerful CPUs and GPUs on the remote server.
  Function: Handles data analytics, machine learning model training, and other computationally intensive tasks requiring significant processing power.

2) **Software Components**

The software components of the off-board system in an automatic harvester play a crucial role in data analysis, predictive maintenance, and providing a user interface for farmers to monitor and control the harvester remotely. Here are the key software components of the off-board system:

- Communication Software

  Description: Software responsible for handling communication between the off-board system and multiple on-board systems of individual harvesters.
  Function: Facilitates real-time data transfer, remote control, and coordination between the off-board and on-board systems.

- Remote Monitoring and Control Software

  Description: Software that provides a user interface for farmers or operators to remotely monitor and control the harvester.
  Function: Allows users to view real-time data, receive alerts, and adjust settings. The interface may include a dashboard displaying relevant information about the harvester's status and performance.

- Operating System and Middleware

  Description: The foundational software that manages the remote server's hardware resources and provides middleware for running various applications.
  Function: Ensures smooth operation of software applications and facilitates communication between different software components.

These software components work together to provide centralized management, analysis, and control of multiple automatic harvesters. The off-board system's capabilities in data analytics and predictive maintenance contribute to improved overall efficiency, while the user interface allows for user-friendly interaction and customization based on specific agricultural requirements. Ongoing advancements in software technologies continue to enhance the capabilities of off-board systems in supporting the optimal performance of automatic harvesters.

3) Maintenance and Support: Ensuring the efficient and dependable operation of an automatic harvester involves a comprehensive technique for renovation and help. Regular preventive upkeep practices, inclusive of scheduled inspections, cleansing, and lubrication, are important to pick out and deal with capability issues earlier than they enhance. Predictive preservation techniques, leveraging sensor information analysis and device mastering fashions, allow a proactive response to emerging problems, minimizing downtime. Remote monitoring plays a crucial role in allowing actual-time statistics transmission from the on-board gadget to the off-board device. This helps with continuous tracking, signals operators to irregularities, and supports remote diagnostics for fast problem-solving decisions. A person-pleasant interface affords operators a dashboard for monitoring the harvester's fame and receiving preservation indicators, while special protection logs file sports for historical reference. The implementation of diagnostic equipment, both on-board and remotely, empowers the harvester to self-diagnose, streamlining the troubleshooting process. A devoted technical help group provides assistance, complemented by ordinary training programs to equip operators with the important abilities for habitual renovation responsibilities. Spare parts management, which includes inventory management and robust dealer relationships, ensures the supply of additives when needed.

Regular software program updates, together with firmware and software program improvements, make a contribution to improved overall performance and characteristic updates. Remote update skills permit the harvester to stay current with today's improvements. Comprehensive documentation, consisting of renovation manuals and troubleshooting courses, serves as a treasured source for operators. Finally, a remarks mechanism permits users to file issues, share studies, and advocate improvements. This feedback loop contributes to continuous improvement in the design and functionality of the automatic harvester, making sure it remains at the forefront of agricultural innovation. In essence, a properly-dependent maintenance and help strategy no longer only addresses immediate concerns but additionally fosters the lengthy-term performance, reliability, and sustainability of computerized harvesters in modern-day agricultural practices.

4) Security Measures: Securing automated harvesting requires a multi-pronged approach to protecting the equipment and its active components. Physically, the harvesting area should have security cameras, lighting and access, while a GPS tracking system can monitor the location in real time Cybersecurity systems are essential most of all, requiring encrypted communication channels, firewalls, and intrusion detection systems. Regular software updates are needed to patch vulnerabilities. Authentication and access control systems, such as biometrics or RFID cards, ensure that only authorized personnel can access the harvester's monitoring systems. Data encryption during storage and transmission protects sensitive information. Remote monitoring and planning capabilities provide real-time monitoring and remote security maintenance services. Waste detection systems, including seal sensors, alert operators to physical interference. Employee and staff training increases awareness and the ability to report suspicious activity. An emergency response plan addresses potential safety issues as well as isolation and recovery procedures. Compliance ensures compliance with industry standards. Continuous security analyses and updates are essential to adapt to evolving threats, making the integration of physical, cybersecurity, and operational processes increasingly important for security management.

B. *Motion Control system*

The harvester incorporates four primary motions that are integral to its operation.

1) Cutting tool rotation
2) Vertical motion of the robot arm
3) Horizontal motion of the robot arm
4) Motion of the harvester through the path

These four coordinated motions collectively contribute to the harvester's performance, enabling it to perform precise and effective harvesting operations across a variety of terrain and vegetation profiles.

The rotation speed of the cutting tool is manually controlled and depends on the particular type of crop being harvested.Each type of crop has a default rotating speed. The robotic arm integrated into the harvester consists of two joints and one tip, with individual motors assigned to control the movement of each joint. The power supply to these motors is under the precise regulation of a computer system embedded in the harvester. This computer system acts as the central control unit, organizing the movement and coordination of the robotic arm parts.This centralized control mechanism ensures the systematic and responsive operation of the robotic arm, optimizing its performance during harvesting operations. The horizontal motion of the robot arm is executed around the hinge, and the rotational speed of this motion is controlled manually, similar to the cutting tool. Simultaneously, the turning angle of the horizontal movement is regulated by the computer system integrated into the harvester. The maximum turning angle of the robot arm is set to 120 degrees.The computer system, equipped with sensors, measures the road width using sensor inputs. Later, the CPU processes this information and calculates the required turning angle for the robot arm to effectively navigate the determined path width. Once the turning angle is determined, the computer system adjusts the power supply to the motors responsible for the horizontal movement.This dynamic control mechanism ensures that the robot arm adapts to different path widths. The vertical motion of the robotic arm controls the cutting level of the harvester. The computer system (CPU) installed in the harvester manages this operation meticulously. The CPU uses sensors to detect the level of cut required for the harvester.After identifying the optimal cutting level, the CPU adjusts the position of the robot arm by precisely controlling the motors in the joints. These motors work in concert to position the cutting tool at a specific height, which coincides with the detected cutting level. Automated harvesters achieve autonomous navigation by using GPS technology and various sensors to determine their position and plan a path through fields. The harvester's computer system analyzes the field to optimize the harvest path, considering factors such as obstacle avoidance, efficiency, and total coverage.Speed and direction control systems are integrated to allow adjustments based on specific crops, vegetation density, and environmental conditions. These features collectively enable the harvester to navigate the field automatically and efficiently while optimizing harvester performance.

IV. MATHLAB SIMULATION

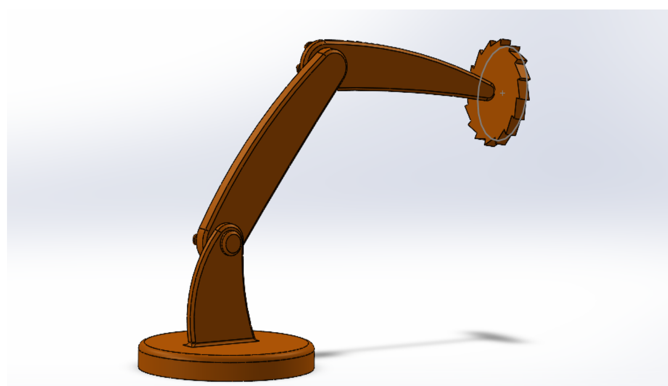

Fig. 3. Robotic arm

A. *Eqations*

Desired Trajectory

function [xd,yd] = Desired Trajectory(u)

$xd = 1 + 0.5 * sin((2 * pi/5) * u + pi/2);$
$yd = 1 + 0.5 * cos((2 * pi/5) * u + pi/2);$

inverse kinematics

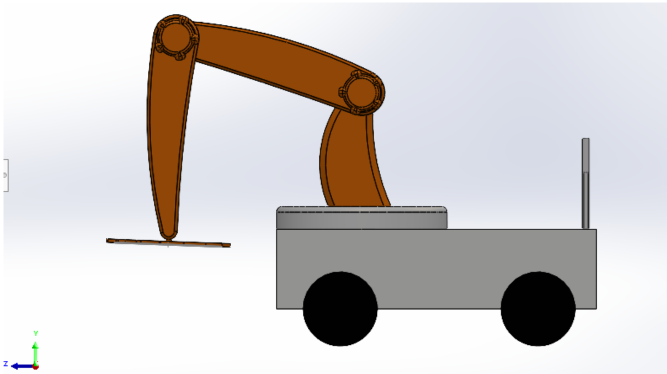

Fig. 4. side view of the machine

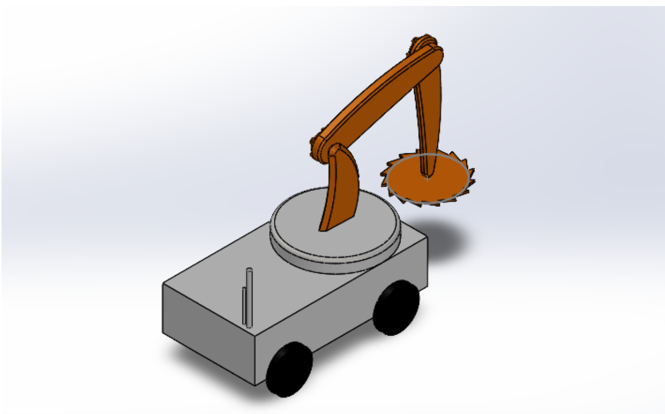

Fig. 5. machine

function [theta1d,theta2d] = inverse kinematics(xd,yd) l1=1;

l2=1;

$theta2d = acos((xd^2 + yd^2 - l1^2 - l2^2)/(2 * l1 * l2));$
$theta1d = atan(yd/xd) - atan((l2 * sin(theta2d))/(l1 + l2 * cos(theta2d)));$

Forward Kinematics

function [xa,ya] = Forward Kinematics(teta1 a,theta2 a)

l1=1;

l2=1;

$xa = l1 * cos(teta1_a) + l2 * cos(teta1_a + theta2_a);$
$ya = l1 * sin(teta1_a) + l2 * sin(teta1_a + theta2_a);$

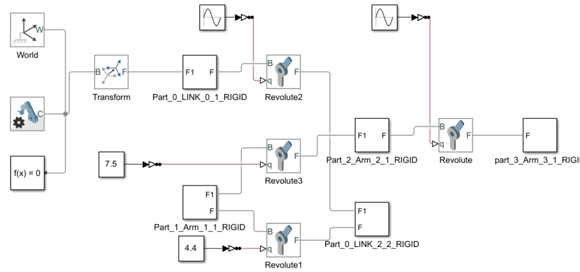

Fig. 6. Mathlab Plot for the robotic machine

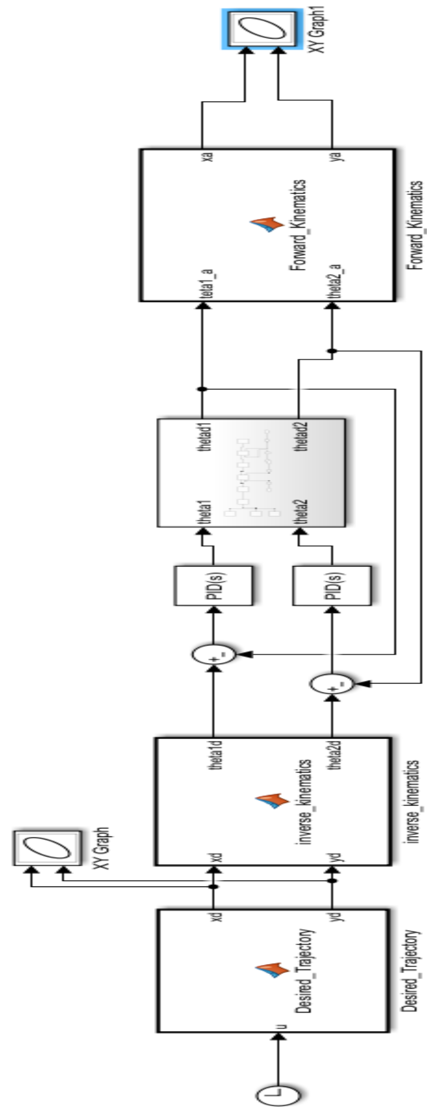

Fig. 7. Horizantal movement mathlab simulink

Desired Trajectory-In the context of robotics or control systems, a desired trajectory refers to the desired path or motion that a system or robot should follow.It can be specified in terms of position, velocity, and acceleration over time.

Forward Kinematics:Forward Kinematics is the process of determining the position and orientation of the end-effector (e.g., robot's hand or tool) given the joint angles and lengths of a robot's links.

Inverse Kinematics:Inverse Kinematics is the opposite process, where you determine the joint angles required to achieve a desired end-effector position and orientation.

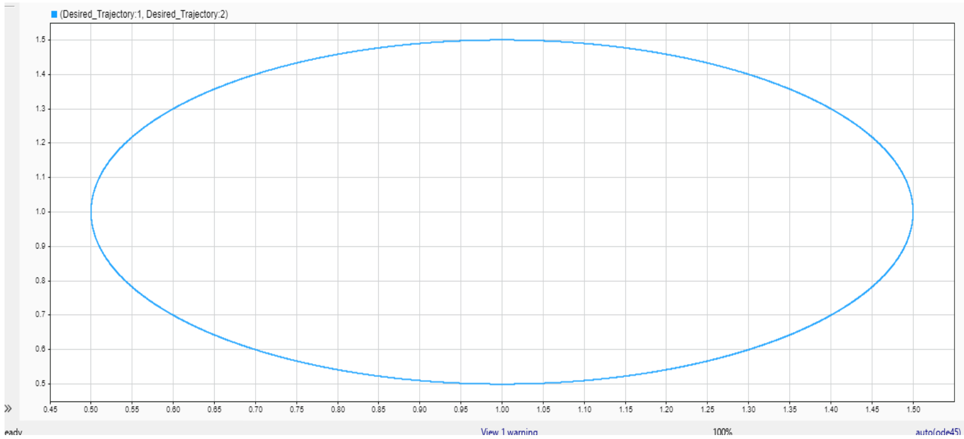

Fig. 8. XY graph of desired trajectory 1 and desired trajectory 2

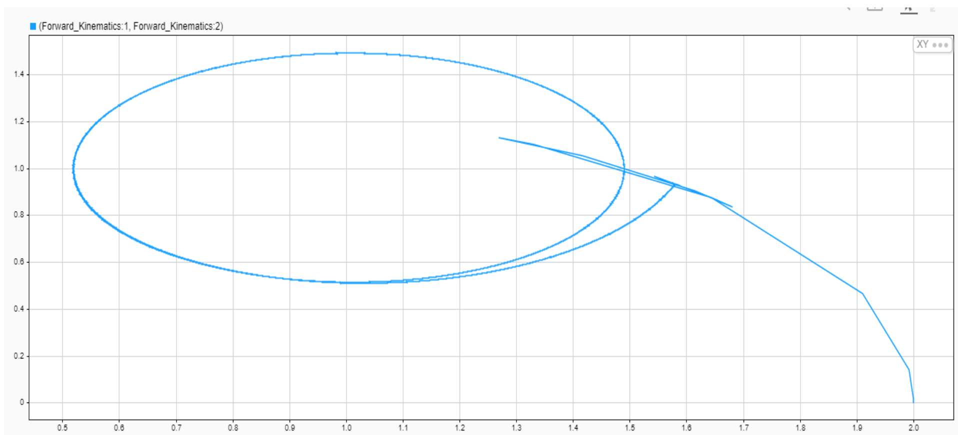

Fig. 9. XY graph of Forward Kinematics 1 and Forward Kinematics 2

V. Conclusion

The document outlines the development of a robot combine harvester for paddy harvesting. A key component is modeling the robotic arm used for harvesting operations. The author provides a diagram showing the joints and tip of the arm. While details of the simulation are not provided, it can be assumed Mathlab software was used to test control of the arm's vertical and horizontal motion. This would allow optimizing the precision of cutting operations before physical implementation. Further simulation details would strengthen an understanding of how the harvester's performance was validated prior to real-world testing.

VI. Acknowledgement

We extend our heartfelt gratitude to Professor Buddika Jayaserkara and Dr. Ruwanthika for their invaluable guidance, support, and expertise that significantly contributed to the success of this research. Their unwavering encouragement and insightful suggestions have been instrumental throughout this endeavor. We also express our sincere thanks to them for their time, mentorship, and dedication in shaping this work.

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