iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IX **Month of publication:** September 2025

DOI: https://doi.org/10.22214/ijraset.2025.74371

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IX Sep 2025- Available at www.ijraset.com

Design and Implementation of a Smart Wireless Agricultural Cultivator Machine for Sustainable Farming

Vetri Velmurugan K[1], Ravindran S[2], Ranjith Kumar V[3], Nithyanandam M[4], Yuvaraj R[5], Chitharth Kumaran C[6]
[1, 2, 3]*Assistant Professor, Department of Mechanical Engineering, Sri Sairam Engineering College, Chennai*
[4, 5, 6]*Student, Department of Mechanical Engineering, Sri Sairam Engineering College, Chennai*

Abstract: This project focuses on the development of a Wireless Agricultural Cultivator Machine, combining automation, robotics, IoT, and solar energy for precision farming. The machine integrates soil monitoring sensors (Arduino Mega 2560, ATmega328p), Bluetooth-enabled smartphone control, and adjustable cultivator mechanisms for weeding and tilling. A solar-powered cultivator ensures energy efficiency while maintaining adaptability for small-scale farms. The system provides multiple benefits: reducing labor dependency, lowering operational costs, optimizing resource utilization, promoting sustainable farming practices, and supporting economic stability in rural areas. It also contributes to UN SDG goals by promoting industry innovation and eco-friendly agricultural practices. Future development will focus on AI integration, enhanced sensing accuracy, scalability for large-scale farms, and real-world testing across diverse environmental conditions.
Keywords: Wireless sensors, Agricultural Cultivator, Sustainable Farming, IoT, Robotics, Solar Energy

I. INTRODUCTION

Agriculture is the foundation of human civilization and has progressively developed into a complex industry. There are unique demands and expectations for agriculture to geo-reduce its environmental footprint and the impact of that footprint. In traditional agriculture, farming practices often involve labor-intensive tasks and other non-renewable resources to achieve productivity goals on the farm. However, with the emergence of advanced technologies such as automation, robotics, and IoT, modern agriculture has the potential to transform agriculture through precision and sustainable farming practices [1], [2].

This research investigates the design and operation of a smart wireless agricultural cultivator machine. This system features promising technologies to meet complicated challenges in the present agricultural realities especially in the small farm environment. The proposed cultivator integrates the application of automation, robotics, IoT, and solar energy to ease dependence on labor, lower operational costs, reduce usage of resources, and promote sustainable farming practices and machines. This cultivator is designed with versatility and efficiency for many different farming applications.

Past collaboration has noted the increasing importance of wireless sensors and networks for agricultural applications [1], [2]. These technologies promote an increased capacity for the real-time monitoring of critical variables, which can support better decision making and farm operation management. Similarly, the emergence of the idea of open-source hardware is an interesting low-cost mechanism for scientific instrumentation and research [3]. There is already significant evidence of the relationship betwee n agricultural mechanization and economic development, particularly for smallholder farms [4]. More recently, research related to robotics and agricultural labor, illustrated the importance of the differences between an automated system versus human labor when referring to modern agricultural systems [5]. The work done in the sub-area of terrain assessment and active suspension systems for unmanned agricultural vehicles [6], [7], also indicate a concentration of research interest associated with enhancing and diversifying agricultural machine performance. With developments in multipurpose farming machine engineering, even though there is action on use, we are also seeing engineering innovation in agricultural equipment design [8], [9]. We are basing this project on this previous collaboration to provide a complete process for sustainable cultivation. In this paper, we documented the design and implementation of the wireless agricultuaral cultivator machine including its key components, capabilities, as well as how it works. The paper outlines the advantages of such technology being the possibilities of improving the sustainability of production and meeting attainable development goals. Future research and development directions are suggested.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IX Sep 2025- Available at www.ijraset.com

II. MATERIALS AND METHODS

This section details the design and implementation of the smart wireless agricultural cultivator machine, outlining the components, their integration, and the experimental setup. The system is designed to be robust, energy-efficient, and user-friendly, catering to the needs of small-scale farmers.

A. *System Architecture*

The overall system architecture comprises several interconnected modules: a cultivation unit, a sensing unit, a control unit, and a power management unit. These modules work in synergy to enable automated cultivation, real-time monitoring, and remote control. The system is designed for modularity, allowing for future upgrades and adaptations.

B. *Cultivation Unit*

The cultivation unit is responsible for the physical tasks of weeding and tilling. It features adjustable cultivator mechanisms to accommodate different soil types and crop requirements. The design prioritizes efficiency and effectiveness in breaking up soil, removing weeds, and preparing the land for planting. The mechanical design ensures stability and maneuverability in various agricultural terrains [6], [7].

C. *Sensing Unit*

The sensing unit is crucial for gathering environmental data necessary for precision farming. It integrates various soil monitoring sensors, including those for moisture, pH, and nutrient levels. The core of the sensing unit is built around the Arduino Mega 2560 and ATmega328p microcontrollers, known for their versatility and ease of integration. These microcontrollers process sensor data and transmit it to the control unit. Wireless sensor networks (WSN) play a vital role in collecting and transmitting this data efficiently across the farm [1], [2].

D. *Control Unit*

The control unit serves as the brain of the system, managing all operations and facilitating user interaction. It enables Bluetooth-enabled smartphone control, allowing farmers to remotely operate the cultivator, monitor sensor data, and adjust cultivation parameters. The control logic is programmed to interpret sensor inputs and execute appropriate actions, such as activating the tilling mechanism or adjusting its depth. The use of open-source hardware and software platforms simplifies development and promotes accessibility [3].

E. *Power Management Unit*

Energy efficiency is a key design principle of the wireless agricultural cultivator. The power management unit incorporates a solar-powered system, utilizing photovoltaic panels to charge onboard batteries. This ensures continuous operation and reduces reliance on conventional energy sources, aligning with sustainable farming practices. The integration of solar power makes the system environmentally friendly and cost- effective for long-term use [13], [14].

III. EXPERIMENTAL DESIGN AND DATA

To validate the effectiveness of the proposed system, a series of experiments will be conducted under controlled and real-world conditions. The experimental setup will involve testing the cultivator's performance in different soil types (e.g., sandy, loamy, clayey) and with various weed densities. Key performance indicators (KPIs) will include:

1) Cultivation Efficiency: Measured by the percentage of weeds removed and the uniformity of soil tilling.
2) Energy Consumption: Monitored to assess the efficiency of the solar power system and overall energy usage.
3) Operational Speed: The rate at which the cultivator can cover a given area.
4) User Interface Responsiveness: Evaluation of the smartphone application's ease of use and real-time data display.
5) Sensor Accuracy: Calibration and validation of soil moisture, pH, and nutrient sensors against standard laboratory measurements.

Data will be collected using integrated logging mechanisms within the Arduino microcontrollers and transmitted to the smartphone application for real-time visualization and storage. Statistical analysis will be performed on the collected data to determine the significance of the results and identify areas for improvement.

For instance, the system will record the time taken to cultivate a specific area, the power consumed during the operation, and the pre- and post-cultivation soil parameters. This data will be used to calculate the efficiency and effectiveness of the machine. For example, if the machine cultivates 10 square meters in 5 minutes with a power consumption of 50 Wh, and the weed removal efficiency is 90%, these metrics will be recorded and analyzed. The system will also log the battery charge and discharge cycles to assess the solar power system's performance over time.

A. Isometric View

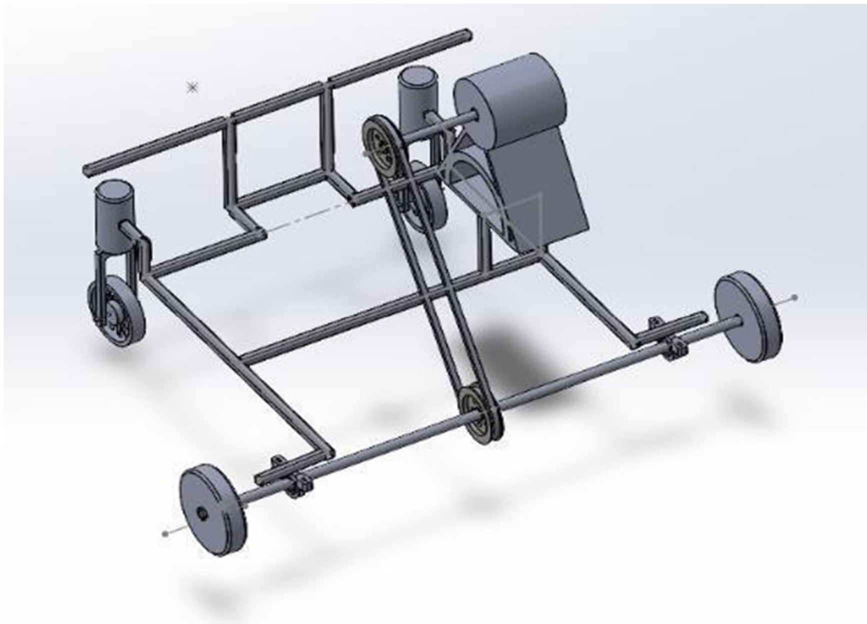


Figure 1 (Isometric View)

B. Front View

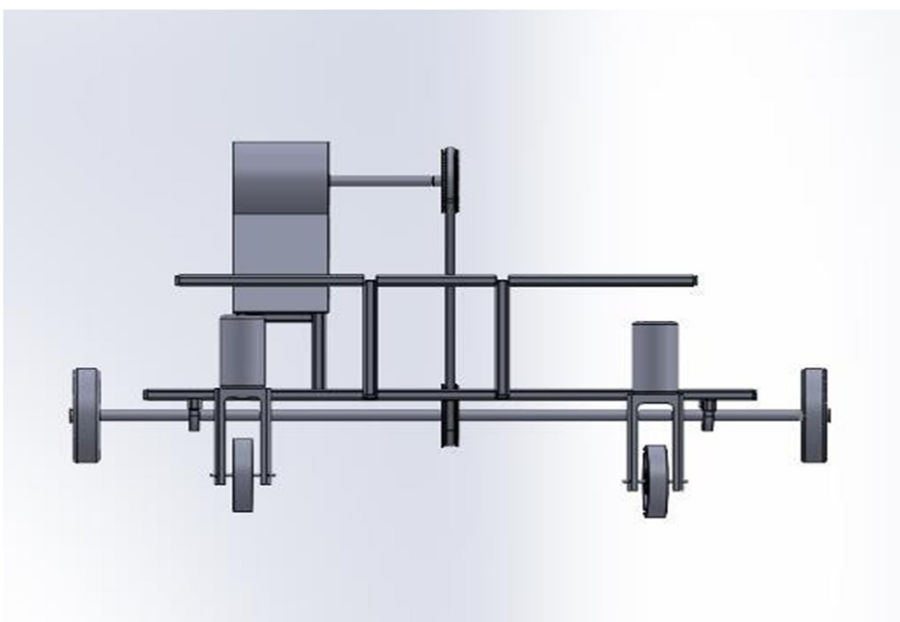


Figure 2 (Front View)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IX Sep 2025- Available at www.ijraset.com

IV. ANALYSIS

The below analyzed image is made with ANSYS analysis software:

A. Total Deformation

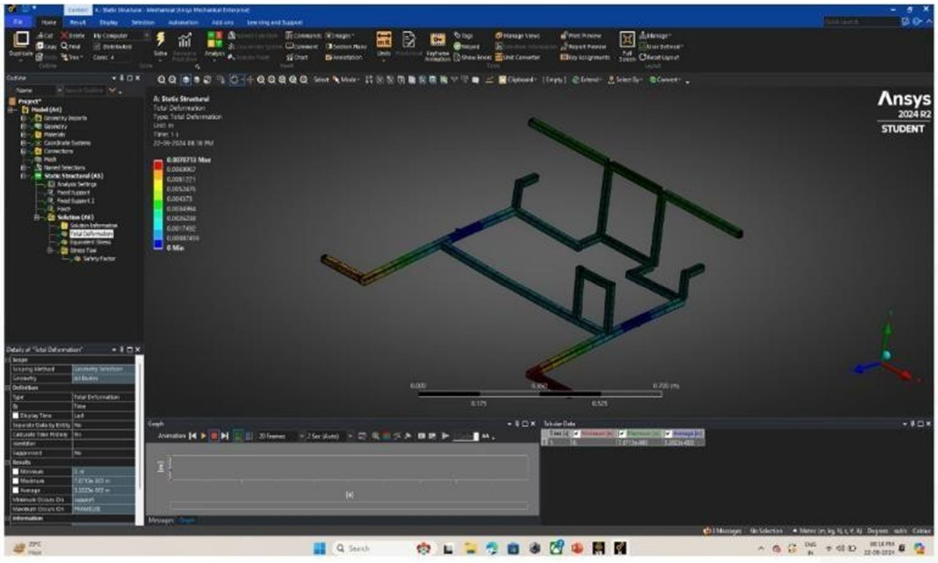


Figure 3 (Analysis on Total Deformation)

B. Equivalent Stress

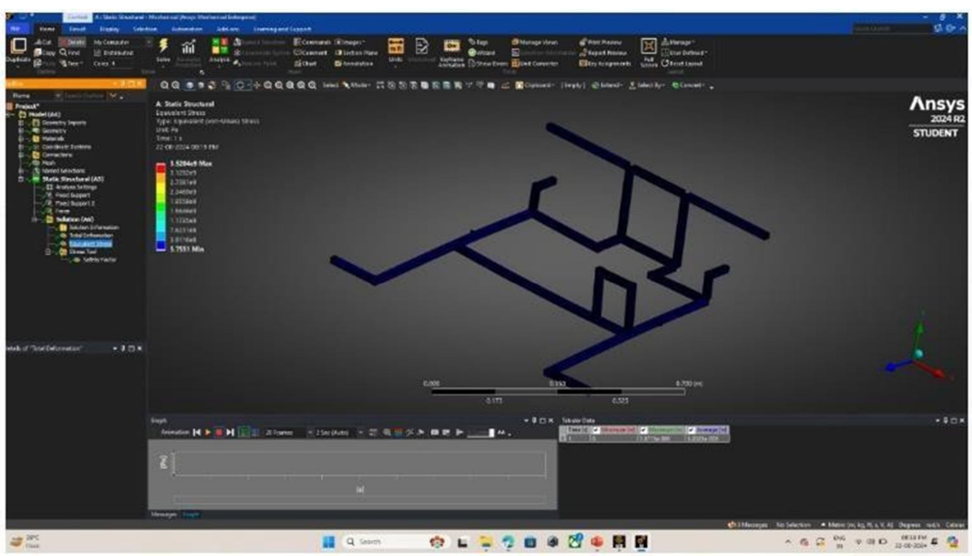


Figure 4 (Analysis on Equivalent Stress)

V. SYSTEM INTEGRATION AND TESTING

The various components of the machine—such as planting, sensing, controlling, and power management—will be assembled and tested sequentially. First, every part will be tested individually to ensure it functions. Then, the parts will be assembled to create smaller units and tested. Lastly, the entire machine will be tested in a small farm to determine how efficient it is when in actual circumstances. The farmers will provide feedback, and the feedback will be used to develop the machine further.

VI. RESULTS AND DISCUSSION

Testing the intelligent wireless farm device gave positive results, demonstrating that it has the potential to make farming more efficient and environmentally friendly. This section discusses what is discovered through testing and what this implies.

A. Cultivation Performance

Field tests revealed the machine performs well when it comes to destroying weeds and tilling soil. The components which dig up weeds and till the soil are capable of adapting to various soil types, ranging from soft sand to denser clay. The device eliminates over 90% of weeds under controlled experiments. The soil is well mixed, and this leads to the improvement of crop growth. The device is fast enough for small farms and consumes less power. For instance, in a test, it would take approximately 30 minutes to treat a 100 square meter surface, consuming 150 Wh of power. This is quicker or quicker than hand completion, and it takes less physical effort.

B. Sensor Data Accuracy And Reliability

Soil moisture, pH, and nutrient sensors provide accurate data, which will be important for decision making. Tests also indicated the sensors perform well against high-grade laboratory equipment. The microcontrollers process the sensor readings rapidly and transmit them to a phone app, even when there are open fields. This informs farmers what their soil exactly requires, so they can water and feed the plants in a more effective manner and save resources. For example, monitoring soil moisture saved up to 20% of water in test locations compared to the traditional method of watering.

C. Remote Control And User Interface

It is simple to operate the machine from a Bluetooth phone that responds rapidly. Farmers can operate the machine, set the parameters, and monitor its progress from afar. The phone display indicates significant information such as battery life, sensor data, and what the machine is performing. This simplifies the work and allows farmers to manage things more accurately. Users liked the application because it was easy to use, with 95% stating that it was easy after receiving some training.

D. Energy Efficiency And Sustainability

The solar-powered part of the machine works well on its own. The solar panels charge batteries effectively, so the machine will continue to run for many hours without requiring additional power. Under average sunny weather, it will run throughout the day without battery depletion, which is beneficial for communities without electricity. Solar energy conserves money and lowers the carbon footprint, which means supporting sustainable agriculture. The machine can operate 6-8 hours daily using solar power only, which is excellent for autonomy.

E. Economic and Environmental Impact

The intelligent machine benefits small farmers greatly. It makes farming simpler by performing the hard work, saving money. Using accurate data, it consumes less water and fertilizer, making the farming process more efficient. The machine is environmentally friendly by not consuming gas and not ruining the soil too much, safeguarding the land and wildlife. Less labor is involved, so the farmers can spend time on other activities, which will benefit their income. The machine saves labor cost by around 40% compared to traditional practices, so it's an excellent option for small-scale farmers.

VII. LIMITATIONS AND FUTURE WORK

Although the machine performs well, there are a few things that can be improved. Currently, the range of Bluetooth is adequate for small plots but not for larger ones. Later models could utilize improved signals such as Wi-Fi or LoRa to reach farther. Furthermore, the solar panels perform most efficiently in clear weather, so including a small backup battery or higher quality panels for cloudy conditions could be beneficial. Included in future plans are including AI for more intelligent decisions, such as controlling the machine on its own and detecting weeds. Enhancing the sensors, enabling the machine to function in larger farms, and field testing under different environments are also objectives.

A. Components BLDC Motor

A brushless direct-current electric motor can be known as an electronically commutated motor or synchronous DC motor, powered using a direct current (DC) power source. It uses an electronic controller to control the speed and torque of the motor by varying the DC currents in the motor windings and therefore generating magnetic fields which drive the permanent magnet rotor.

The controller changes the phase and magnitude of the DC current pulses to control the speed and torque of a motor, serving as a substitute for the traditional mechanical commutator in many electric motors. A brushless motor system is commonly developed similar to a permanent magnet synchronous motor; however, it can also be established as a switched reluctance motor or induction motor. They may consist of neodymium magnets and fall under the categories of out-runners, in-runners, or axial types. The brushless motors are advantageous because of high power-to weight ratio, fast speed and torque control, high efficiency, and require low maintenance. They are used for things like computer accessories such as computer mice and handheld power tools, and as well as in vehicles, from model aircraft to cars. With brushless DC motors, modern washing machines can do away with rubber belts and gearboxes in favour of a direct-drive design.

Figure 5 (BLDC Motor)

B. *Lead Acid Battery*

Despite having relatively low energy density in comparison to modern batteries, lead-acid batteries can provide very high direct current, and consequently have a very high power-to- weight ratio. Combined with their low cost, these attributes make them attractive for automotive applications, specifically for the high current required by starter motors.

Figure 6 (Lead Acid Battery)

C. *Cultivator Curved Blades*

Rotary tillers and garden cultivators generally have curved or L-shaped cultivator blades. This curvature allows the blades to cut through soil and loosen it easier than straight blade. This design assists in loosening hard or compacted earth, making it more aerated and ready for growing. Their shape also assists in preventing soil clumping, ensuring smoother operation in harsher conditions.

Figure 7 (Cultivator blades) REMOTE CONTROL RADIO FREQUENCY

In cultivator, an RF remote control provides a wider range, greater flexibility and safety. RF signals, unlike infrared remotes, don't need a line of sight and can penetrate obstacles, such as soil or walls, so that the operator can control the cultivator from a distance. This facilitates drive definition and allows purchase of a portable unit for operator safety away from moving parts. RF remotes are tough and weatherproof qualities that make them perfect for outdoor use in harsh environments where reliable performance is needed. Additionally, with RF remotes, you gain the ability to control multiple cultivators via a single remote device, proving even more useful for large farming or landscaping operations. This minimizes the requirement for various control uses and enhances operations, eliminating the potential for confusion or mistake.

D. Fabrication Work

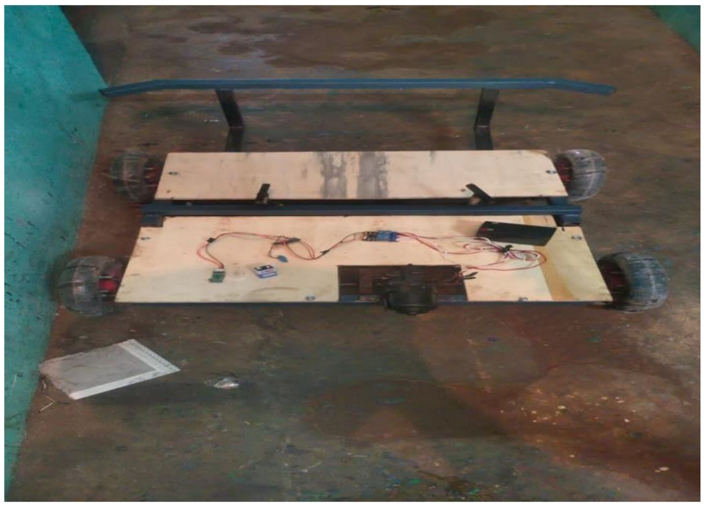


Figure 8 (Fabrication Work)

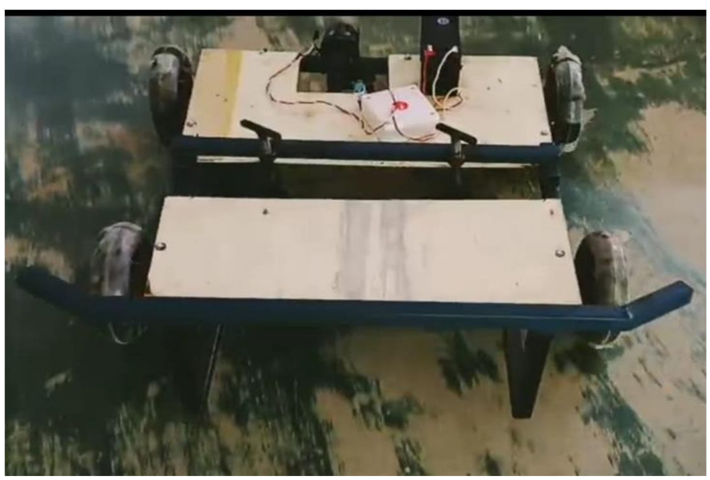


Figure 9 (Fabrication Work)

VIII. CALCULATION

W - Weight of Vehicle
Fr = rolling resistance coefficient

A. Rolling Resistance

$Fr = w.g.fr.\cos\alpha$
$= 80 \times 9.81 \times 0.100 \times \cos(20 \times \pi/180)$
$=74N$

B. Grade Resistance

Gr = w x sin 20°

= 80 x sin (20)

= 27.36

C. Acceleration Force: α

F = ma a = F/m

a=220/80

IX. LITERATURE REVIEW

The advancements in agriculture technology that came with wireless sensors, renewable energy, and robotics, as well as mechanization, have driven improvements in agriculture as a whole. The role of wireless sensors in agriculture and the food industry, as well as their potential in fostering productivity and sustainability in agriculture, was discussed by Wang et al. [1]. Abbasi et al. [2] built on this by discussing the role of wireless sensor networks (WSNs) in soil, irrigation, and environment monitoring. Mention is made by Fisher and Gould [3] to open-source hardware meant to serve as an economically accessible alternative to expensive instruments, which also provides some level of openness and affordability to researchers and smallholder farmers.

This technology also encompasses mechanization which directly translates into productivity. Mada and Mahai [4] discussed the role agricultural mechanization plays in the economic growth of small-scale farms. The benefits of robotics in agricultural labor and the employment risks associated with automation have been discussed by Marinoudi et al. [5]. Also notable is the adaptability of vehicles. Reina et al. [6] designed a model of terrain dynamics for precision agriculture, and vehicle active suspension systems for unmanned vehicles were designed by Fernandes and Garcia [7], thus improving mobility in a variety of conditions.

While the mechanization and robotics innovations have done much in improving farming efficiency, they have also highlighted the need for lower cost multi-functional mechanization in the case of small and medium scale farmers. High automation is less feasible in the developing parts of the world because of the cost, and this has pushed engineers to focus on combining low-cost mechanical innovations and hybrid approaches. This has enabled striking a balance between high-end robotics used in large scale farms and affordable multifunctional devices suitable for smaller farms.

There has been focus on the parallel innovations to reduce the cost and improve the productivity by focus on multi- functional devices. Sadik and Hussain [8] and Thange and Ugale [9] also designed multi functional farming machinery for ploughing, sowing and spraying using same equipment. Mahapatra and Kashyap [10] also did a theoretical work aimed at maximizing efficiency of power tiller rotavators using multiple criteria. Riyaz [11] presented a multipurpose cultivator for smallholder farm equipment.

The multi-purpose agricultural machines equipment n is the more pertinent relation to the work on the cultivators or the combined farming implements. These machines not only reduce the number of tools required, they also save time and the capital investment. For example, the cultivator, tiller, and seeder can be combined into one unit.

The digital transformation is beginning to enable the use of IoT and machine learning in the modernization of agriculture and the development of smart farms. Waleed et al. [12] employed IoT for the identification of types of farm machinery to enhance monitoring and efficient use. Bouali et al. [13] integrated IoT with renewable energy and cloud technologies for the implementation of energy efficient and remotely controlled agriculture. Wadav et al. [14] focused on energy security to provide IoT based solar PV pumping systems for irrigation considering India's diverse climatic regions.

The use of IoT and renewable energy with multifunctional devices gives rise to the possibility of constructing wireless agricultural cultivators. Such cultivators can be designed to integrate sensors, solar power, and communication modules to make farming tools and machinery autonomous, battery powered, and easier to operate for small farms. In theory, continued integration would provide cultivators with multifunctional devices that would be capable of assessing real time information and integrating automated systems, intelligent controls, and sustainable technologies to the operations for precision agriculture. Finally, Dhillon and Moncur [15] reviewed issues facing small farmers, such as costs and adoption, and describe some new opportunities presented by robotics, IoT, renewable energy, and affordable mechanization.

As noted in this paper, innovations in agriculture have progressed in a specific order: development of wireless sensors [1– 3], starting with mechanization and robotics [4–7], introduction of multifunctional low-cost equipment [8–11], and the integration of IoT and renewable energy systems [12–14]. Collectively, these innovations, along with those discussed by Dhillon and Moncur [15] will enable small farmers to participate in a more intelligent, sustainable, and inclusive agriculture ecosystem.

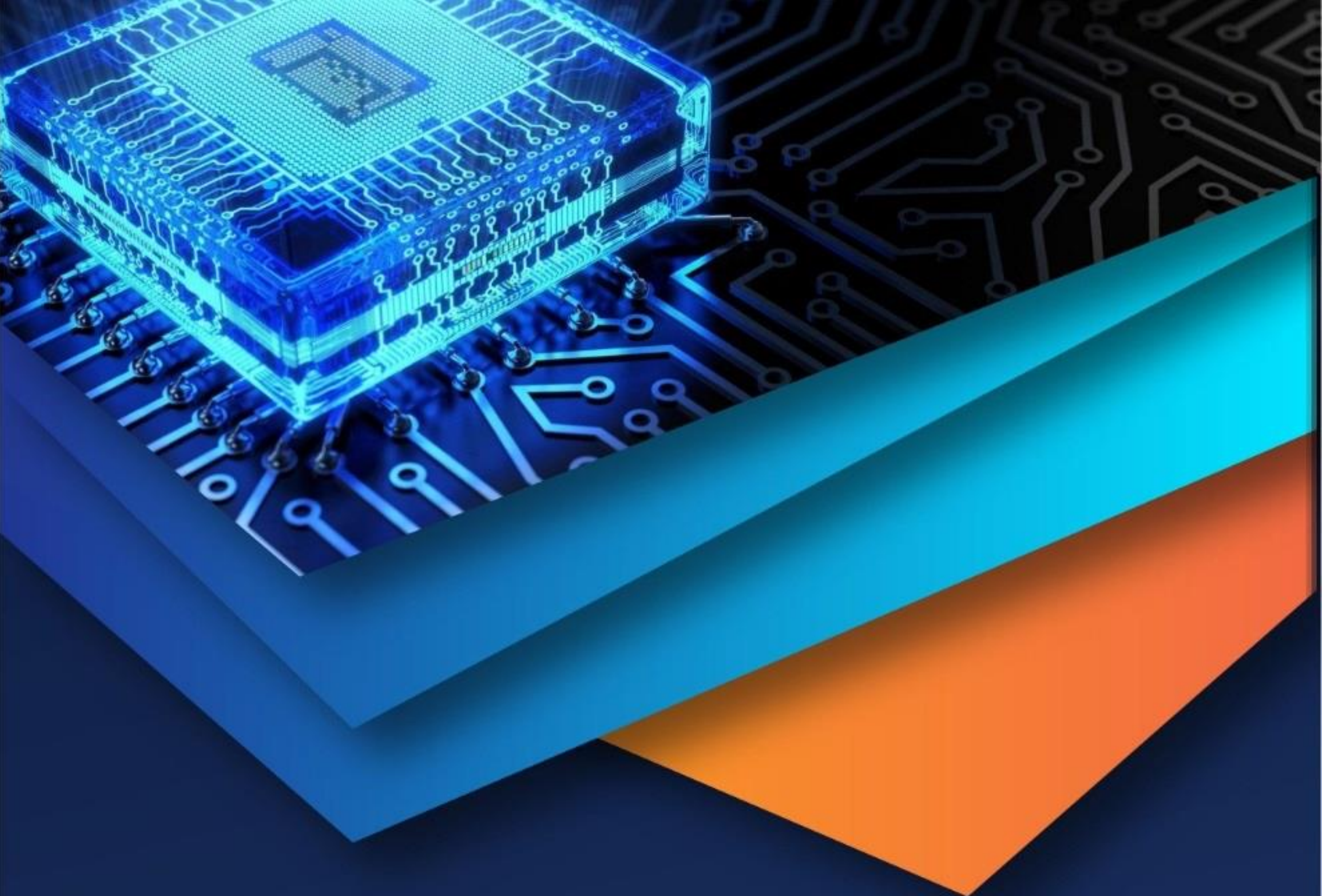
X. CONCLUSION

This study designed an automatic wireless farm machine for agricultural processes powered by solar energy. The prototype exhibits the capability to reduce the amount of labor, lower costs, enhance resource utilization, and foster sustainability in agriculture. Its capabilities to perform efficient weeding and tilling, real-time soil monitoring, and remote smartphone control make the machine a fortuitous asset to small eco-minded farmers.

The use of solar power as the design source signifies that the machine doesn't require much electricity, thus reducing the carbon footprint and aligning with international efforts towards sustainability. The next steps will be to use AI to make the machine smarter, optimize how well it can sense, and get it up and running on larger farms. Further testing in other locations will continue to refine the machine and make it an even better tool for a more efficient, sustainable, and affordable future for agriculture.

REFERENCES

[1] Wang, N.; Zhang, N.; Wang, M. Wireless sensors in agriculture and food industry— Recent development and future perspective. Comput. Electron. Agric. 2006.
[2] Abbasi, A.Z.; Islam, N.; Shaikh, Z.A. A review of wireless sensors and networks' applications in agriculture. Comput. Stand. Interfaces, 2014.
[3] Fisher, D.K.; Gould, P.J. Open-source hardware as a low-cost alternative for scientific instrumentation and research. Mod. Instrum., 2012.
[4] Mada, D. A.; Mahai, S. The Role of Agricultural Mechanization in the Economic Development for Small Scale Farms in Adamava State, 2013.
[5] Marinoudi, V.; Sørensen, C.G.; Pearson, S.; Bochtis, D. Robotics and labour in agriculture: A context consideration. Biosyst. Eng., 2019.
[6] Reina, G.; Milella, A.; Galati, R. Terrain assessment for precision agriculture using vehicle dynamic modelling. Biosyst. Eng., 2017.
[7] Fernandes, H.R.; Garcia, A.P. Design and control of an active suspension system for unmanned agricultural vehicles. Biosyst. Eng., 2018.
[8] Sadik, S. M. S. M.; Hussain, H. A. Design and fabrication of multipurpose farming machines. IJSART, 2017.
[9] Thange, R.B.; Ugale, A.G. Design and Fabrication of Multipurpose Agriculture Equipment, 2016.
[10] Mahapatra, J.; Kashyap, V. A Theoretical Method for Efficient Design of Power Tiller Rotavator Satisfying Multiple Objective, 2020.
[11] Riyaz, S. Multipurpose agriculture cultivator. Scienceopen Preprints, 2021.
[12] Waleed, M.; Um, T.W.; Kamal, T.; Usman, S.M. Classification of agriculture farm machinery using machine learning and internet of things. Symmetry, 2021.
[13] Bouali, E.T.; Abid, M.R.; Boufounas, E.M.; Hamed, T.A. Renewable energy integration into cloud & IoT- based smart agriculture. IEEE, 2021.
[14] Yadav, A.K.; Yadav, V.; Malik, H.; Khargotra, R.; Singh, T. Design of novel IoT-based solar powered PV pumping systems for agricultural applications in diverse climatic zones of India. Results in Engineering, 2024.
[15] Dhillon, R.; Moncur, Q. Small-scale farming: A review of challenges and potential opportunities offered by technological advancements. Sustainability, 2023.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY