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AI-based IOT Robotics for Precision Regenerative Agriculture

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Abstract

This research introduces an AI-based IOT farm robot to address the current lack of labor and inefficiencies in Pakistan's agricultural sector, which are still relying primarily on conventional manual methods. The proposed 'Agro-Bot' reduces human labor input and increases rustics utilization, thereby increasing efficiency and sustainability of farm activities. The industry's current limitations i.e., lack of skilled farmers and little automation are still holding it back. Furthermore, the general application of tractors with gasoline further pollutes the environment with poisonous chemicals. To counter this, the high-tech robot employs a completely battery-operated system in an attempt to minimize pollution and anchorage green farming. Equipped with a mounted tiller, the robot achieves maximum land tilling and soil preparation. The robot also comes equipped with sensors to detect the pH content of the soil and offers automatic watering when necessary. High-precision seed sowing is achieved with reduced human capital, enhancing precision and consistency in plant growth. AI-based IOT control enhances farm operations and promotes automation levels in agriculture in Pakistan through a smartphone app. Overcoming tremendous challenges related to individuals and preservation of nature, this study enhances modernization and development in agriculture with enhanced productivity and improved balance of nature.

Index Terms: *Artificial Intelligence, Autonomous Robot (Automation), IoT Agriculture, Precision/Smart Irrigation/Farming, and Regenerative Agriculture.*

I. INTRODUCTION

A large number of the world's economies are reliant on agriculture for raw materials, food, and jobs [1]. But moreover, the ever-growing population of the world and climatic changes have made problems for the agricultural sector even worse. Over the last few years, Internet of Things (AI-based IOT) has emerged as one promising technology that has the ability to transform the agriculture sector. AI-based IOT solutions can also optimize the use of resources, reduce labor costs and increase crop yields [2]. Some of the areas where AI-based IOT can make a big impact are in watering and seeding. Watering and seeding are the two critical steps in crop production. These systems contain a lot of manual labor, which tends to result in unevenly spaced seeds, inadequate water supply, and loiter yields.

The adoption of AI-based IOT systems and robotics in agriculture transforms the traditional farming practices by permitting automation in soil monitoring, ploughing, seeding and irrigation. Research indicates how multitasking agricultural robots equipped by microcontrollers like the ESP32 integrate various sensors and actuators for seamless operation [5]. This research presents an overview of the design and development of a sophisticated multi-tasking Agro-Bot that assists farmers in monitoring farm work remotely. The robot employs technologies such as Dual Tone Multi-Frequency (DTMF), GSM modules, thermal sensors, sound sensors, GPS location tracking, and flex sensors to perform several tasks like detection of pests, intruder alarm, and spraying pesticides [6].

The Agro-Bot operates through DTMF signals so that farmers to drive it from anywhere with the use of a mobile phone. It has a metal body to ensure any resistance and comes equipped with self-security features, including GPS tracking and pressure sensors, against theft. Robot logic-based decision making capability enables it to navigate agriculture facilities, perceive obstacles, and respond to the environment changes. The study emphasizes the robot to reduce farmer's workload, productivity, and also address problems such as farmland farming and crop protection [6].

The pH value of soil is a primary factor affecting crop yields, nutrient availability, and soil health. Conventional laboratory methods of approximating pH, e.g., glass electrodes, are precise but have drawbacks such as fragility, high expense, and tedious procedures. The paper discusses improved alternatives, such as Ion-Sensitive Field-Effect Transistors (ISFETs) and Conductimetric sensors. ISFETs, with substitution of a metal gate with a pH-sensitive membrane, provide good, solid-state pH sensing that is highly sensitive and can be miniaturized. Conductimetric sensors, making use of polymers such as Polyaniline (PANI), sense pH based on variation in electrical conductivity and are cheap and simple to build. Despite their advantages, both technologies face challenges such as sensitivity drift and calibration requirements. The authors propose a novel in-situ soil pH sensor using metallic nanoparticles (e.g., antimony and zinc) to enhance sensing efficiency and eliminate the need for external power sources. This portable, nanotechnology-based sensor aims to provide real-time, accurate pH measurements directly in the field, addressing the limitations of existing methods and supporting precision agriculture practices. Table I shows the state-of-the-art development in Agro-Seedo domain.

Table I: The State-Of-The-Art Development in Agro-Seedo Domain

S. No.	Ref#	Year	Current State-of-the Art Literature	Key Focus	Summary
1.	[3]	2024	Title: Design and Development of a Multi- Tasking Autonomous Agriculture Robot using ESP32 Microcontroller	Autonomous Multitasking Agricultural Robot	A Solar-Powered Robot Controlled Via ESP32 Microcontroller and Wi-Fi, designed for Ploughing, Seeding, Irrigation, and Harvesting, Improving Efficiency While Promoting Sustainable Agriculture
2.	[4]	2024	Title: Integrated Multi-Dimensional Technology of Data Sensing Method in Smart Agriculture	Advanced Data Sensing Framework	Uses Wireless Sensor Networks, Mobile Robots, and Machine Learning to Improve Precision Farming Through Real-Time Monitoring and Edge Computing
3.	[5]	2022	Title: Multi-Tasking Agricultural Robot	Multi-Functional Robotic Farming System	A Solar-Powered Robot Using Zigbee and Joystick Control to Perform Ploughing, Seeding, Grass Cutting, and Pesticide Spraying, Reducing Manual Labor
4.	[6]	2022	Title: Review of Agriculture Robotics: Practicality and Feasibility	Challenges in Agricultural Robot Implementation	Identifies Barriers Like Infrastructure, Reliable Connectivity, Human-Robot Interaction, and Software Reusability, Limiting Scalability Despite Technological Advancements
5.	[7]	2022	Title: The Design of General Purpose Autonomous Agricultural Mobile-Robot: "AGROBOT"	Autonomous Precision Farming Robot	Uses GPS, IMU, and TARBIL Cloud Services for field Monitoring, Spraying, and Yield Analysis. Features a Modular, Low-Cost Design
6.	[8]	2021	Title: Agricultural Robot for Automatic Ploughing and Seeding	Multi-Functional Farming Robot with Bluetooth Control	Performs Ploughing, Seeding, Humidity Monitoring, and Pesticide Spraying using an AVR Microcontroller and Bluetooth-Based Manual Control
7.	[9]	2021	Title: Soil pH Sensing Techniques and Technologies	Advanced Soil pH Sensing	Reviews Traditional and Modern Techniques, proposing a Sensor using Metallic Nanoparticles for Real-Time, Portable pH Measurement
8.	[10]	2020	Title: Advanced Multi-Tasking AGROBOT	Smart Soil pH Sensor	Highlights Limitations of Existing Soil pH Sensing Methods and proposes an in-situ-sensor using Metallic Nanoparticles for Precision Agriculture

This research aligns with sustainable development goal "Climate Action". As the world strives to achieve the 2030 Agenda for Sustainable Development, technological innovation is one of the drivers of the 17 Sustainable Development Goals (SDGs). The SDGs, which are United Nations - endorsed, provide an integrated framework to tackle the world's most significant challenges - from poverty and inequality to climate action and sustainable industrialization. In recognition of this charge, the Electrical Engineering Department at Bahria University aligned Final Year Research's (FYP's) with SDGs so that innovations from the students can create a positive impact on society and the environment.

II. DESIGN METHODOLOGY

CAD design is the base of this fabrication of the research. This base will ensure that all of the components are arranged and aligned in the set aims. The system's structure and operation can be researched and thereby ensures precise assembly and smooth operation. Mechanisms regarding the process of ploughing, seeding, etc., will be designed by the CAD design as shown below keeping in view the environment sustainability and automation in the process.

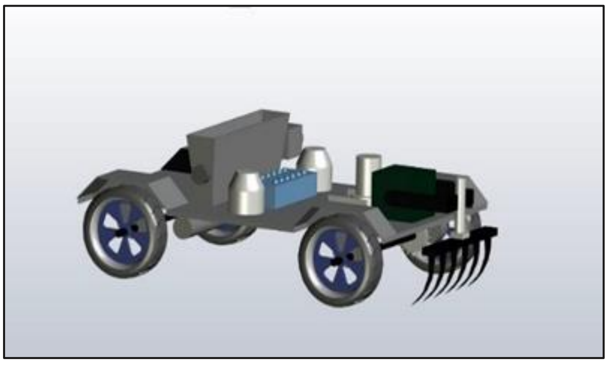

Figure 1: Front View of Robot

A. Tilling Mechanism

This robot has a tiller mechanism that is operated by a stepper motor as seen in Figure 2 and Figure 3. The mechanism moves up and down depending on the input received through AI-based IOT [11]. This will result in accurate and controlled ploughing without using fossil fuels. This design supports eco-friendliness with the automation of the process of ploughing to achieve efficiency.

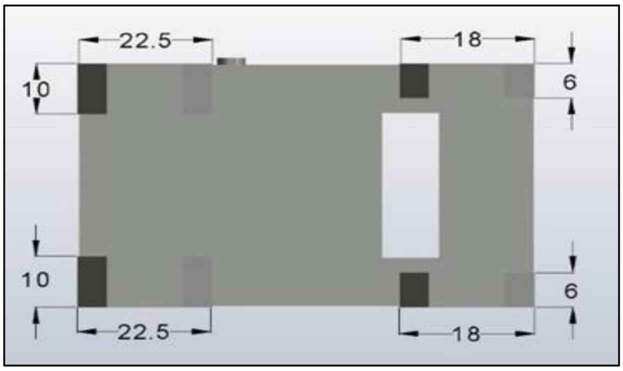

Figure 2: Top View Robot Chassis

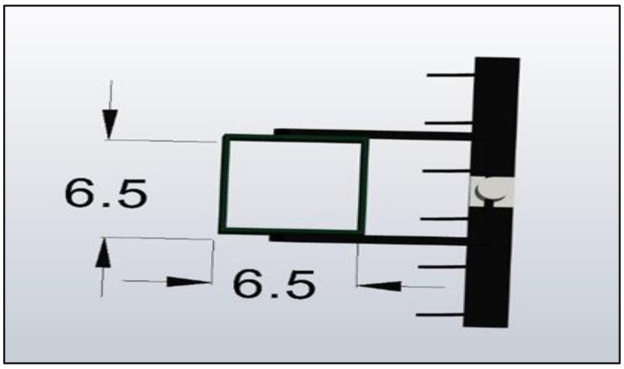

Figure 3: Tilling Mechanism

B. Seeding Mechanism

This seeding mechanism proposes using the system of DC motor-based mechanism as seen in Figure 4 controlled by AI-based IOT and hence provides for the best mechanism of regulated seeding using regulation of speed in which conditions of the soil are optimized while considering conditions for growing the crop. In turn, it helps reduce the effort done manually, has minimal probability of error, and promotes distribution of seeds in homogeneous portions.

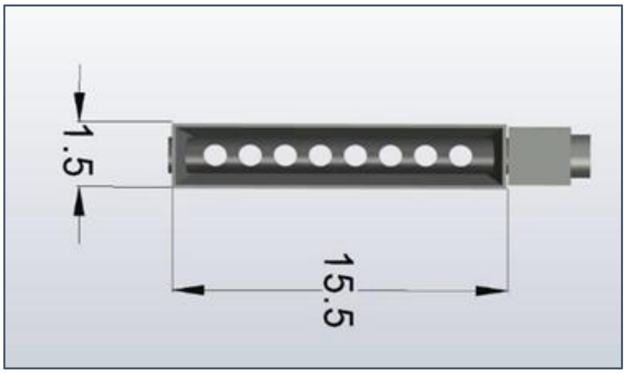

Figure 4: Seed Sowing Mechanism

C. Watering Mechanism

This water tank with a water pump attached is placed on the robot itself, while providing an evenly balanced amount of water to the crops with sprinklers, and the water pressure maintained by the system allows the irrigation to be done without manually having to intervene. Therefore, it reduces the necessity for outside water sources while it also maximizes the consumption of water, making it less time consuming and labor-intensive.

D. PH Value Monitoring

It has integrated a soil moisture sensor on the robot, not only measuring soil moisture but also showing data related to the pH value of the soil. Since it is designed to move upward and downward, it gets the readings at different soil depths for more accurate determination. The pH sensor connected to the robot's system is controlled through the AI-based IOT application, giving real-time monitoring and feedback. The pH data can be easily accessed by farmers through the AI-based IOT app., thus enabling them to make the right decisions regarding soil treatment and crop care. Through automation an integration of AI-based IOT technology, it aim to reduce manual effort and enhance the efficiency of soil management [2].

E. Agro-Seedo Motor Control

The shaft of the DC motor is coupled with chain drive mechanism that allows rotational motion from the motor which is to be transferred to the wheels of the robot. This chain drives mechanism as shown in, '*Error! Reference source not found'*. enables the robot to travel over ground efficiently, delivering the needed torque and traction for movement in various landscapes. With different operating speeds and angles and by enabling speed control, the DC motors and motor driver do such work as tilling, sowing and irrigation. All of this time, the mechanism has to ensure smooth motioning and steering.

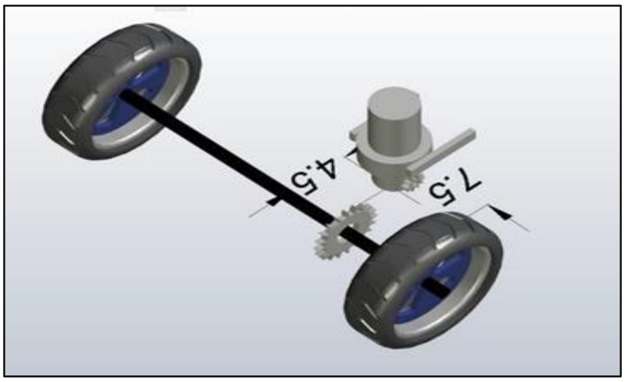

Figure 5: DC Motor Mechanism

F. The Physical Structure

The body design, therefore, took into account the crucial parameter of the robot's wheel dimensions, measuring 12 inches in diameter. Thereafter, it carefully drafted the body frame to provide adequate space for the wheels and motors, while ensuring that the robot remains stable and balanced during movement. As a result, the axle (rod) lengths for the wheel's diameter determined during the frame design stage, allowing for an even distribution of weight so that the robot does not become unstable during operation. It chose aluminum for the ploughing mechanism because it is both strong and light weight, making it ideal for handling the repeated force and stress that comes to with working the soil. It doesn't break easily and the lasts a long time, which is exactly what's needed in the field. For the wheel rods, it also is built with aluminum since it can handle heavy loads without bending or cracking, so the wheels stay steady and rotate smoothly even when moving over rough or uneven ground.

The central chassis and body frame is made of a 20-gauge iron sheet. Iron was utilized for the chassis due to the fact that it can withstand the weight of all mounted components without caving in, and it offers a stable base that will distribute the entire weight flawlessly around the whole frame. This even weight distribution keeps the robot stable and no part under the undue pressure and this adds to the structure's durability and longevity (See Figure 6- Figure 11).

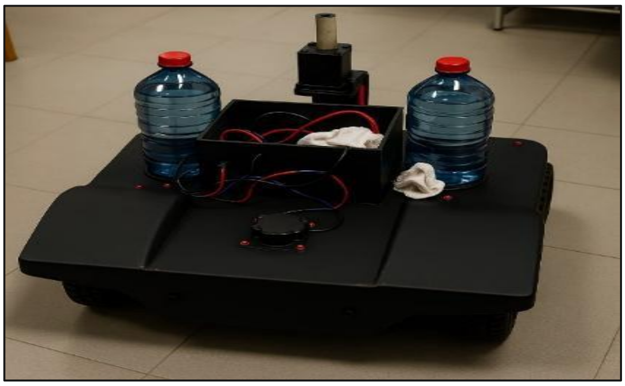

Figure 6: Front View of Robot

Figure 7: Chain Mechanism

Figure 8: Turning Mechanism

Figure 9: Bottom View of Robot

Figure 10: Structure of Robot

Figure 11: Overall View of Robot

Through the application of aluminum to construct parts where strength and flexibility are both required and iron to the structural support, the overall framework gets the ideal balance between weight, strength, longevity and this renders the robot effective and reliable to carry out its intended agricultural tasks.

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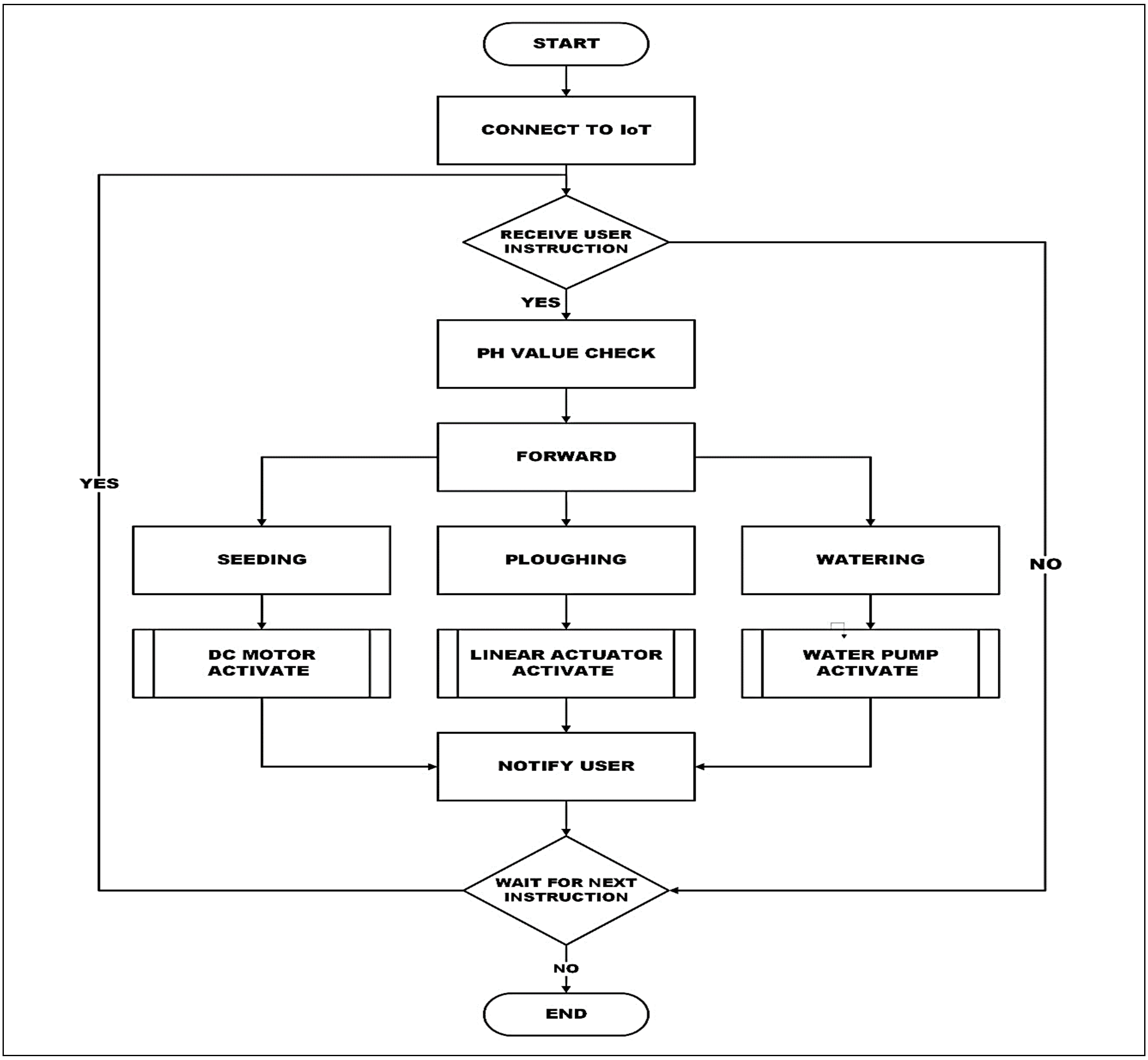
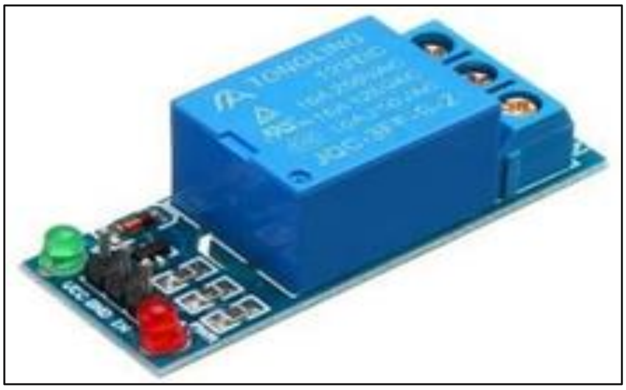


Figure 12: Flowchart of AI-Based IOT Aglro-Seedo Procedure

G. Water-Pump and Relay Module

To automate soil watering, a 12V DC water pump is used alongside a relay module (see Figure 13).

(a)



(b)

Figure 13: (a) A 12V Water Pump; (b) Relay Module

The relay module acts as an electronic switch, controlled by the ESP32 microcontroller to turn the water pump on and off based on soil moisture readings.

H. AI-Based App Development

It used MIT App Inventor to design an intuitive AI-based IOT interface for controlling the robot [12]. The platform allows us to create a custom application for tasks like monitoring sensor data, controlling the water pump, and operating the motors wirelessly.

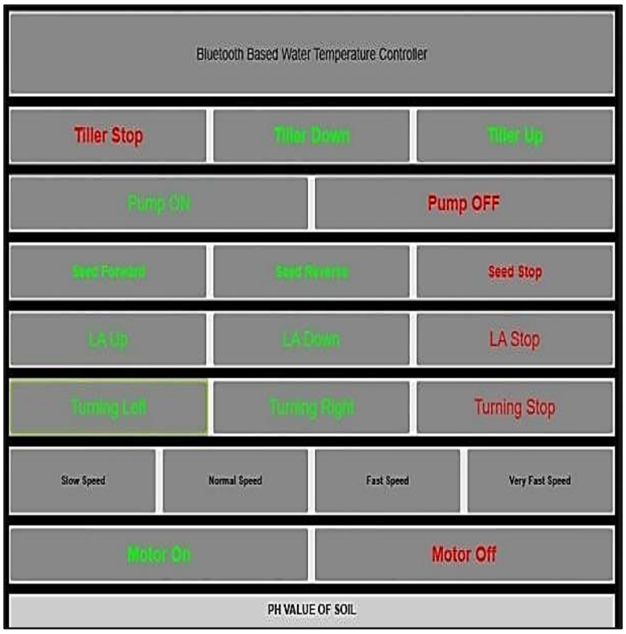


Figure 14: AI Based App Development

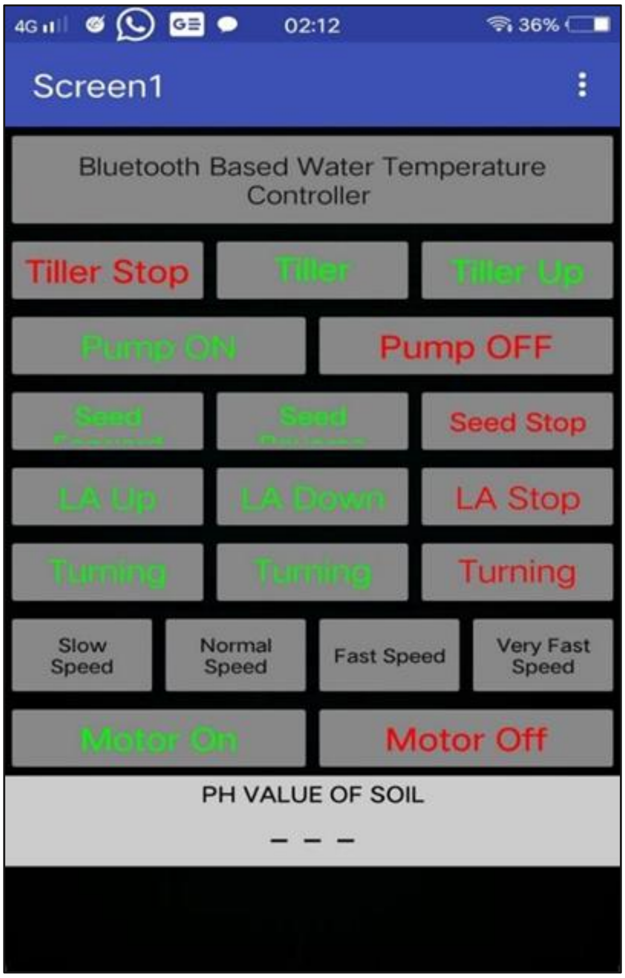


Figure 15: User Interface from Mobile

I. Circuit Design and Component Specifications

The circuit diagram of the ploughing and tilling system highlights the integration of mechanical and electronic components that enable semi-automated or fully automated soil preparation.

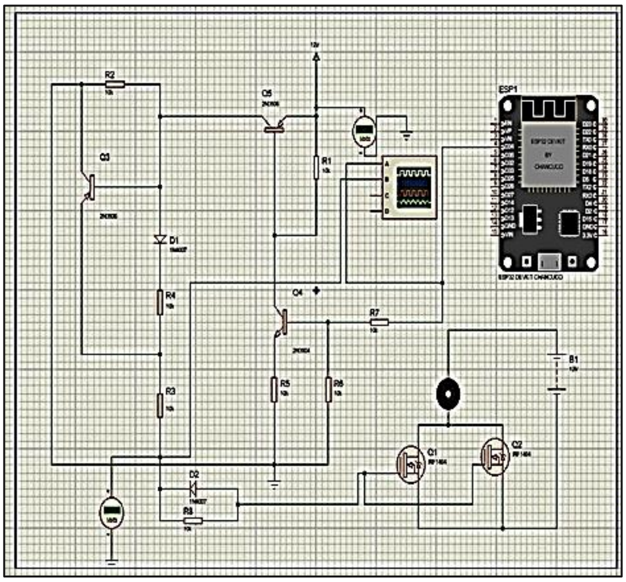


Figure 16: Circuit Diagram Illustrating Elements of Ploughing and Tilling

The dimensions of individual components play a crucial role in determining the overall design, balance, and functionality of the machine. Accurate measurements ensure that each part fits correctly within the assembly and contributes to smooth operation without causing misalignment or unnecessary strain on other elements.
For the frame, the length, width, and height are carefully chosen to provide stability while minimizing excess weight, making it easier to transport and operate in agricultural fields. Below tables elaborate related information.

Table II: Components Dimensions

S. No.	Component	Dimensions (L × B) (Inches)	Weight (Kg)
1.	**Base Frame**	56.5 × 34	—
2.	**Water Bottles (×2)**	Ø7 (cylindrical)	7 × 2 =14
3.	**Battery**	9.5 × 5.5	10
4.	**Motor**	7.5 × 4.5	11
5.	**Tiller Box**	6.5 × 6.5 + rods	10
6.	**Seed Sower**	15.5 × 1.5	4.5

Table III: Total Weight Calculation

S. No.	Component	Quantity	Weight (Kg)	Total (Kg)
1.	**Water Bottles**	2	7	14
2.	**Battery**	1	10	10
3.	**Motor**	1	11	11
4.	**Tiller + Rods**	1	10	10
5.	**Seed Sower**	1	4.5	4.5
6.	**Total**			49.5 kg

Table IV: Assume Coordinates of Components on Base

S. No.	Component	Approx. Position (X, Y) (Inches) Centre of Mass	Weight (Kg)
1.	**Battery**	(10, 17) → front-left	10
2.	**Motor**	(46, 17) → rear-right	11
3.	**Water Bottle 1**	(20, 5) → left side	7
4.	**Water Bottle 2**	(20, 29) → right side	7
5.	**Tiller Box**	(53, 17) → back-center (6" behind frame)	10
6.	**Seed Sower**	(30, 17) → center	4.5

It'll assume the base's origin (0,0) is at the front-left corner. It'll compute the center of gravity (X, Y) as a weighted average:

X-Coordinate:
$X_{cg} = \sum(X_i \times W_i) / \sum W_i$
$X_{cg} = 10\times10+46\times11+20\times7+20\times7+53\times10+30\times4.5 / 49.5$
$X_{cg} = 100+506+140+140+530+135 / 49.5$
$X_{cg} = 1551 / 49.5$
$X_{cg} = 31.3$ in

Y-Coordinate:
$Y_{cg} = \sum(Y_i \times W_i) / \sum W_i$
$Y_{cg} = 17\times10+17\times11+5\times7+29\times7+17\times10+17\times4.5 / 49.5$
$Y_{cg} = 170+187+35+203+170+76.5 / 49.5$
$Y_{cg} = 841.5 / 49.5$
$Y_{cg} = 17.0$ in

The robot can carry out major farm operations autonomously such as ploughing, watering, and planting seeds. Soil pH level monitoring and sensor-controlled automatic irrigation increase precision farming. Battery power-driven operation has extremely low environmental footprint in comparison with traditional tractors. AI-based IOT compatibility allows remote control and monitoring via mobile devices, increasing usability. Overall, the research was successful in fulfilling its primary objectives and validated the feasibility of adopting smart farm solutions in Pakistan.

III. RESULTS AND FINDINGS

Designed a user-friendly app for controlling the agricultural robot using MIT App Inventor. Buttons are available on the app to operate the robot, check sensor readings, and activate automated functions. Following the development of the app, it tested its functionality to ensure smooth communication between the app and the robot's control system.
The water pump was successfully integrated with the system of the robot, so that it will automatically water and manage water. Thus, this work shows its potential to reduce water loss and enhance water efficiency in agricultural contexts. The motor driver was designed and developed to handle the movement of the robot. The motor driver was developed to be a control system that will allow for smooth and precise movement of the robot. The system was integrated with a soil sensor resistive rod based, which monitored the pH levels of the soil. This is proof that the research can acquire and analyses vital soil data to make proper decisions to ensure proper crop growth.
The figure below illustrates the operation of the ESP (Electronic Speed/Pulse Controller or ESP32 microcontroller, depending on context) when configured to deliver a 100% Pulse Width Modulation (PWM) signal.

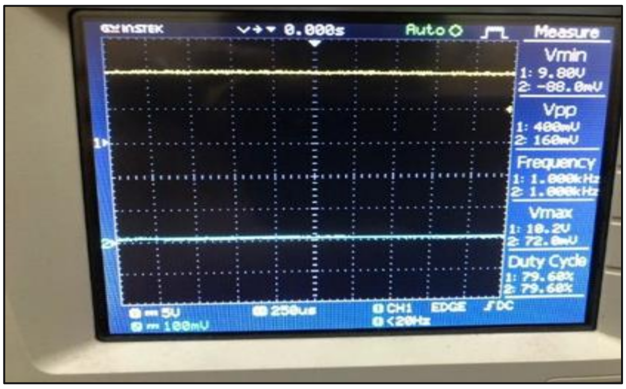


Figure 17: ESP at 100% PWM Signal Output

IV. RECOMMENDATIONS FOR FUTURE DEVELOPMENT OF AI-BASED IOT AGRICULTURAL ROBOT

In order to optimize the efficiency, usability, and practical impact of the suggested AI-based IOT agricultural robot, some improvement and development directions are suggested as recommendations for the future versions. These improvements will make the robot a more effective, sustainable, and user-friendly tool for farmers. Combining solar charging systems can significantly improve the robot's energy autonomy and sustainability. Using solar power, the robot can also recharge itself occasionally when it is not in use, less relying on manual recharging and grid supplies which help the better in efficiency. This will be very supportive in rural or remote locations with no electricity supply where the robot does not require too much recharging. Furthermore, solar charging has the capability of reducing the robot's carbon footprint, an environment-friendlier choice for farmers.

V. CONCLUSION

This AI-powered AI-based IOT agriculture robot is a game-changer for Pakistan's farming. It tackles labor shortages and outdated methods by automating tasks like tilling, seeding, watering, and soil monitoring. Using AI, it makes smart decisions to boost crop yields while saving resources and cutting emissions with its battery-powered design. The smartphone app lets farmers control it easily, reducing manual work. While testing shows that it is reliable, there is still room to improve battery life and scalability. This research demonstrates that technology can make farming greener and more efficient, paving the way for a sustainable future.

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Authors Contributions

All the authors equally contributed to this research study.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Data Availability Statement

No data is used in this research.

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