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Automated Fertilizer Dispensing System for Crops

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Abstract

Agriculture remains a cornerstone of the Indian economy, yet traditional farming methods often suffer from inefficiencies, particularly in fertilizer application. The Automated Fertilizer Dispensing System for Crops aims to address these challenges by integrating embedded systems technology to automate the fertilizer dispensing process, reducing human intervention and optimizing resource utilization. This system is particularly designed for hydroponic farming, where precise nutrient delivery is critical for crop health and yield. The proposed system leverages a PIC18F452 microcontroller, which controls solenoid valves to dispense fertilizers in precise ratios based on real-time environmental conditions detected by a DHT-11 temperature and humidity sensor. A flow sensor monitors the fertilizer mixture, ensuring accurate dispensing as per pre-configured crop-specific requirements. The system provides a user-friendly interface via an LCD display and keypad, allowing farmers to input desired fertilizer ratios and monitor real-time data. Additionally, the system minimizes overuse of fertilizers, thereby reducing environmental pollution and promoting sustainable agricultural practices. Through automation, this project aims to enhance efficiency, reduce labour costs, and improve crop productivity while ensuring optimal nutrient distribution. Future advancements may include IoT-based remote monitoring and AI-driven adaptive fertilization techniques to further refine the precision and adaptability of the system across different farming conditions.

Keywords: DHT-11 Temperature & Humidity Sensor; Hydroponic Farming; PIC18F452 Microcontroller; Flow Sensor; LCD Display & Keypad; IoT- Based Remote Monitoring; AI-Driven Adaptive Fertilization Techniques

Introduction

Agriculture has been the core of the Indian economy since well before the coming of the industrial revolution. With all the advancement in technology, traditional methods of farming, including manual fertilization, continue to dominate the practice of farming across much of India. Manual fertilization is not only time-consuming but also human errorprone, which makes it inefficient and causes environmental degradation through excessive application or misuse of fertilizers. There is a necessity for accuracy in fertilizer application since overuse of fertilizers may result in serious environmental problems including groundwater pollution, water body eutrophication, and health risks such as methemoglobinemia, or popularly referred to as "blue baby syndrome." To resolve these issues, the idea of an Automated Fertilizer Dispensing System for Crops has come about. This system utilizes embedded systems technology to mechanize the fertilization process, providing accurate and effective application of fertilizer and reducing human handling.

The system proposed is to be tailored to hydroponic farming, which is a soil-less way of cultivating crops using nutrient-rich water solutions. Hydroponic farming is increasingly popular because it can yield high yields using less space and water and as such is well suited for urban farming and regions where there is little arable land. Yet, the success of hydroponic agriculture greatly relies on the proper use of fertilizers in appropriate ratios. The Automated Fertilizer Dispensing System seeks to meet this requirement by employing a PIC18F452 microcontroller, water flow sensors, humidity sensors, and solenoid valves to release fertilizers in specific ratios depending on the particular needs of the crop that is being grown. This system not only minimizes the labor of manual fertilization but also ensures that fertilizers are used efficiently, resulting in less environmental damage and more sustainable agricultural practices.

Conventional Fertilizer application methods

In traditional soil-based agriculture, fertilizers are applied by broadcasting, banding, or injecting solutions into the field. Broad-spectrum chemical fertilizers (e.g. urea, DAP, NPK mixes) and organic manures are typically broadcast by hand or machine across soil. These methods are inherently imprecise: nutrients are unevenly distributed, with large portions remaining unused or lost to runoff, volatilization, and leaching. For example, only a fraction of applied nitrogen reaches the crop, while the rest contaminates water bodies and groundwater[1]. Excess fertilizer runoff triggers algal blooms and hypoxia (oxygen depletion) in lakes and streams. Leached nitrates in drinking water pose serious health risks, including methemoglobinemia ("blue baby syndrome"). Thus, conventional fertilization tends to waste resources and degrade the environment.

Traditional practices rely heavily on coarse scheduling and blanket dosages. Farmers often apply fertilizers at fixed intervals or mix them into irrigation water without real-time feedback. This "set-it-and-forget-it" approach ignores site-specific crop needs and changing weather, leading to over-application. Moreover, heavy manual labour is required to mix and distribute fertilizers manually on each field. In India especially, labour-intensive methods dominate because many farmers lack access to precision equipment. This inefficiency not only increases input costs but also causes soil nutrient imbalances and health problems: for example, high nitrate levels in fields can leach into wells and cause public health issues[2].

By contrast, a hydroponic automated system delivers nutrients in a closed loop. In hydroponics, plants are grown in nutrient-rich water, and fertilizers are continuously recirculated. This minimizes waste by reusing the solution, and the precise ratio of nutrients is maintained. Automation of fertilizer injection means that only the necessary nutrients are added, tailored to the crop's stage and the real-time conditions. In practice, automated fertigation has been shown to greatly reduce excess fertilizer use. For example, one study reported that a control-based fertigation system cut fertilizer consumption by about 10%–30% compared to traditional methods, while improving water-use efficiency. In short, traditional fertilizer application (manual broadcast or fixed schedules) suffers from large inefficiencies and environmental harm, whereas automated hydroponic dosing targets nutrients precisely to plant needs, reducing waste and pollution.

Hydroponic farming

The hydroponic system may be drawing lots of population nowadays but the process was developed in the end part of 600 B.C under King Nebuchadnezzar II and was named Hanging Gardens of Babylon. These are thought to have been among the earliest mass scale hydroponic endeavors. The demand of the Hydroponic system is emerging extremely as free land spaces are shrinking[3]. Even though the agriculture is soil-less, the growth rate of the plants is rapid and hence the production is relatively high. The requirement of hydroponics also covers the reasons such as off-season harvesting, lesser consumption of water, pesticide-free, and no actual reliance on the weather.

Hydroponics refers to a technique of cultivating plants in water without using soil[4]. Water is to be loaded with nutrients and plants require an inert medium for the root system. Incorporating technology facilitates planning of food/crops and therefore assist bridge in the food security chain. While the trend towards hydroponic growth in Indian agriculture is on the increase yearly, it would appear there exists a big pool of farmers with little knowledge concerning hydroponic systems. Across India Hydroponic farming is extending its roots[5].

A hydroponic system with greenhouse farming, is revolutionizing urban farming to a scale which is making the process of agriculture easier. Hydroponic is turning out to be one of the lucrative businesses in India. There are numerous aspects such as vast population which ensures that the growth rate of the market can be enhanced, conducive climatic conditions, availability of favourable labour costs and smart human capital. Also, the hydroponic techniques, food security, pest control and other necessities of farming.

There is already expertise in the market. Vine plants and leafy vegetables can be cultivated with hydroponics. Commercially there are two important considerations to be taken care of, one is vacant space and another is cost, depending on what you wish to cultivate the system must be set up accordingly. Hydroponic farming can be done very conveniently in gardens and rooftops too. Yet there are some problems associated in implementing Hydroponics in India:

Lack of Education & Awareness

The absence of education and exposure among farmers for all these issues and technical advances is a great issue[6]. There is a need for technical know-how, right down to micro-managing the temperature and the humidity. A single blip in ambient temperature could lead to huge losses for the crops. Most farmers aren't even cognizant of hydroponics, never mind how to utilize it. When we look at the fact that this technology is flourishing largely in the start-up segment of young, Urban Indians, the issue becomes apparent.

Heavy Initial Investment & Maintenance Costs

Establishing a hydroponic farm is far more costly than conventional farming, particularly in India[7]. To control the environment and grow the plants, at least a building-like structure is required, as well as food-grade plastic trays and pipes. This setup typically ranges from Rs. 50,000 and above per 1,000 sq. ft. Plumbing equipment and automation, including sensors, controllers, water pumps, and lights, all come with hefty costs. Other needs involve funds donated to consultants, expenses incurred to manage ambient temperature, water purification, and creating manufactured plant nutrients like nitrogen, potassium, calcium nitrate, phosphorus, and other micronutrients like manganese, zinc, and others.

Lack of Financial support from the Government

Hydroponics have enormous initial investment expenses so it is not realistic for a normal Indian farmer to bear all the expenses himself. In India, the state and central government subsidized the capital expenditures of farmers ready to invest on hydroponics. Moreover, the precise subsidy suitable is different for every state. Recently the government of Maharashtra has granted a 50% subsidy to farmers to implement hydroponics for rearing animal fodder-Hydroponic Farming[8]. Likewise, the subsidy has been planned for all states individually by the National Horticulture board. According to most of them, however, these are credit-linked subsidies and the farmer is supposed to repay the amount within a specified time period. Also, with the exception of the state of Maharashtra the subsidies provided by the other states are very minimal in order to commence hydroponics which discourages the farmers.

Surveys on Hydroponics

Surveys on hydroponics reveal a growing awareness and interest in soilless farming techniques, particularly among urban populations, young entrepreneurs, and sustainability advocates[5]. Respondents often highlight the benefits of hydroponics such as reduced water usage, faster plant growth, and the ability to grow crops in limited spaces.

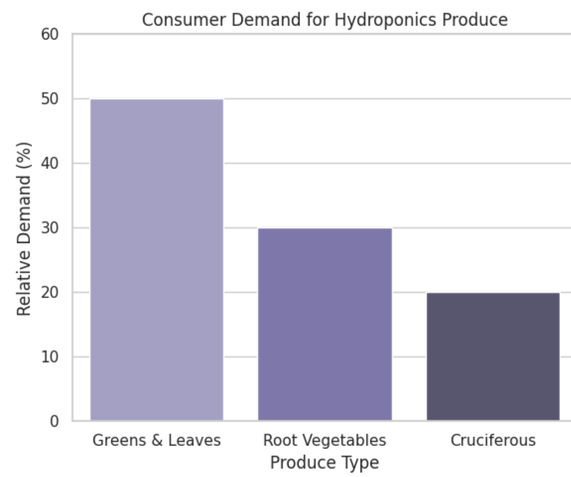

Fig 1. Consumer demand for hydroponics produce

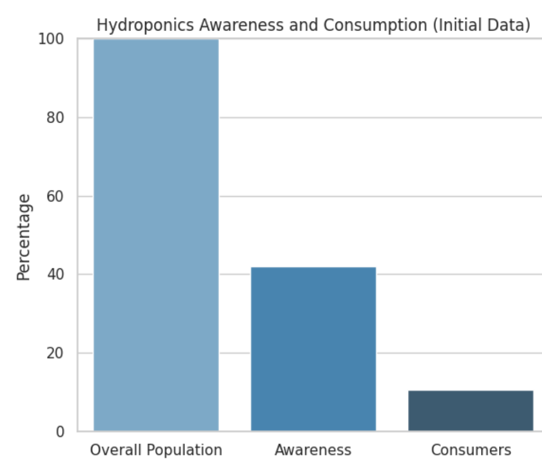

Fig 2. Hydroponics awareness & consumption (outdated survey)

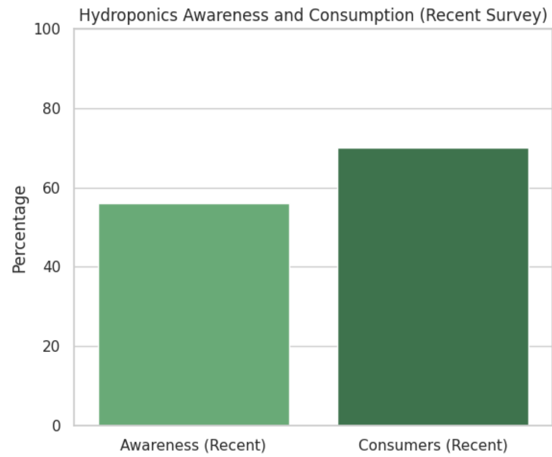

Fig 3. Hydroponics awareness & consumption (recent survey)

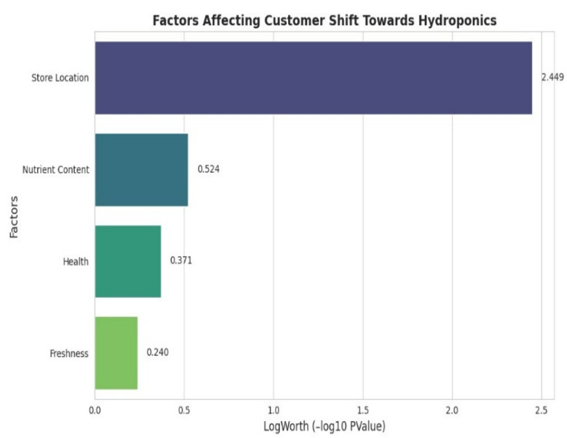

Fig 4. Factors affecting customer shift towards hydroponics

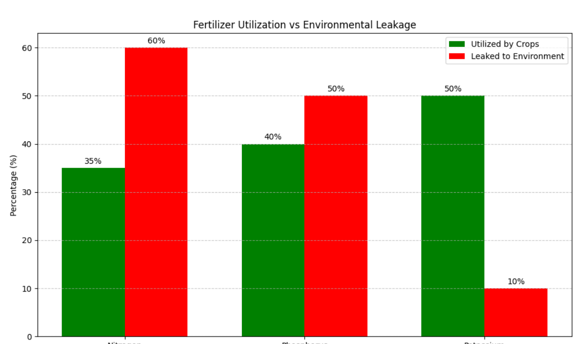

Fig 5. Fertilizer Utilization & Environmental Leakage

Circuit Design & Proposed Method

The Automated Fertilizer Dispensing System for Crops is a highly advanced system to automate hydroponic crop fertilizer application. The system utilizes embedded systems technology, such as a PIC18F452 microcontroller and sensors for accurate and efficient fertilizer dispensing. The circuit design for the Automated Fertilizer Dispensing System centres around the PIC18F452 microcontroller, which coordinates input from a DHT-11 temperature and humidity sensor and a flow sensor to automate fertilizer delivery with precision. The automated fertilizer dispensing system is a sophisticated hydroponic solution that intelligently manages nutrient delivery through seamless integration of environmental sensing, user input, and precision control. Built around the PIC18F452 microcontroller, it continuously processes data from a DHT-11 sensor monitoring temperature (0-50°C) and humidity (20-90%), alongside a Hall-effect flow sensor tracking liquid movement with 450 pulses per Liter accuracy. Farmers interact via a 16x2 LCD displaying real-time metrics like flow rates, cumulative usage, and environmental conditions, paired with a matrix keypad for setting crop-specific EC/pH targets, adjusting dosing schedules, and system calibration. Actuation is handled by MOSFET-driven solenoid valves capable of 0-10L/min flow control, governed by PID algorithms maintaining $\pm5\%$ nutrient concentration tolerance through pulse-width modulation synchronized with sensor feedback. A robust 5V power supply with EMI filtering and overvoltage protection ensures stability, while backup capacitors sustain operations during brief outages. Validated through Proteus simulations modelling sensor responses and failure scenarios, the system self-calibrates for variables like fluid viscosity and temperature drift, performing initialization checks, environment scans, and dose calculations before executing precision delivery.

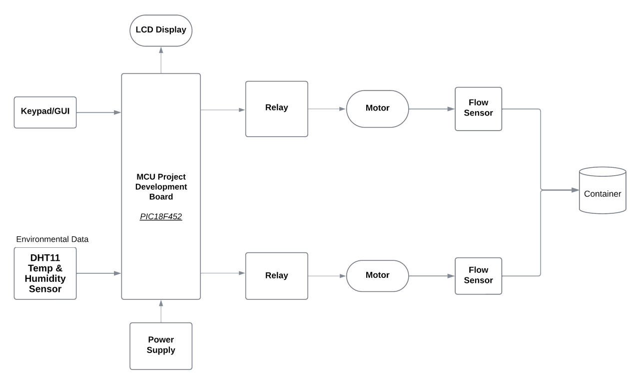

Fig 6. Block Diagram

The block diagram of the proposed system (Figure 6) provides a visual representation of how the components interact with each other.

The proposed method for the Automated Fertilizer Dispensing System involves a series of steps that ensure precise and efficient fertilizer application. The system operates based on real-time environmental data and user inputs, automating the fertilization process to minimize human intervention and reduce the risk of over-fertilization. Below is a detailed explanation of the proposed method:

System Initialization

The system starts by initializing the PIC18F452 microcontroller and all connected components, including the DHT11 sensor, water flow sensors, solenoid valves, and LCD display. The microcontroller checks the status of each component to ensure that the system is ready for operation.

Environmental Data Collection

The DHT11 sensor collects real-time data on temperature and humidity levels in the environment. This data is sent to the microcontroller, which processes it to determine the optimal conditions for fertilizer application.

User Input

The user inputs the desired fertilizer ratios and scheduling parameters using the keypad or GUI. The microcontroller processes this input and configures the system to dispense fertilizers in the specified ratios.

Fertilizer Dispensing

Based on the environmental data and user inputs, the microcontroller sends control signals to the solenoid valves to regulate the flow of fertilizers. The water flow sensors monitor the flow rate of fertilizers and send this data back to the microcontroller to ensure accurate dispensing.

Real-Time Feedback

The LCD display provides real-time feedback to the user, showing information such as temperature, humidity, flow rates, and system status. The user can monitor the system and make adjustments as needed, ensuring that the fertilization process is both efficient and accurate.

System Adaptation

The system continuously adapts to changing environmental conditions, adjusting the fertilizer dispensing process to maintain optimal conditions for plant growth. The microcontroller uses the data from the DHT11 sensor and water flow sensors to make real-time adjustments, ensuring that the system operates efficiently under varying conditions.

End of Cycle

Once the fertilization process is complete, the system resets and prepares for the next cycle. The user can review the data from the previous cycle and make any necessary adjustments for future fertilization.

Design Specifications

The system is built around the PIC18F452 microcontroller, which serves as the central control unit due to its robust processing capabilities and efficient peripheral interfacing. A 16x2 LCD display is used to provide real-time feedback and system prompts, while a 4x4 matrix keypad allows the user to input configuration parameters such as password, dosing ratio, and schedule. The system integrates a DHT11 sensor to monitor ambient temperature and humidity, and an HZ-06 flow sensor to measure the precise volume of fertilizer dispensed. A Python-based GUI is developed to offer a user-friendly interface for monitoring and control, making the system scalable for future IoT integration. The entire hardware is powered through a regulated 5V DC supply with EMI filtering and over-voltage protection and is housed in a compact acrylic/PCB-based enclosure for safety and durability.

Results and Discussion

Simulation and literature evidence indicate that automated hydroponic fertilization yields substantial benefits over conventional methods. In greenhouse-scale tests of similar systems, crop yield and resource efficiency improved markedly. Environmentally, these improvements directly promote sustainability. Using 10–30% less fertilizer means proportionally less nutrient runoff into waterways. The system's precision also avoids the spikes of nutrient concentration that trigger algal blooms. By maintaining optimal conditions, plant health improves, and waste is minimized. Economically, even accounting for the initial equipment cost, the reduction in fertilizer and labour yields a fast payback.

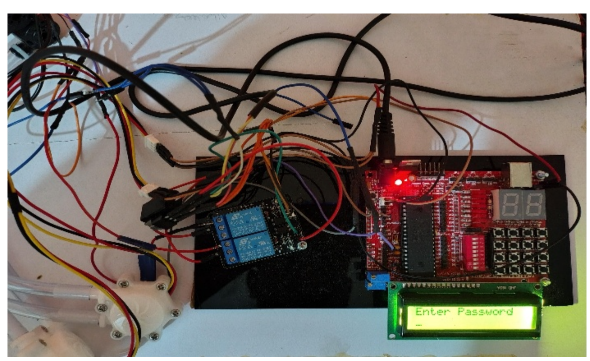

Fig 7. Project prototype

The development of the Automated Fertilizer Dispensing System utilized various hardware and software tools critical for embedded system design and validation. MPLAB X IDE served as the primary environment for writing and compiling embedded C code for the PIC18F452 microcontroller, using the XC8 Compiler. The compiled hex file was uploaded via In-Circuit Serial Programming (ICSP) using a PICkit 3 programmer.

During prototyping, a regulated DC power supply and digital multimeter were employed to monitor voltage levels and ensure circuit stability. External libraries were integrated for interfacing a 16×2 LCD and 4×4 keypad, enabling real-time data display and user input acquisition.

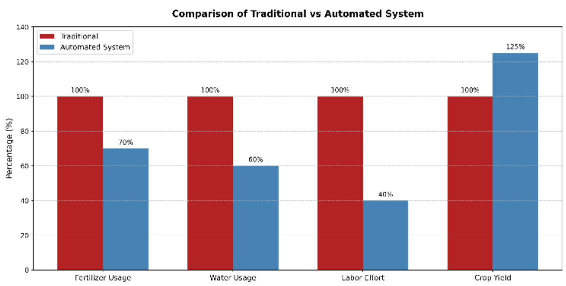

Fig 8. Comparative Analysis of Resource Efficiency Between Traditional and Automated Fertilizer

Comparative analysis of key resource efficiency parameters between conventional and automated fertilizer dispensing methods. The proposed automated system exhibits a marked reduction in fertilizer and water consumption, significantly lowers labor requirements, and achieves an approximate 25% improvement in crop yield. These enhancements collectively validate the system's effectiveness in implementing precision-based nutrient management for sustainable agriculture.

In summary, the expected impact of the proposed system is significant. By precisely metering nutrients, it increases fertilization efficiency (measured as crop yield per unit fertilizer) and reduces waste. Real-time feedback and adaptive control ensure robust operation in changing conditions. The outcome is a more sustainable hydroponic practice: higher yields with lower inputs, reduced environmental pollution, and lower operating costs. These performance benefits make the automated dispenser well-suited to modern precision agriculture.

Future Scope

Cloud-Enabled Optimization of Automated Fertilizer Dispensing Systems via AWS Integration**.** While the present work focuses on the design and implementation of a standalone Automated Fertilizer Dispensing System (AFDS), future advancements will lie in the seamless integration of cloud computing services to enhance its scalability, intelligence, and overall system resilience. Amazon Web Services (AWS), with its suite of IoT, analytics, and machine learning tools, presents a robust ecosystem to transition the AFDS into a smart, connected solution aligned with modern precision agriculture practices.

IoT Connectivity and Remote Monitoring

The adoption of AWS IoT Core can facilitate secure and scalable device-cloud communication using MQTT protocols, enabling real-time data exchange from soil sensors, actuators, and environmental monitoring modules. This would allow centralized control and visibility of geographically distributed dispensing units, enabling farmers and stakeholders to monitor and manage system operations remotely with minimal latency.

Scalable Data Storage Architecture

Sensor data, operational logs, and diagnostic information can be effectively stored using a hybrid data architecture. Amazon S3 would serve as a repository for unstructured data such as logs and images. In contrast, structured datasets such as device status, usage history, and configurations could be managed through Amazon DynamoDB or Amazon RDS. This multi-tiered data management system supports high availability, durability, and rapid query execution, thereby aiding historical trend analysis and decision support.

Serverless Data Analytics Pipeline

For real-time and batch data processing, the integration of AWS Lambda with Amazon Kinesis would establish a serverless, event-driven pipeline. These services enable real-time transformation, filtering, and routing of sensor telemetry with minimal infrastructure overhead. Additionally, AWS Glue and Amazon Athena could be employed to extract, transform, and analyze data for pattern detection and report generation, thus enabling data-driven insights into system performance and field conditions.

Edge Intelligence and Low-Latency Processing

Utilizing AWS IoT Greengrass, computational capabilities can be extended to the edge, allowing localized data processing and decision-making at the device level. This ensures operational continuity and rapid actuation in latency-sensitive scenarios, such as emergency stops or critical fertilizer recalibration, even in the absence of continuous cloud connectivity.

Predictive Analytics through Machine Learning

Integration with Amazon SageMaker enables the development of custom machine-learning models trained on historical and real-time field data. These models can predict optimal fertilizer schedules by analyzing variables like crop type, soil composition, moisture content, and weather forecasts. Such predictive insights can significantly improve fertilizer usage efficiency, reduce waste, and enhance overall crop productivity.

Security and Cost Optimization

AWS offers a robust security framework incorporating Identity and Access Management (IAM), data encryption, secure device provisioning, and network traffic controls. These measures ensure the confidentiality and integrity of agricultural data. Moreover, AWS's pay-as-you-go pricing model makes the solution financially viable across diverse agricultural scales, from smallholder farms to industrial agribusinesses.

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