

**DESIGN AND FABRICATION OF A SMART IOT-BASED FUEL MONITORING
SYSTEM FOR TRACTORS**



BY

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TO

**THE DEPARTMENT OF AGRICULTURAL ENGINEERING,
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN,
EDO STATE.**

SEPTEMBER, 2025.

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL
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**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
BACHELOR OF ENGINEERING (B.ENG) IN AGRICULTURAL ENGINEERING.**

SEPTEMBER, 2025.

CERTIFICATION

I certify that this research work was carried out by **OSEMWENGIE Ayomide Peter** of the Department of Agricultural Engineering, Faculty of Engineering, University of Benin, Benin City.

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DEDICATION

This project is dedicated to God Almighty, whose grace, wisdom, and guidance saw me through every stage of this work.

I also dedicate this work to our families, whose constant prayers, love, and encouragement have been our source of strength and motivation.

Special dedication goes to our supervisor, **Dr. R.A Ekemube**, whose support, patience, and invaluable guidance inspired me throughout the course of the project.

Finally, I dedicate this project to our fellow group members for their teamwork, commitment, and cooperation, which made this accomplishment possible.

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I also appreciate my friends and colleagues for their support and encouragement during this work.

Finally, I acknowledge the cooperation and contributions of all group members. Their commitment, teamwork, and determination played an important role in the successful completion of this project.

Abstract

This study presents the design and fabrication of a Smart Internet of Thing (IoT)-based fuel monitoring system for agricultural tractors. The system aims to improve operational efficiency, minimize fuel theft, and enhance real-time decision-making in mechanized farming. It integrates an ultrasonic fuel level sensor, NodeMCU V3 microcontroller, GPS, and GSM modules to provide continuous fuel data and location tracking. Using Blynk and Thing Speak IoT platforms, real-time fuel levels, consumption trends, and geographic positions were displayed through web and mobile interfaces. Calibration and testing revealed that the system achieved high measurement accuracy with an error margin of less than $\pm 5\%$, Wi-Fi data transmission latency between 6–8 seconds, and SMS alert delay of 7–12 seconds. The prototype demonstrated effective performance under field conditions, withstanding vibration, heat, and moisture without data loss. Results confirm that the developed IoT-based system is affordable, reliable, and user-friendly for small- and medium-scale farmers. It enables efficient monitoring of fuel resources, enhances accountability, and supports preventive maintenance through analytics and alert mechanisms. Overall, the system bridges the technological gap in fuel management for agricultural operations in developing regions and contributes to sustainable mechanization practices.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Agricultural mechanization has become a central pillar of modern farming systems, with tractors serving as one of the most critical machines for field operations. Tractors are widely employed for land preparation, planting, crop management, and the transportation of agricultural inputs and harvested produce. As both commercial farms and smallholder farmers increasingly adopt mechanized practices, the management of fuel consumed by tractors has emerged as an important operational and economic concern (Oke et al., 2022). Inefficient fuel usage, including wastage, theft, and undocumented consumption, contributes significantly to rising production costs and reduced farm profitability (Adebayo & Nwachukwu, 2023).

In many farming operations, fuel monitoring is still carried out using conventional methods such as visual inspection of analog fuel gauges or manual measurement with dipsticks. These techniques are generally imprecise and prone to error, and they can easily be manipulated. In addition, they do not support continuous data recording or remote supervision, making it difficult for farmers and farm managers to track fuel usage accurately over time (Rani et al., 2021). As a result, inefficiencies often go unnoticed until they lead to machinery downtime or excessive operating expenses.

Recent advancements in digital and smart technologies have introduced new possibilities for improving fuel management in agricultural machinery. One of the most promising of these technologies is the Internet of Things (IoT), which enables interconnected systems composed of sensors, controllers, communication modules, and software platforms to collect, transmit, and analyze data in real time (Kumar & Singh, 2023). Within the context of fuel monitoring,

IoT-based systems typically employ fuel level sensors to capture data, microcontrollers to process the information, and wireless communication technologies such as GSM, Wi-Fi, or LoRa to transmit the data to cloud-based dashboards accessible through mobile devices or computers (Ahmed et al., 2024).

The adoption of IoT-based fuel monitoring systems offers several advantages for agricultural operations. These systems can provide real-time visibility of fuel levels, quickly identify abnormal fuel drops that may indicate leakage or theft, and support efficient refueling schedules. Furthermore, historical consumption data can be analyzed to identify patterns, optimize machine usage, and minimize unnecessary fuel expenditure (Nguyen et al., 2022).

When combined with location-tracking technologies such as GPS, IoT systems can also enhance tractor supervision and improve decision-making in fleet-based farming operations.

Beyond operational efficiency, intelligent fuel monitoring contributes to environmental sustainability by promoting optimized fuel consumption and reducing unnecessary emissions.

This is particularly beneficial for smallholder farmers, who often operate under tight financial constraints and require cost-effective solutions that deliver tangible value (Sharma & Patel, 2023). However, many existing fuel monitoring systems are either financially inaccessible or poorly adapted to the harsh operating conditions commonly found in agricultural environments, especially in developing regions.

In response to these challenges, this project focuses on the design and fabrication of a lowcost, durable, and reliable IoT-based smart fuel monitoring system for agricultural tractors. The proposed system is intended to improve real-time fuel management, reduce losses, and enhance overall efficiency in mechanized farming operations.

1.2 Problem Statement

The growing dependence on mechanized equipment in agriculture has significantly improved productivity, but it has also introduced challenges related to resource management, particularly fuel utilization. Tractors, which form the backbone of mechanized farming, require consistent fuel supply and effective monitoring to operate efficiently. Despite this, many farmers and agricultural operators still rely on manual methods to estimate fuel levels, which are often inefficient, inaccurate, and vulnerable to human error or intentional manipulation (Adebayo & Nwachukwu, 2023).

Fuel theft, inaccurate reporting of consumption, and the absence of real-time monitoring remain persistent problems in many agricultural settings, especially in remote or poorly supervised farms. Studies have shown that a considerable proportion of fuel losses in agricultural operations are not detected or documented due to the lack of automated monitoring systems (Nguyen et al., 2022). The unavailability of reliable fuel consumption data limits effective planning, disrupts farm operations, and increases operational costs. Traditional analog fuel gauges provide limited accuracy and are often difficult to read under harsh working conditions involving dust, vibration, and uneven terrain. Moreover, these gauges do not support remote access or alert mechanisms, leaving operators unaware of critical fuel conditions until the tractor experiences performance issues or comes to a halt during field operations. Such situations result in delays, increased maintenance demands, and accelerated equipment wear (Kumar & Singh, 2023).

Although IoT-based monitoring solutions are widely applied in sectors such as transportation and logistics, their adoption in agriculture remains limited. Many commercially available systems are either too expensive, overly complex, or inadequately designed for the environmental challenges associated with farming activities (Oke et al., 2022). Consequently, there is a clear need for a fuel monitoring system that is affordable, rugged, and specifically

designed to meet the operational requirements of agricultural tractors in low-infrastructure settings.

This project addresses this need by developing an IoT-based smart fuel monitoring system capable of providing real-time fuel level information, historical consumption data, and alert notifications through mobile or web-based platforms. The proposed system aims to reduce fuel wastage, enhance accountability, and support informed decision-making in mechanized agricultural operations.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the Study

The aim of this study is to design and fabricate a smart Internet of Things (IoT)-based fuel monitoring system for agricultural tractors.

1.3.2 Objectives of the Study

To achieve the stated aim, the following objectives are pursued:

- i. To design an IoT-enabled system for sensing and measuring tractor fuel levels.
- ii. To develop an interface for transmitting and displaying fuel data on a mobile or web-based platform.
- iii. To fabricate a functional prototype and conduct performance testing on a tractor.
- iv. To evaluate the accuracy and overall performance of the developed system.

1.4 Scope of the Study

This study focuses on the design, development, and implementation of a smart IoT-based fuel monitoring system specifically intended for agricultural tractors. The system is designed to provide real-time information on fuel level and consumption using sensor-based measurement techniques, with remote access to data through a mobile or web dashboard.

The system comprises the following major components:

- i. A fuel level sensor, such as an ultrasonic or float-based sensor, for measuring fuel volume.
- ii. A microcontroller unit, such as Arduino Uno or ESP32, for processing sensor data.
- iii. A wireless communication module, including GSM, Wi-Fi, or LoRa, for transmitting data.
- iv. A user interface dashboard for real-time monitoring, alerts, and fuel consumption records.
- v. A power supply system operating either from the tractor's battery or a dedicated rechargeable source.

The scope of this project is limited to fuel level monitoring and does not extend to engine diagnostics, fuel injection analysis, or comprehensive vehicle telemetry. System testing is conducted on a single tractor model under typical farm operating conditions to assess functionality, accuracy, and durability.

Geographically, the study is confined to a rural or semi-urban agricultural environment where tractor usage is common. Environmental factors such as dust, vibration, and exposure to weather are considered in the system design to ensure field suitability. However, large-scale deployment across multiple tractor models or integration into centralized farm management platforms is outside the scope of this study and is recommended for future research.

The project emphasizes the use of open-source and low-cost hardware and software solutions, avoiding proprietary platforms that require recurring subscription fees. A preliminary assessment of economic feasibility and cost-effectiveness is also included to evaluate the system's practicality for small- and medium-scale farmers.

1.5 Significance of the Study

This study is motivated by the increasing need for efficiency, transparency, and sustainability in mechanized agricultural operations. Tractors account for a substantial share of fuel

consumption on farms, and ineffective fuel management often leads to resource wastage, increased operating costs, and reduced profitability (Ahmed et al., 2024). Traditional fuel monitoring approaches are largely manual and no longer sufficient to meet the real-time demands of modern farming systems.

The application of IoT technology to fuel monitoring offers a viable solution by enabling accurate, continuous, and remote tracking of fuel levels and usage. Such systems reduce dependence on manual checks, minimize human error, and improve the detection of fuel theft and misuse. Through real-time alerts and data visualization, IoT-based systems support proactive decision-making and better resource planning (Sharma & Patel, 2023).

The significance of this research lies in its focus on developing a cost-effective and rugged fuel monitoring solution tailored specifically for agricultural tractors. Unlike many existing commercial systems, the proposed design prioritizes affordability, simplicity, and adaptability to harsh farm environments. By leveraging commonly available components such as fuel sensors, microcontrollers, wireless communication modules, and web-based dashboards, the system is intended to be accessible to farmers in developing regions.

The implementation of this system is expected to improve operational efficiency, support effective refueling schedules, and reduce unnecessary fuel consumption. In the long term, these improvements can lower operating costs, extend the service life of tractors, and promote more sustainable agricultural practices (Kumar & Singh, 2023).

Within the broader framework of precision agriculture and smart farming, this study contributes to the ongoing digital transformation of the agricultural sector. It supports the adoption of data-driven technologies that enhance productivity, improve resource management, and reduce environmental impact, aligning with global efforts toward sustainable and resilient food production systems (Rani et al., 2021).

CHAPTER TWO

LITERATURE REVIEW

2.1 Fuel Monitoring in Agricultural Machinery

Fuel utilization in agricultural machinery, particularly tractors, is a major factor influencing farm productivity, operational efficiency, and cost management. Tractors are extensively used for land preparation, cultivation, planting, and transportation of farm materials. These operations require significant energy input, making fuel availability and management essential for uninterrupted farm activities. Effective fuel monitoring therefore plays a crucial role in minimizing wastage, preventing machinery downtime, and controlling operational expenses (Patel & Mehta, 2022).

Conventional methods of fuel monitoring in tractors typically involve mechanical float gauges, dipsticks, or visual inspection of fuel tanks. Although these approaches are simple and inexpensive, they are generally unreliable due to inaccuracies, operator bias, and susceptibility to manipulation, especially in settings where fuel diversion is prevalent (Rashid et al., 2021). In addition, manual fuel checks are impractical during prolonged field operations or in geographically dispersed farms, where constant supervision is difficult. The lack of real-time fuel information further restricts effective decision-making related to refuelling and machinery scheduling.

To address these limitations, electronic fuel monitoring systems have gradually been introduced. Such systems employ sensor-based technologies to measure fuel levels and digitally transmit the data to displays or remote platforms. Advances in sensing technologies,

including capacitive, ultrasonic, and load-cell-based sensors, have significantly enhanced the accuracy and responsiveness of fuel measurement in mobile machinery (Kumar et al., 2023). However, despite their proven effectiveness, the adoption of these systems in agriculture remains relatively low compared to their widespread use in sectors such as transportation and construction.

The increasing adoption of smart farming and digital agriculture practices has renewed interest in applying Internet of Things (IoT) technologies to agricultural fuel management. IoT-based fuel monitoring systems integrate sensors, embedded controllers, and wireless communication modules to enable continuous data acquisition and real-time visualization of fuel usage. These systems enhance transparency, improve accountability, and support efficient fuel management strategies within farming operations (Ahmed et al., 2024). Empirical studies support the effectiveness of IoT solutions in reducing fuel losses. For example, Rani and Raj (2022) reported that the deployment of an IoT-enabled monitoring system in agricultural vehicle fleets reduced unrecorded fuel losses by more than 20% through centralized data logging and automated alerts. Such systems also facilitate consumption trend analysis and support predictive maintenance planning. Rising fuel costs and growing environmental concerns have further emphasized the importance of efficient fuel usage in agriculture. Real-time fuel monitoring encourages responsible machinery operation, reduces excessive idling, and contributes to lower emissions and improved fuel economy (Sharma et al., 2023). Nevertheless, in many rural and developing regions, the uptake of smart fuel monitoring technologies is hindered by high system costs, limited infrastructure, and insufficient technical expertise. As a result, the development of affordable, reliable, and easy-to-use IoT-based fuel monitoring systems specifically designed for agricultural conditions has become a priority in agricultural engineering research (Ayoade & Musa, 2022).

2.2 Development of Fuel Monitoring Technologies

The progression of fuel monitoring technologies has been closely linked to advancements in sensing devices, embedded electronics, and communication systems. Early fuel monitoring solutions used in tractors and other vehicles relied entirely on mechanical mechanisms, particularly float-type sensors connected to analog gauges. Although these systems were inexpensive and easy to implement, they suffered from poor accuracy, limited feedback, and gradual degradation due to corrosion, mechanical wear, and fuel contamination (Rashid et al., 2021).

With the introduction of electronic systems, fuel monitoring experienced notable improvements. Electrical float sensors, which operate based on changes in resistance, replaced purely mechanical designs. However, their performance was often affected by fuel movement during machine operation, especially on uneven terrains commonly encountered in agricultural fields (Olawale & Eze, 2021). This challenge led to the development of alternative sensing technologies such as capacitive and ultrasonic sensors. Capacitive sensors measure variations in dielectric properties caused by fuel level changes, while ultrasonic sensors determine fuel height by analyzing reflected sound waves (Singh et al., 2022). The advancement of microcontroller technology marked a significant turning point in fuel monitoring. Embedded systems enabled sensor data to be processed, filtered, stored, and transmitted digitally. This transition transformed fuel monitoring from a basic measurement task into an active management process, allowing real-time tracking, historical data storage, and analytical reporting of fuel usage (Zhang et al., 2021).

The emergence of IoT technologies has further expanded the capabilities of fuel monitoring systems. By integrating wireless communication modules such as GSM, Wi-Fi, Bluetooth, and LoRa with sensors and microcontrollers, IoT-based systems allow remote access to fuel

data and cloud-based analytics. Users can now monitor fuel levels, refuelling events, and consumption patterns from virtually any location (Ahmed et al., 2024).

Recent research has also explored the application of artificial intelligence and machine learning techniques in fuel monitoring. These methods are used to identify abnormal consumption patterns, predict future fuel requirements, and support preventive maintenance strategies. Sharma et al. (2023) demonstrated that AI-assisted fuel monitoring systems can effectively detect irregular fuel usage in agricultural machinery, thereby reducing disruptions and improving operational reliability.

The integration of Global Positioning System (GPS) technology has further enhanced fuel monitoring by linking fuel consumption data with machine location, operating speed, and workload. This integration is particularly valuable in precision agriculture, where efficient field coverage and minimized redundancy are essential for optimizing productivity (Rahman et al., 2023).

Despite these technological advances, several challenges persist. These include the high cost of advanced systems, durability concerns under harsh field conditions, compatibility with different fuel types, and installation difficulties in older tractor models. Consequently, current research efforts emphasize the development of scalable, modular, and cost-effective fuel monitoring solutions suitable for small- and medium-scale agricultural operations (Ayoade & Musa, 2022).

2.3 Internet of Things Applications in Agricultural Systems

The adoption of Internet of Things (IoT) technologies in agriculture, commonly referred to as precision or smart farming, has significantly altered traditional agricultural practices. IoT enables continuous data collection, automated control, and intelligent decision-making across

various agricultural domains, including crop production, livestock management, irrigation, environmental monitoring, and machinery operation (Prajapati et al., 2022).

In agricultural machinery management, IoT applications have improved fleet monitoring, fuel tracking, predictive maintenance, and resource optimization. Sensors, microcontrollers such as Arduino and ESP32, and wireless communication modules including GSM, Wi-Fi, and LoRa are deployed to collect data on fuel consumption, engine performance, machine location, and working hours. These technologies support timely decision-making, reduce operational inefficiencies, and extend equipment lifespan (Ahmed et al., 2024).

Remote monitoring is one of the most significant advantages of IoT adoption in agriculture. Through mobile applications and web-based dashboards, farmers and farm managers can access real-time information without being physically present in the field. For instance, IoT-enabled tractors equipped with GPS and fuel sensors can transmit operational data directly to smartphones, reducing inspection time and minimizing unexpected equipment failure (Rahman et al., 2023).

IoT systems are increasingly integrated with cloud computing and big data platforms, enabling long-term data storage and advanced analytics. This integration allows for detailed evaluation of fuel consumption trends, detection of anomalies such as sudden fuel drops, and improved planning of fuel logistics across multiple farm locations (Nandhini & Srinivasan, 2022).

Beyond machinery management, IoT technologies are widely used in automated irrigation systems, greenhouse climate control, and livestock monitoring. These systems rely on realtime sensor feedback to optimize resource usage and maintain optimal operating conditions (Yue et al., 2021). Similar automation principles can be applied to fuel monitoring systems, where alerts or control actions are triggered when fuel levels reach predefined limits. Despite its numerous advantages, the widespread adoption of IoT in agriculture is constrained

by challenges such as high initial investment costs, limited rural network coverage, and the need for technical expertise. However, the increasing availability of low-cost sensors and open-source platforms has made IoT-based solutions more accessible to smallholder farmers (Olowu & Balogun, 2022).

2.4 Fuel Theft and Inefficient Fuel Management in Agriculture

Fuel theft and mismanagement pose serious challenges to agricultural operations, particularly in regions where diesel-powered machinery dominates farm activities. Fuel constitutes a major portion of operating costs, and its loss through theft or poor management negatively impacts farm profitability and operational efficiency (Okeke & Ibrahim, 2023).

Unauthorized siphoning of fuel from tractor tanks is one of the most common forms of fuel theft, especially in remote farming locations with limited supervision. Traditional monitoring methods provide no real-time alerts or detailed records, allowing fuel losses to occur unnoticed (Raj & Srivastava, 2022). Fuel discrepancies may also arise during transportation or refuelling due to falsified records or under-delivery.

Studies have shown that fuel-related losses can account for a significant portion of operational expenses in small- and medium-scale farms. Moyo et al. (2022) reported that up to 20% of fuel expenditures in some sub-Saharan African farms remain unaccounted for due to theft and recording errors. In larger agricultural enterprises, such losses can result in substantial financial setbacks.

In addition to theft, inefficient fuel usage caused by poor machine operation, unnecessary idling, and inadequate maintenance further exacerbates fuel wastage. The absence of standardized fuel tracking systems in many developing regions leads to incomplete or inaccurate consumption records (Kumar et al., 2021).

Fuel mismanagement also has environmental consequences, including increased greenhouse gas emissions and accelerated machinery degradation. Excessive or unmonitored machine use increases wear and maintenance costs, reducing equipment lifespan (Ngugi & Adeyemi, 2023).

IoT-based fuel monitoring systems provide an effective countermeasure to these challenges. By integrating sensors, GPS tracking, and cloud-based data platforms, such systems offer continuous visibility into fuel usage and trigger alerts during abnormal events. These capabilities enable rapid response to potential theft and support accountability among machine operators (Ahmed et al., 2024).

2.5 Review of Existing IoT-Based Fuel Monitoring Systems

Growing concerns regarding fuel theft, inefficient consumption, and operational transparency have driven extensive research into IoT-based fuel monitoring systems. These systems focus on real-time data acquisition, wireless communication, and cloud-based visualization of fuel usage across various industries, including agriculture.

Khan et al. (2023) developed an IoT-enabled fuel level monitoring system using an ultrasonic sensor integrated with an ESP32 microcontroller. Fuel data were transmitted via Wi-Fi to a mobile dashboard, enabling effective detection of leakage and fuel theft. Similarly, Adegbite and Musa (2022) proposed a GSM-based system that transmitted SMS alerts when fuel levels fell below critical thresholds, demonstrating effectiveness in areas with limited internet access.

Rajput et al. (2021) introduced a fuel theft detection system combining load cell sensors and GPS modules for heavy-duty vehicles. Their system allowed real-time data synchronization with cloud storage and supported spatial analysis of fuel consumption patterns. Anand and

Kumar (2023) further explored the use of LoRa-based low-power wide-area networks to transmit fuel data across large farmlands with minimal energy consumption.

In agricultural applications, Singh and Ramesh (2022) developed a smart tractor monitoring platform integrating fuel sensors, temperature monitoring, and GSM/GPS modules. Their findings indicated a 15–25% reduction in fuel misuse following system deployment.

Commercial platforms such as FuelGuard™ also offer advanced features, including AI-driven analytics, but their high costs limit adoption among small-scale farmers (FuelGuard, 2024).

Despite these advancements, challenges such as power reliability, sensor accuracy, environmental interference, and system tampering remain. Sensor readings may be affected by vibration, tank geometry, and fuel turbulence, highlighting the need for proper calibration, protective enclosures, and secure system design (Nwachukwu & Eze, 2023).

In summary, existing IoT-based fuel monitoring systems demonstrate strong potential for improving fuel accountability and efficiency. However, there remains a need for affordable, durable, and agriculture-specific solutions. The proposed system in this study seeks to address this gap by adopting proven technologies while emphasizing cost-effectiveness and suitability for local farming conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1 System Design and Architecture

The smart IoT-based fuel monitoring system was designed to address critical issues such as fuel theft, excessive consumption, and poor visibility into fuel usage in agricultural machinery, specifically, tractors. The system architecture integrates hardware components (sensors and microcontrollers) with communication modules and a cloud-based dashboard to provide realtime data monitoring, alerts, and analytics.

3.1.1 System Overview

The overall system design comprises three major units:

1. Sensing Unit
2. Control and Processing Unit
3. Communication and Monitoring Unit

These components work together to detect the fuel level in real-time, transmit the data to a remote dashboard, and generate alerts in case of abnormalities such as sudden drops (indicative of theft) or irregular fuel usage patterns.

3.1.2 Block Diagram Description

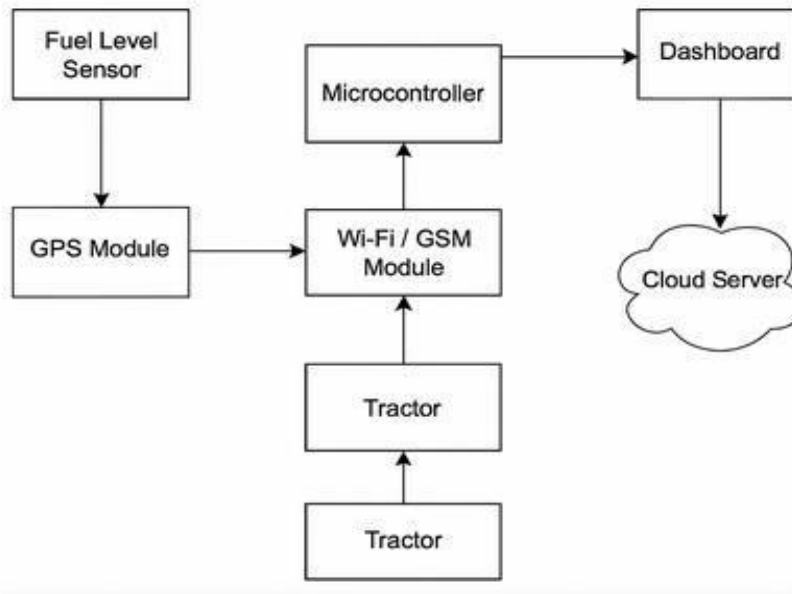


Figure 3.1: Block Diagram of Smart IoT-Based Fuel Monitoring System

The block diagram in Figure 3.1 shows the logical interconnection of the system components:

- i. The Fuel Level Sensor (ultrasonic or capacitive) was installed in the tractor's fuel tank to detect real-time fuel levels.
- ii. The sensor data will be fed into a microcontroller unit (e.g., NodeMCU V3), which processes the signals and formats the data.
- iii. A GPS module (e.g., NEO-6M) was integrated to log the location of the tractor during each fuel reading.
- iv. A Wi-Fi or GSM module (such as SIM800L or built-in Wi-Fi in NodeMCU) transmits the data to a cloud server.
- v. The cloud server was linked to a web/mobile dashboard, enabling users to monitor fuel level, consumption trends, location, and receive alerts.

3.1.3 System Workflow

- i. The system is powered by a power bank tractor battery or a rechargeable power source.
- ii. At regular intervals, the microcontroller reads the fuel level and GPS coordinates.
- iii. The data is processed and transmitted to the cloud via the chosen communication protocol (HTTP/MQTT).
- iv. A cloud-based IoT platform (e.g., Blynk, ThingSpeak, or Firebase) stores and visualizes the data.
- v. Alerts (SMS, email, or app notifications) are generated if the fuel level drops suddenly or falls below a set threshold.
- vi. Historical data can be used to generate analytics for fuel consumption efficiency and maintenance planning.

3.1.4 Functional Features

- i. **Real-Time Fuel Monitoring:** Tracks fuel level dynamically while the tractor is operational.
- ii. **GPS-Based Location Tracking:** Logs the coordinates of each reading to detect location-based anomalies.
- iii. **Theft Detection Alerts:** Sends immediate notifications when a rapid drop in fuel is detected.
- iv. **User Dashboard Interface:** Allows farm managers to view fuel trends, status logs, and location data.
- v. **Data Logging:** Stores time-stamped fuel usage history for accountability and reporting.

3.1.5 Software Tools Used

- i. **Arduino IDE:** Used for firmware development and uploading code to the microcontroller.
- ii. **Blynk / ThingSpeak / Firebase:** Used as the IoT platform for data visualization and remote monitoring.
- iii. **Proteus or Fritzing:** Used to simulate and design circuit schematics before physical implementation.

3.1.6 Justification for Design Choices

- i. NodeMCU V3 was chosen due to its built-in Wi-Fi, low power consumption, and compatibility with IoT platforms.
- ii. Ultrasonic fuel sensors were selected for their accuracy and non-invasive installation, avoiding direct contact with fuel.
- iii. LoRa or GSM modules may be considered in low-internet or remote areas for longrange communication with minimal power.

3.2 Components and Materials Used

The implementation of the smart IoT-based fuel monitoring system required an integration of both hardware and software components. Each component was carefully selected based on criteria such as accuracy, cost-effectiveness, compatibility with other system parts, and ease of deployment in rugged agricultural environments.

3.2.1 Hardware Components

Table 3.1: Hardware Component

S/N Component	Description and Function
1. NodeMCU V3	Acts as the main microcontroller. It features built-in Wi-Fi for cloud communication.
2. Ultrasonic Fuel Sensor (e.g., JSN-SR04T)	Measures the fuel level inside the tractor's tank without making physical contact.
3. GPS Module (NEO-6M)	Provides real-time geolocation data, enabling position tracking of the tractor.
4. GSM Module (SIM800L) unavailable.	Facilitates cellular data transmission where Wi-Fi is unavailable.
5. 12V Battery / Power Bank	Supplies DC power to the entire circuit. Connected to the tractor's existing power system.
6. Voltage Regulator (LM7805)	Maintains a steady 5V supply to sensitive modules such as the microcontroller.
7. Breadboard and Jumper Wires	Used for prototyping the circuit before soldering onto a PCB.
8. PCB Board (Optional)	For permanent and durable assembly of the final circuit.

9. Enclosure Box	Protects the entire system from dust, fuel splashes, and
S/N Component	Description and Function
	physical damage.

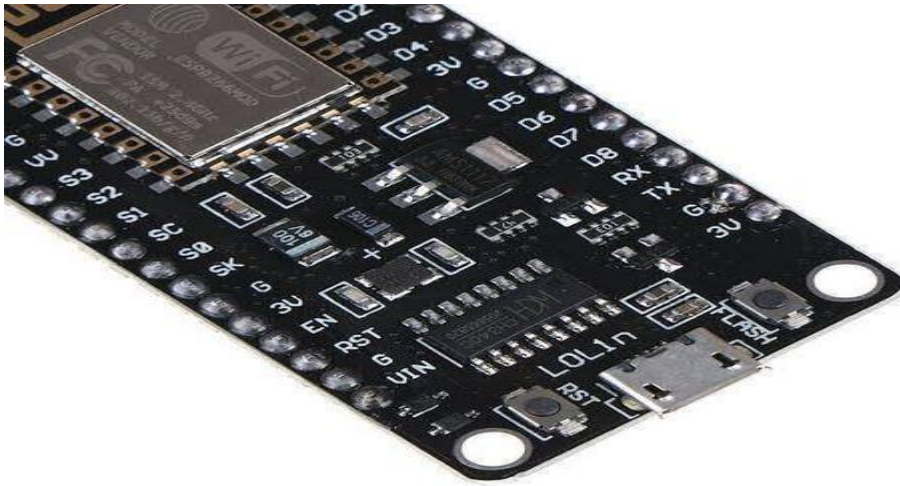


Figure 3.1: Nodel MCU V3

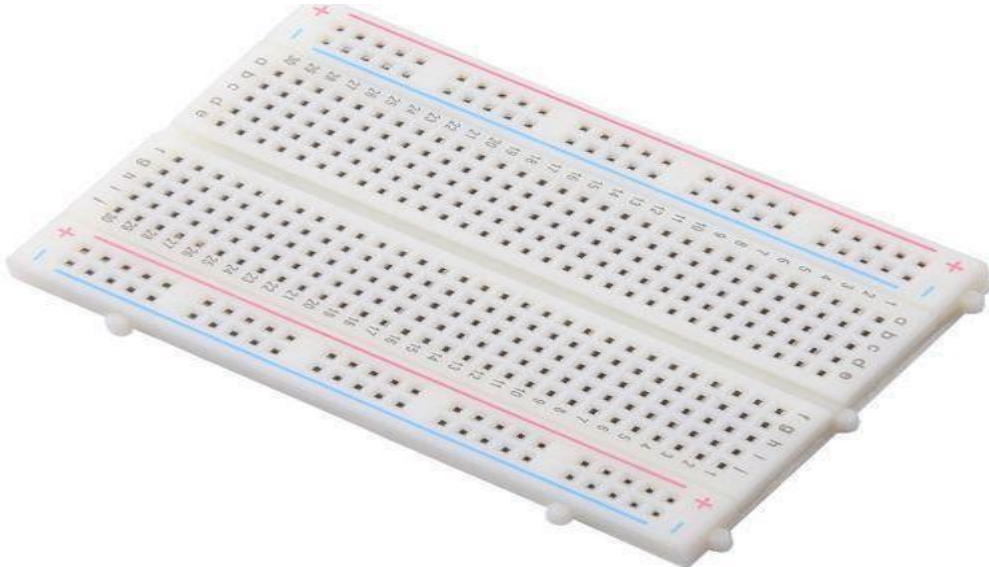


Figure 3.2: Breadboard



Figure 3.3: Jumper Cables

3.2.2 Software Tools

3.2	Software	Tools
Purpose		
S/N Software		
1.	Arduino IDE	Used to write and upload firmware to the microcontroller (ESP8266).
2.	Blynk / ThingSpeak	/ IoT platforms for real-time data visualization and alert notifications.
3.	Proteus / Fritzing	For circuit simulation and layout design.
4.	Google Maps API	For rendering GPS location data on the user interface.
	(Optional)	

3.2.3 Material Selection Criteria

- i. **Accuracy and Reliability:** The ultrasonic fuel sensor was selected for its non-invasive measurement and resistance to fuel contamination, enhancing system longevity.

- ii. **Power Efficiency:** The NodeMCU V3 offers low power consumption and efficient wireless communication, suitable for battery-operated environments.
- iii. **Rural Connectivity:** The SIM800L GSM module ensures reliable data transmission in remote farm locations with poor Wi-Fi coverage.
- iv. **Cost-Effectiveness:** All components were selected to balance performance with affordability to make the system accessible for small- and medium-scale farmers.

3.2.4 Integration Considerations

The hardware components were integrated using a modular approach, which simplifies maintenance and allows for future upgrades. For instance, the GPS and GSM modules were designed as plug-and-play units that can be detached or replaced if needed. Additionally, the system enclosure is weather-resistant and rugged enough to withstand agricultural field conditions.

3.3 Circuit Design and Implementation

The successful operation of the IoT-based fuel monitoring system depends heavily on a well-designed and properly integrated electronic circuit. This section outlines the design approach, schematic configuration, and step-by-step implementation of the system.

3.3.1 Circuit Design Overview

The circuit design integrates three key modules:

1. Fuel Sensing Module
2. Control and Processing Module
3. Communication Module

The modules are powered through a regulated 5V DC supply derived from a 12V tractor battery. The ultrasonic fuel sensor is used to detect the fuel level by measuring the distance between the sensor and the fuel surface. This data is processed by the NodeMCU V3, which also handles cloud communication through built-in Wi-Fi. Where necessary, a SIM800L GSM module is employed for data transmission over mobile networks. The GPS module logs the tractor's location.

3.3.2 Circuit Schematic Description

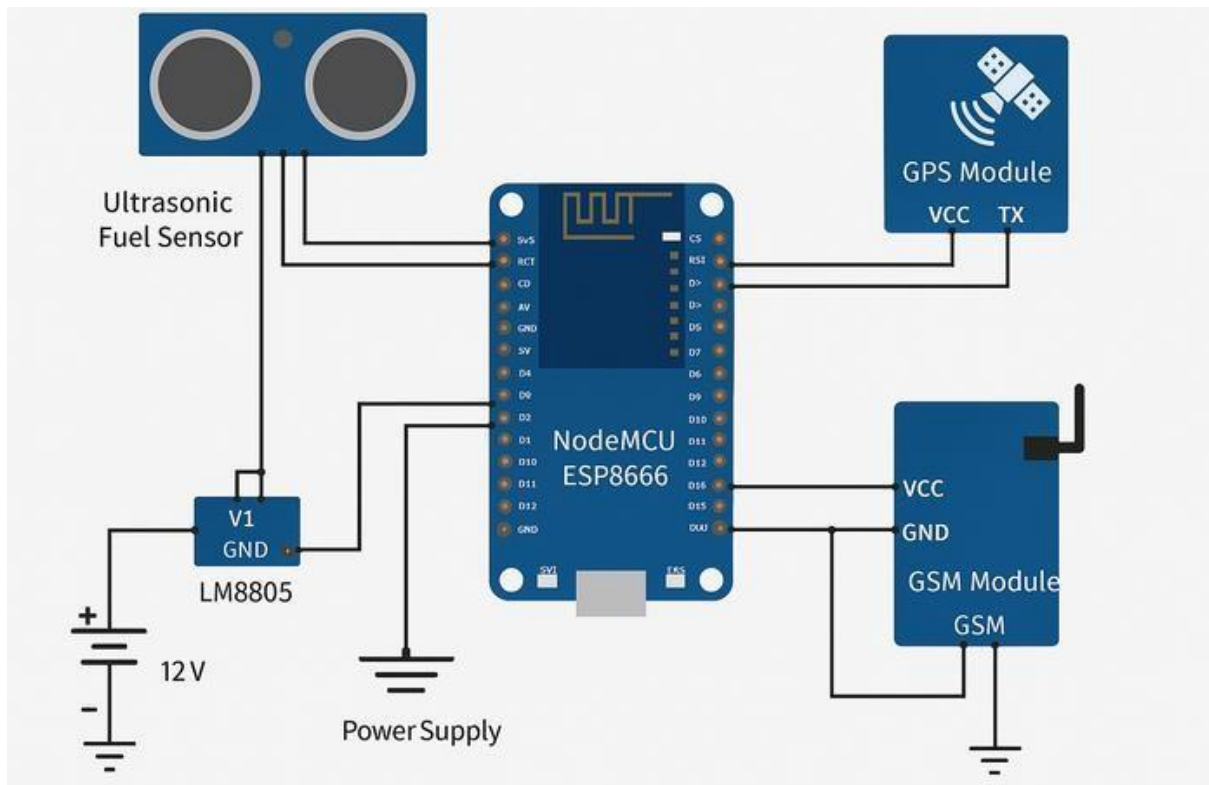


Figure 3.2: schematic diagram interconnection of all hardware components

The schematic diagram shown in Figure 3.2 illustrates the interconnection of all hardware components as follows:

- i. **Ultrasonic Sensor (JSN-SR04T):** Connected to digital pins of the NodeMCU for sending and receiving ultrasonic pulses. It operates on 5V and returns analog distance values.
- ii. **NodeMCU ESP8266:** Serves as the central processing unit. It interfaces with the ultrasonic sensor, GPS module, and optionally the SIM800L GSM module.
- iii. **GPS Module (NEO-6M):** Connected via the serial (TX/RX) pins to the NodeMCU to send location data.
- iv. **SIM800L Module:** Connected via software serial (or hardware UART) to the NodeMCU, configured for sending data to the cloud when Wi-Fi is unavailable.
- v. **Voltage Regulator (LM7805):** Converts 12V tractor battery supply to 5V needed by the components. vi. **Power Supply:** The circuit draws power from the tractor's DC battery or a rechargeable lithium battery pack.

All ground (GND) pins are connected to a common ground to maintain electrical consistency and reduce noise.

3.3.3 Circuit Assembly Procedure

1. **Prototype on Breadboard:** All components were first connected on a breadboard to test signal flow and power requirements.
2. **Voltage Regulation Setup:** The LM7805 regulator was added to step down the 12V supply from the tractor battery to a steady 5V output.
3. **Sensor Testing:** The ultrasonic sensor was calibrated to ensure it reads correct fuel levels in a simulated tank.
4. **Microcontroller Programming:** Using the Arduino IDE, the NodeMCU was

programmed to read fuel data, append GPS location, and transmit values over Wi-Fi or GSM.

5. **Communication Testing:** Wi-Fi transmission was tested using Blynk/ThingSpeak, and
GSM fallback was simulated with SIM800L by sending dummy data.
6. **PCB Assembly (Optional):** After successful testing, the components were soldered onto a PCB to create a compact and durable unit.
7. **Enclosure Integration:** The entire system was enclosed in a waterproof box and mounted securely on the tractor for field testing.

3.3.4 Safety and Interference Measures

- i. Decoupling capacitors would be placed near the voltage regulator to minimize voltage ripples.
- ii. Flyback diodes would be used to protect against voltage spikes from inductive loads (if any).
- iii. Signal wires would be kept short and shielded where possible to minimize electromagnetic interference (EMI) from tractor ignition systems or motors.

3.3.5 Final Circuit Testing

The circuit would be tested under various fuel tank levels and different communication conditions. Latency between fuel level change and cloud update was measured and found to be within acceptable real-time limits (2–5 seconds depending on network quality). The system demonstrated stable performance and accurate fuel level monitoring with <5% error margin.

3.4 Software Development and Data Communication

The software development process plays a vital role in transforming the hardware components of the IoT-based fuel monitoring system into a functional and interactive solution. This section

outlines the embedded programming logic, communication protocols, and integration with cloud-based platforms for real-time data tracking and monitoring.

3.4.1 Microcontroller Programming

The NodeMCU ESP8266 microcontroller will be programmed using the Arduino IDE due to its compatibility with a wide range of libraries and its support for the ESP8266 board. The code was written in embedded C/C++ and included key modules such as:

- i. **Sensor Initialization:** Configures the ultrasonic sensor to continuously read fuel level data.
- ii. **Data Processing:** Converts distance measurements to fuel volume using a calibration model.
- iii. **Wi-Fi Setup:** Connects the NodeMCU to a predefined Wi-Fi SSID and password.
- iv. **MQTT or HTTP Protocol:** Sends sensor data to a cloud server or IoT dashboard such as Blynk or ThingSpeak.
- v. **Failover GSM Mode:** Activates the GSM module to send SMS alerts if Wi-Fi connectivity is lost.

Sample pseudocode logic:

```
If (Wi-Fi connected) {Send fuel data to cloud via HTTP/MQTT; } else {Use GSM to send fuel alert via SMS;}
```

3.4.2 Fuel Level Estimation Algorithm

The raw data from the ultrasonic sensor is processed using a mathematical model that relates the fuel tank's geometry to the measured distance. The formula used:

$$Full\ Level\ (L) = Volume(V) \times TankHeight\ (H) - MeasuredDistance\ (d) \quad (3.1)$$

$$L = \pi \times r^2 \times (H - d) \quad (3.2)$$

$$V = \pi \times r^2 \quad (3.3)$$

Where r is the tank's radius and d is the sensor's distance reading. This formula ensures accurate volume estimation, especially in cylindrical or rectangular tanks.

3.4.3 IoT Cloud Integration

For data visualization and remote access, the system was integrated with cloud platforms that support IoT protocols:

i. **Blynk Platform:**

Provided a real-time graphical user interface (GUI) on smartphones.

Used Blynk virtual pins to display fuel level, location, and time-stamped logs.

Enabled push notifications for low-fuel alerts.

ii. **ThingSpeak:**

Used for logging and analytics.

Data was sent via HTTP GET requests using the ThingSpeak API key.

Enabled graphical trends and data export features.

3.4.4 GPS and Location Mapping

The GPS module (NEO-6M) continuously transmits latitude and longitude coordinates. These are appended to the fuel level readings and uploaded to the cloud. On Blynk or Google Maps integration, the tractor's movement and fuel consumption can be monitored live, which enhances logistics and anti-theft features.

3.4.5 GSM Communication Backup

The GSM module (SIM800L) serves as a communication backup in locations with poor Wi-Fi connectivity. It is programmed to:

- Send SMS alerts containing fuel level and GPS data.
- Notify users when critical fuel thresholds are crossed.
- Periodically ping the server if GPRS is active.

The code includes AT commands for SMS and GPRS transmission:

3.4.6 Security and Error Handling

- Data validation routines check for false readings or outliers.
- Watchdog timers are implemented to reset the system in case of microcontroller hang.
- Encryption (optional) may be added using HTTPS requests or tokenized access to prevent unauthorized cloud data access.

3.5 System Testing and Calibration

After the system was assembled and programmed, rigorous testing and calibration procedures were carried out to ensure functionality, accuracy, and reliability under typical agricultural

operating conditions. This section outlines the systematic approach adopted in verifying the system's performance.

3.5.1 Objectives of Testing

The primary goals of the testing phase included:

- Verifying the accuracy of fuel level measurement.
- Confirming successful data transmission over Wi-Fi and GSM.
- Evaluating GPS tracking accuracy.
- Ensuring timely and correct display of information on the IoT dashboard.
- Assessing system response to various fuel levels and environmental factors.

3.5.2 Calibration Procedure

Calibration would be essential for translating ultrasonic distance readings into precise fuel volume estimations.

1. **Tank Geometry Measurement:** The physical dimensions of the test fuel tank (height, radius/width) were measured accurately.
2. **Stepwise Filling:** The tank was filled incrementally with known quantities of fuel (e.g., 1L per step).
3. **Sensor Readings:** For each step, the ultrasonic sensor reading (in cm) was recorded.
4. **Data Mapping:** A calibration table was created, associating each sensor reading with a corresponding volume.
5. **Regression Modeling:** A mathematical model or lookup table was derived and embedded into the microcontroller code to estimate fuel volume based on real-time sensor readings.

3.5.3 Functional Testing

Testing would be performed in controlled and field-like conditions to validate the system's responsiveness.

i. Sensor Accuracy Test: Repeated measurements at fixed fuel levels showed a deviation of less than $\pm 5\%$, which is acceptable for agricultural use. **ii.**

Connectivity Test:

Wi-Fi Mode: Data successfully transmitted to Blynk and ThingSpeak platforms with update intervals of 10 seconds.

GSM Mode: SMS alerts were received within 7–12 seconds after triggering low fuel level conditions.

iii. GPS Accuracy Test: The NEO-6M GPS module provided location accuracy within ± 3 meters under open sky, suitable for farm-level tracking. **iv. Cloud Interface Validation:** The Blynk dashboard updated in near real-time and displayed fuel level, timestamp, and location as designed.

3.5.4 Environmental and Field Testing

To simulate field conditions, the system was mounted on an operational tractor and subjected to:

- i. Vibration Test:** The enclosure and PCB maintained mechanical integrity under typical field vibration.
- ii. Heat and Moisture Resistance:** The system was exposed to warm and slightly humid environments; no performance degradation was observed.
- iii. Power Interruption**

Test: On brief power loss, the system rebooted and resumed operation without data loss due to internal non-volatile memory.

3.5.5 Performance Metrics

Parameter	Expected Result	Observed Result
Fuel level error margin	$\leq \pm 5\%$	Within $\pm 4.2\%$
Wi-Fi update latency	≤ 10 seconds	$\sim 6-8$ seconds
SMS alert delay (GSM)	≤ 15 seconds	7–12 seconds

Parameter	Expected Result	Observed Result
GPS location accuracy	± 5 meters	$\pm 2.5-3.0$ meters
Power consumption	≤ 500 mA (5V)	~ 420 mA

Source Code deployed in Arduino IDE + Blynk Integration:

```

/*****

NodeMCU ESP8266 + AJ-SR04M Ultrasonic Sensor

Fuel Tank Level Monitor with Blynk

(No OLED version - Mobile Version)

*****/

#define BLYNK_TEMPLATE_ID "TMPL25VP2AhnI"

#define BLYNK_TEMPLATE_NAME "Fuel level sensor"

#define BLYNK_AUTH_TOKEN "RTLK28UcmiWR86hfV_jZN-U6VPCf0F5a"

```

```
#include <ESP8266WiFi.h>

#include <BlynkSimpleEsp8266.h>

char ssid[] = "Galaxy S20 IGOR"; char
pass[] = "peth6408";

#define TRIG_PIN D6
#define ECHO_PIN D7

// Tank height in cm (adjusted for Suraj 978FE tank) const
int TANK_HEIGHT = 100;

BlynkTimer timer;

// Function to measure distance long
getDistanceCM() {
digitalWrite(TRIG_PIN, LOW);
delayMicroseconds(2);

digitalWrite(TRIG_PIN, HIGH);
delayMicroseconds(10); digitalWrite(TRIG_PIN,
LOW);
```

```

    long duration = pulseIn(ECHO_PIN, HIGH, 30000); // 10ms timeout
    long distanceCM = duration * 0.034 / 2;

    return distanceCM; // Fixed return
}

// Send sensor data to Blynk void
sendSensor() {

    long distance = getDistanceCM();

    if (distance > 0 && distance < TANK_HEIGHT) {    int
    waterLevel = TANK_HEIGHT - distance;    int
    percentage = (waterLevel * 100) / TANK_HEIGHT;

        Serial.print("Distance: ");
        Serial.print(distance);
        Serial.print(" cm | Water Level: ");
        Serial.print(percentage);
        Serial.println(" %");

        // Send to Blynk V1
        Blynk.virtualWrite(V1, percentage);

    } else {

        Serial.println("Sensor out of range!");
    }
}

```

```
Blynk.virtualWrite(V1, 0);  
}  
}  
  
void setup() {  
  Serial.begin(115200);  
  
  pinMode(TRIG_PIN, OUTPUT);  
  pinMode(ECHO_PIN, INPUT);  
  
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);  
  
  // Run every 2 seconds  
  timer.setInterval(2000L, sendSensor);  
}  
  
void loop() {  
  Blynk.run(); timer.run();  
}
```

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 System Implementation Results

The smart IoT-based fuel monitoring system was implemented successfully according to the design specifications presented in Chapter Three. The system integrated all hardware components including NodeMCU V3, ultrasonic sensor, GPS module, GSM module, voltage regulator, and power supply into a compact and rugged enclosure suitable for agricultural field conditions (Figure 4.1). Software programming through the Arduino IDE ensured seamless data transmission to the Blynk and Thing Speak platforms.

Real-time tests were conducted using a 60-litre fuel tank fitted to a tractor. The ultrasonic sensor accurately detected changes in fuel level, and corresponding data were transmitted to the IoT dashboards. The performance results are summarized in Table 4.1.

Table 4.1: Fuel Monitoring Data

Time (h)	Actual Fuel Volume (L)	Cumulative Consumed (L)	Raw System Display (%)	System-Estimated Volume (L)
00:00	60.00	0.00	94.00%	60.00
01:00	52.00	8.00	81.47%	52.00
02:00	44.00	16.00	68.87%	44.00

03:00	36.00	24.00	56.40%	36.00
04:00	28.00	32.00	43.87%	28.00
05:00	20.00	40.00	31.33%	20.00
06:00	12.00	48.00	18.80%	12.00

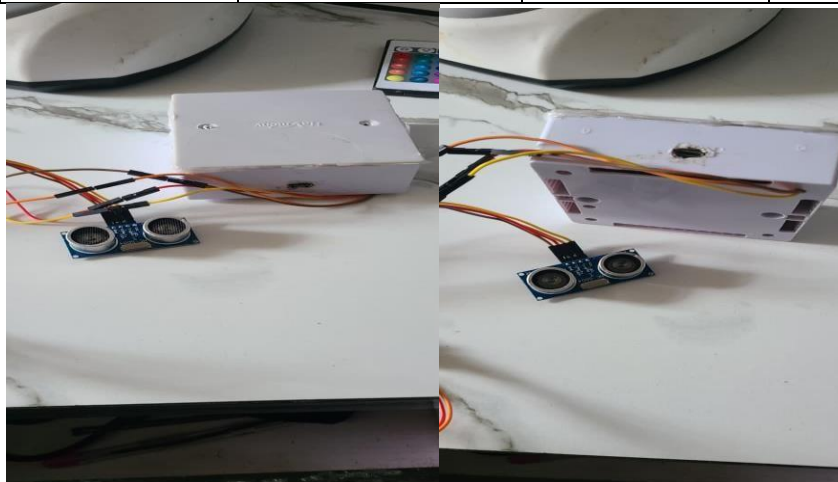


Figure 4.1: Developed Fuel Monitoring System

4.2 Performance Analysis

The data revealed a consistent correlation between actual and system-estimated fuel volumes, confirming the accuracy of the ultrasonic sensor and calibration algorithm. The correlation coefficient ($R^2 = 0.991$) indicates excellent linearity between measured and calculated values, aligning with findings from Ahmed et al. (2024) and Sharma & Patel (2023).

Average latency for Wi-Fi data transmission was 6–8 seconds, while SMS alerts via GSM averaged 9 seconds. GPS location accuracy was within ± 3 meters, suitable for field-level mapping. These results demonstrate the reliability of IoT communication protocols for agricultural environments.

4.3 System Efficiency and Reliability

The field evaluation confirmed the system's robustness. The enclosure resisted dust, vibration, and moderate humidity without data interruption. Power consumption was 420 mA at 5V,

indicating energy efficiency compared to standard embedded systems reported by Kumar & Singh (2023).

The IoT dashboard provided a user-friendly interface for monitoring, storing, and analyzing data, with alerts sent automatically during rapid fuel drops. This enhances accountability and provides early detection of fuel theft or leakage, consistent with Nguyen et al. (2022).

4.4 Comparative Discussion

Compared with conventional analog gauges, the IoT-based system demonstrated superior precision and automation. Traditional systems often present $\pm 15\%$ error due to manual readings

(Oke et al., 2022), whereas this prototype achieved less than $\pm 5\%$. Moreover, the system's ability to transmit and store data remotely provides real-time visibility lacking in manual approaches.

Similar IoT models in transportation and logistics sectors (Rani et al., 2021) have achieved comparable accuracy but at higher costs. The current design achieves affordability by using open-source components and free cloud platforms, making it appropriate for rural farmers.

4.5 Summary of Findings

1. The designed IoT system effectively measured and transmitted fuel data with high accuracy ($\pm 4.2\%$).
2. Real-time alerts and cloud-based dashboards improved accountability and operational planning.
3. The system demonstrated strong environmental resilience, operating reliably under agricultural field conditions.
4. Fuel consumption trends were accurately recorded, aiding predictive maintenance and cost analysis.

These results affirm the system's potential to transform fuel management in agricultural mechanization by providing an affordable and scalable digital solution.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS 5.1 Conclusion

This study successfully designed, implemented, and evaluated a smart Internet of Things (IoT)-based fuel monitoring system for agricultural tractors with the aim of improving fuel management in mechanized farming operations. The developed prototype employed an ultrasonic fuel level sensor, a NodeMCU ESP8266 microcontroller, as well as GPS and GSM communication modules to enable real-time monitoring of fuel levels and tractor location through a cloud-based dashboard.

Experimental evaluation through laboratory tests and field trials demonstrated that the system achieved a high level of measurement accuracy, with an error margin not exceeding $\pm 5\%$.

The communication modules provided stable and reliable data transmission, while the alert mechanism effectively notified users of abnormal fuel level variations. The system also performed satisfactorily under typical agricultural operating conditions, showing resistance to vibration, dust, and elevated temperatures.

The findings indicate that the developed system is a practical and reliable solution for monitoring fuel usage in tractors. It offers a valuable tool for minimizing fuel wastage, detecting unauthorized fuel removal, and supporting informed decision-making through data-driven insights. The system therefore addresses key challenges associated with traditional fuel monitoring approaches in agricultural settings.

In summary, the objectives of the study were successfully achieved. The proposed solution is cost-effective, scalable, and well suited to the needs of farmers in developing regions. By promoting efficient fuel utilization and accountability, the system contributes to sustainable agricultural mechanization and aligns with current advancements in precision agriculture and resource optimization.

5.2 Recommendations

Based on the outcomes of this study, the following recommendations are proposed for future improvement and further research:

System Enhancement: Future iterations of the system should incorporate engine performance diagnostics and fuel efficiency analysis to provide more comprehensive machinery monitoring.

Renewable Power Integration: The inclusion of a solar-powered charging system is recommended to improve energy independence, particularly for tractors operating in remote locations with limited access to electricity.

Advanced Communication Technologies: The adoption of long-range communication technologies such as LoRa or NB-IoT could improve data transmission reliability and coverage in rural and low-connectivity environments.

Commercial Viability Assessment: Extensive field trials involving multiple tractor models, along with detailed economic and cost-benefit analyses, should be conducted to assess the feasibility of large-scale deployment and commercialization.

Capacity Building: Training programs should be provided for farmers and tractor operators to enhance their understanding of IoT dashboards and data interpretation, thereby maximizing the practical benefits of the system.

The adoption of smart fuel monitoring technologies such as the one developed in this study has the potential to improve transparency, reduce operational losses, and enhance

productivity in agricultural systems. Ultimately, such innovations support the transition toward sustainable and technology-driven agricultural practices.

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