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Original Research Article

Optimizing Drip Irrigation Efficiency: A Comprehensive Study on pH, Moisture Content, and Sensor Testing for Coconut MATAG Cultivation in Nursery Stages in Malaysia

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Abstract: This paper presented an evaluation of preliminary studies and sensor testing aimed at refining irrigation practices for MATAG coconut growth in nursery stages. The study focused on measuring pH and moisture content to assess water distribution accuracy within the experimental setup. Results highlighted the significance of precise irrigation management, showcasing notable pH fluctuations in areas affected by leakage issues, which impacted MATAG coconut growth. The subsequent sensor testing phase evaluated the functionality of flow rate and pressure sensors integrated with an LCD display in real-time data logging. The flow rate sensor successfully captured water flow variations, while the pressure sensor provided real-time pressure readings, enabling swift detection of fluctuations. The Arduino microcontroller and real-time clock integration ensured accurate and timely data logging, facilitating seamless communication with sensors. The findings underscored the developed sensor system's efficacy in detecting clogging issues, emphasizing its importance for MATAG coconut growth and water conservation. The integration of flow rate and pressure sensors, coupled with an LCD display, demonstrated the system's ability to monitor the irrigation setup effectively. This comprehensive testing phase established the system's capability to provide accurate information, enabling users to assess sensor functioning, detect connection problems, and address issues promptly. The successful sensor testing marked a crucial step toward building a dependable and responsive irrigation monitoring solution, empowering growers to make informed decisions for sustainable MATAG coconut cultivation and water conservation.

Keywords: Drip irrigation; Matag coconut; sensor technology; water distribution; irrigation management; flow rate sensor; pressure sensor

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1. Introduction

Agricultural practices were integral to sustaining global food security and economic stability. Among the diverse range of crops cultivated, the Matag coconut (*Cocos nucifera*) stood out due to its multifaceted contributions, spanning from food and oil production to materials for shelter and livelihoods (Nuwarapaksha *et al*., 2023). In this study, we focus on enhancing coconut cultivation in the nursery phase through precise and resource-efficient irrigation systems. MATAG F1 coconut, a hybrid of Malaysia Yellow or Red Dwarf and the Philippines' Tagnanan coconut, was produced through controlled pollination by United Plantations Berhad. It is the most commercialized coconut in Malaysia, while MYD was favored by smallholders for its size and ease of management (Xavier *et al*., 2019; Halim *et al*., 2018).

Efficient irrigation practices were paramount for the successful cultivation of crops, especially for resource-intensive varieties like the Matag coconut. Achieving optimal water delivery while minimizing wastage was crucial for attaining desirable growth rates and yields. The use of automated weather recording stations allowed the storage of the data collected by the sensors and automated the calculation, enabling its use in an integral way (Jha *et al*., 2019; Xue *et al*., 2020). Agricultural automation using microcontrollers and artificial intelligence were tools for collecting information and decision-making in real time, based on algorithms capable of back-feeding databases and improving choices (Talaviya *et al*., 2020; Vij *et al*., 2020).

Drip irrigation, a precision technique, played a pivotal role in addressing this challenge. By directly supplying water to plant root zones in controlled amounts, drip irrigation mitigated water losses due to evaporation and runoff. Its suitability for water-sensitive crops like Matag coconuts ensured consistent moisture, nutrient supply, and oxygenation. The convergence of modern technology with agricultural practices held immense promise in advancing irrigation methods. The Arduino platform emerged as a key player. Arduino, a versatile microcontroller, offered programmable functionalities that could revolutionize irrigation management. When coupled with a real-time clock module, the

Arduino setup empowered precise scheduling and automated control of irrigation cycles. Since Arduino Uno is an open-source platform, all its software, schematics, board layouts, and board designs were freely accessible to the general public. Because of this, it was elementary to adapt the platform to the requirements of individual applications (Ganguly *et al*., 2018).

This integration of technology with agriculture facilitated real-time monitoring and data collection, enabling growers to make informed decisions regarding irrigation strategies. In the context of this study, the primary objective was to address a persistent challenge within drip irrigation systems — the occurrence of clogging within lateral pipes. Clogging posed a serious threat to water flow, disrupting uniform distribution and jeopardizing the health and yield potential of Matag coconut plants. To tackle this issue, a data logging sensor system that monitored pressure and flow rate within the lateral pipes have been developed. By closely analyzing these parameters, our goal was to proactively detect instances of clogging and trigger timely corrective actions. Automated electronic data loggers revolutionized environmental monitoring by enabling reliable high-frequency measurements. However, the potential to monitor the complex environmental interactions involved in global change had not been fully realized due to the high cost and lack of modularity of commercially available data loggers (Wickert *et al*., 2019).

A study by Lakhiar *et al*. (2024) demonstrated the effectiveness of sensor-based monitoring in enhancing water use efficiency in drip irrigation systems. The findings underscored the importance of real-time data collection for optimizing irrigation strategies and maximizing crop yields. This study sought to explore the relationship between Matag coconut growth, efficient irrigation practices, and technological innovation. By harnessing the capabilities of Arduino-based real-time monitoring and data collection, we aspired to contribute to the sustainable and resilient cultivation of Matag coconuts, ensuring their productivity in the face of evolving agricultural challenges. The monitoring system used electronic components and sensors such as: Arduino Uno, Pressure sensor type HK1100C with accuracy ± 3, and Flow sensor type YFS201C with accuracy ±10.

The main objectives of this study were: 1) to develop a data logging sensor system for real-time monitoring of pressure and flow rate within the lateral pipes of the drip irrigation system; 2) to detect instances of clogging in the irrigation system by analyzing variations in pressure and flow rate; and 3) to provide actionable insights to promptly address clogging issues and ensure efficient water distribution to Matag coconut plants in the nursery stages.

2. Materials and Methods

2.1. Experiment Design

The experimental design utilized in this study was a controlled field experiment conducted in a nursery located in an open rain shelter structure on the rooftop of the Faculty of Engineering at Universiti Putra Malaysia (UPM) in Serdang, Selangor, spanning two cultivation seasons from January to June 2022 (Season 1) and July to December 2022 (Season 2). The setup involved the installation of flow rate and pressure sensors (HK1100C and YF-S201C) at critical points in the irrigation system, interfaced with an Arduino UNO microcontroller for data processing and logging. A DS3231 real-time clock module ensured accurate timestamps, while an LCD display provided real-time readings of flow rate and pressure. The system was activated to allow water flow through the pipes, enabling the collection of real-time data and monitoring variations over an extended period to assess system efficiency and detect potential clogging issues. This design allows for replication, providing valuable insights into the effectiveness of the monitoring system on irrigation parameters and its impact on coconut growth (Aisopou *et al.*, 2011).

2.2. Hardware Design

The hardware was designed by selecting electronic components and sensors known for their quality and reliability. The monitoring system is capable of tracking both water flow rate and pressure at the lateral pipe, requiring multiple sensors and related components. Data from the pressure sensor and flow sensor is received, processed, and calculated automatically by the microcontroller. The processed data is then displayed on a screen. Additionally, the system includes an SD card for data storage, which is managed by the microcontroller. The hardware setup for the monitoring design system is shown in Figure 1.

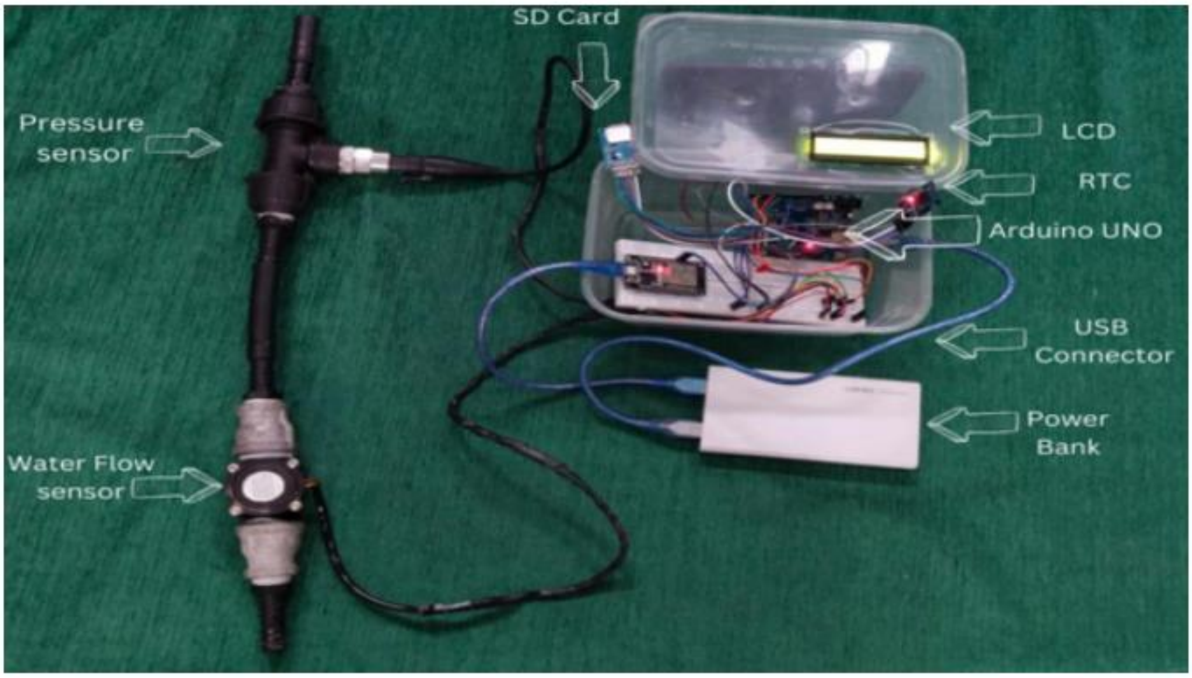

Figure 1. Electronics system and sensor

2.2.1. Adiuno UNO

Arduino-compatible custom sensor expansion boards, commonly referred to as shields, were developed for seamless integration with the standardized pin-headers of the Arduino board, facilitating connections to multiple sensors. The Arduino UNO board was selected as the central processing unit due to its compatibility with a variety of sensors and open-source platform flexibility (Louis, 2018). The key components of the Arduino UNO board used in this setup include a USB connector, power port, microcontroller, analog input pins, digital pins, reset switch, crystal oscillator, USB interface chip, and TX/RX LEDs.

A schematic diagram of the Arduino UNO board in Figure 2 was prepared to outline the major components utilized in the monitoring system (Sapini, 2023). The board was powered by a regulated 5 V supply, which was sufficient to run the microcontroller and other peripheral components. Analog input pins (A0 to A5) were designated for interfacing with sensor inputs, while digital input/output pins (2 to 13) were used for controlling output devices. The ground points were connected to both digital and analog circuitry to ensure proper functionality.

Figure 2. Components of Arduino UNO board

Custom software was developed using the Arduino Integrated Development Environment (IDE), a platform that enables code development in a simplified C++ language. The IDE was installed on a computer and used to upload programs to the Arduino board via the USB connector. The software allowed for real-time data acquisition from sensors and facilitated the operation of the connected components, such as data storage devices and display units. All programs were written and compiled using the Arduino IDE, with the code executed on the microcontroller to control the sensor data logging process.

The shield's design was tested with various sensors, and the data collected was processed by the Arduino UNO in real time. The shield interfaced with the sensors through analog and digital pins, and the acquired data were logged into an SD card for further analysis. This setup enabled continuous monitoring of water flow rates and pressure within the irrigation system, ensuring efficient data collection and system performance validation.

2.2.2. HK1100C pressure sensor

Pressure sensors are essential in modern engineering applications, offering crucial data for various domains, including industrial automation, environmental monitoring, and agricultural practices such as drip irrigation systems. For this study, the HK1100C pressure sensor was selected due to its high accuracy, reliability, and compatibility with agricultural applications. The sensor was integrated into the system to measure water pressure within the drip irrigation setup.

The pressure measurements were derived using the sensor's output voltage (V_{out}) and supply voltage (V_{cc}), calculated based on the following equation:

$$P = 15\ V_{out}/V_{cc} - 1.5 \quad (1)$$

Where:

- PPP is the water pressure in bars,
- V_{out} is the sensor's output voltage, and
- V_{cc} is the supply voltage.

The HK1100C pressure sensor was connected to the system using its color-coded pinout configuration (Figure 3), with red indicating the supply voltage (V_{cc}), black for ground (GND), and yellow for the signal output (V_{out}). This straightforward color-coding facilitated its seamless integration into the monitoring system.

Figure 3. HK1100C Pressure sensor

The sensor operates with a 5 V DC supply voltage, producing an output signal between 0.5 V and 4.5 V DC. Its pressure measurement range spans from 0 to 12 bars with an accuracy of ±3%. Additionally, the sensor features a G1/4" water connection, making it suitable for various liquid applications. It is designed to operate within a temperature range of 1°C to 80°C, constructed from durable materials such as metal and nylon, ensuring its robustness in a range of environmental conditions.

These technical characteristics and reliable performance make the HK1100C sensor a valuable component in monitoring water pressure in irrigation systems, contributing to precise control and optimization of the agricultural process.

2.2.3. YF-S201C water flow sensor

The YF-S201C water flow sensor was employed to measure the water flow rate in this study. This sensor comprises a plastic valve body, rotor assembly (Figure 4a), and a Hall effect sensor (Figure 4b). Its operation is based on the Hall magnetic effect, where the rotation of the rotor, caused by the flow of water, generates an electric pulse via the Hall effect sensor. The quantity of water passing through the sensor is calculated by counting the number of pulses, with each pulse approximately representing 2.25 mL of water. The sensor measures water flow rates within the range of 1 to 30 L/min and can withstand pressures up to 1.75 MPa.

(a) (b)

Figure 4. YF-S201C Water Flow Sensor

The YF-S201C sensor features three essential pins: VCC (power supply), VGND (ground), and OUT (pulse output). The sensor operates on a voltage supply ranging from 5 to 24 volts, with a maximum current of 15 mA. The NPN square frequency signal generated by the Hall effect sensor allows for precise water flow measurements.

The sensors compact design (54 mm in length, 25 mm in width) makes it suitable for various applications. It is constructed from durable plastic, ensuring its longevity and resistance to wear and tear. The sensor operates effectively within a temperature range of up to 80°C and a humidity range of 35% to 90% RH. Additionally, the internal Hall sensor is sealed with glue to prevent water ingress, enhancing its reliability in wet environments. With its resistance to pressures up to 1.75 MPa and robust design, the YF-S201C is an ideal choice for long-term water flow monitoring in agricultural and industrial applications.

2.2.4. DS3231 RTC module

The DS3231 real-time clock (RTC) module was utilized in the monitoring system to provide precise timekeeping. This I2C-compatible RTC module features an integrated temperature-compensated crystal oscillator (TCXO) and a crystal, which contribute to its high accuracy and long-term precision. In the event of a power interruption, the DS3231 is equipped with a battery input that allows it to maintain accurate timekeeping, ensuring continuous operation without the need for recalibration.

The DS3231 tracks time in seconds, minutes, hours, days, dates, months, and years, with automatic adjustments for months with fewer than 31 days and leap year corrections. The clock operates in both 12-hour (with AM/PM indication) and 24-hour formats, making it versatile for a variety of applications. Additionally, the module includes two programmable alarms, providing functionality for scheduled operations or notifications. It also supports a programmable square-wave output, offering further flexibility for integration with other systems.

Data communication between the DS3231 and the microcontroller is facilitated via an I2C bidirectional bus, which serially transmits address and data information. This ensures reliable and efficient data exchange, enabling seamless integration of the RTC module into the overall system architecture. The precise timekeeping functionality of the DS3231 plays a critical role in time-sensitive operations, particularly in scenarios where accurate scheduling and timestamping are essential.

2.2.5 DS3231 RTC module pinout

In Figure 5, the DS3231 module is depicted, highlighting its six essential pins critical for both data retrieval and powering the board. The 32K pin operates as the oscillator output, playing a vital role in the module's timekeeping functions by providing a clock signal. The SQW pin serves as the Square Wave output, generating essential signals that can be utilized for various timing and scheduling tasks within the module. The SCL pin, representing the Serial Clock in the I2C interface, synchronizes data transmission between the DS3231 and the microcontroller, ensuring reliable communication. Similarly, the SDA pin facilitates the seamless transfer of digital information between components, allowing for efficient data exchange.

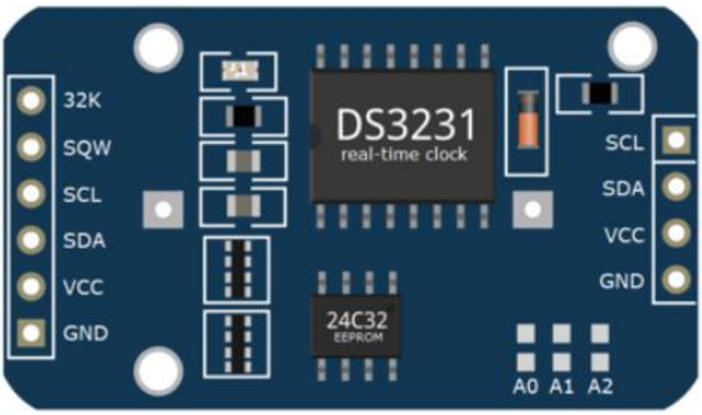

Figure 5. Pinout of DS3231 RTC Module

The VCC pin serves as the positive connection for the power source, ensuring proper functionality and a stable power supply to the module, while the GND pin acts as the ground connection, establishing the essential electrical reference point for the module's operations and completing the circuit. This detailed pinout configuration delineates the fundamental connections of the DS3231 module, enabling smooth communication and consistent power supply within the monitoring system. The arrangement of these pins allows for straightforward integration into various electronic applications, emphasizing the module's versatility and reliability in maintaining accurate timekeeping.

2.3. Software Design

In this research software used was Arduino IDE 2.1.1 in which the coding was done and uploaded into the microcontroller board Arduino UNO. The output of the sensor is analog voltage and digital will be processed by the microcontroller and stored in the SD card.

2.4. Sensor Setup

Flow rate and pressure sensors were carefully installed at critical points within the irrigation system, ensuring proper positioning and secure connections. The sensors were interfaced with an Arduino microcontroller to facilitate data collection and processing.

2.5. LCD Integration

An LCD display was incorporated into the system to provide a real-time visual output of the flow rate and pressure readings obtained from the sensors. Arduino programming was utilized to establish communication between the sensors, microcontroller, and the LCD display. The Arduino Uno (R3) is a popular microcontroller board designed for beginners and professionals. It is based on the ATmega328P (Kulor *et al.*, 2021) microcontroller and has a variety of input/output (Meimei *et al.*, 2021) pins that can be used for controlling and sensing different devices.

2.6. Testing the Sensor

The irrigation system was activated, and water flow was initiated through the pipes. The LCD display started to show real-time data, including flow rate and pressure values retrieved from the respective sensors. The system was monitored over an extended period, during which changes in flow rate and pressure were observed and recorded.

3. Results and Discussions

3.1. Preliminary Studies

Efficient water distribution in a drip irrigation system was crucial to ensuring optimal crop growth and yield. Inaccurate water delivery could lead to uneven moisture levels in the soil, potentially affecting plant health and productivity Bhavsar *et al*., (2023). To address this challenge, a preliminary study was conducted involving the measurement of pH and moisture content as key indicators for determining the correct amount of water distribution within the drip irrigation system.

In a meticulously controlled experimental setup, polybags containing uniform soil compositions and crop types were utilized to assess the irrigation effects on Matag coconut plants. The research began by selecting a representative area equipped with a drip irrigation system, housing early-stage Matag coconut plants. Homogeneous soil samples were carefully collected and placed into individual polybags to ensure consistent soil type and composition across all samples, thereby eliminating variability that could influence the results (Amena, 2021).

Soil pH measurements were conducted at various depths using a pH meter, allowing for the evaluation of potential pH variations within the soil profile. The importance of maintaining optimal soil pH levels for coconut cultivation has been emphasized in previous studies, as pH significantly affects nutrient availability and plant growth (Alexopoulous *et al*., 2021). Additionally, soil moisture content was assessed through the gravimetric method, involving precise weighing, oven-drying at 105°C, and subsequent reweighing of soil samples. The moisture content, expressed as a percentage of the oven-dry weight of the soil, provided valuable insights into soil hydration levels. This method aligns with contemporary practices for moisture measurement, which are critical for understanding irrigation efficiency (Rasheed *et al*., 2022).

A precise drip irrigation system was established, delivering equal amounts of water to different polybags. Water application rates were fine-tuned based on moisture content measurements and the specific water requirements of the plants. Regular readings of pH and moisture content were meticulously collected throughout the study period. Notably, the preliminary study highlighted significant pH fluctuations in areas affected by leakage issues, underscoring the necessity for precise irrigation management in the experimental setup.

During normal irrigation, pH levels remained relatively stable, reinforcing the idea that controlled irrigation practices can effectively maintain soil health (Fadl *et al*., 2024).

However, in regions impacted by leaks, pH levels exhibited significant deviations from the optimal range for Matag coconut growth, indicating that irregular water distribution due to leaks contributed to pH imbalances. This finding aligns with recent studies that have shown the detrimental effects of uneven water distribution on soil chemistry and plant health (Silva *et al*., 2023). Conversely, areas with leakage issues displayed erratic moisture levels, suggesting insufficient water delivery in certain spots and excess moisture in others, which can lead to water stress or root rot in coconut plants (Gavrilescu, 2021).

The implications of these results highlight the critical need for robust irrigation management strategies in coconut cultivation, particularly in regions susceptible to leakage. Future research should focus on developing and implementing advanced irrigation systems that can dynamically adjust to real-time soil moisture levels, thereby optimizing water use efficiency and promoting sustainable agricultural practices.

3.2. Sensor Testing

3.2.1. Flow rate measurement

The flow rate sensor effectively monitored water flow within the irrigation system, yielding reliable data for subsequent analysis. Real-time feedback was provided via an LCD display, which indicated flow rate values that aligned with the expected rates outlined in the system specifications. Any fluctuations in flow rate resulting from adjustments in valve positions were promptly reflected on the LCD, facilitating continuous performance monitoring. The initial trial conducted during sensor testing aimed to validate its functionality, allowing for the identification of potential issues such as wiring errors or compatibility challenges. The data collected from the sensor, as depicted in Figure 6, underscores the efficacy of the monitoring system in capturing and displaying flow rate variations.

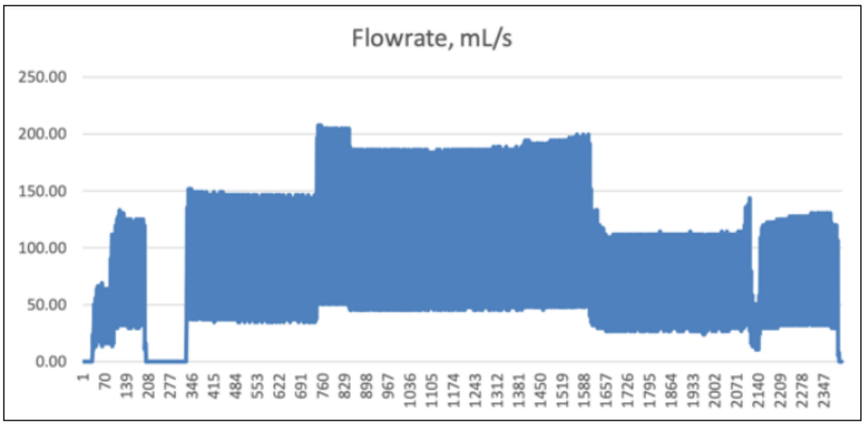

Figure 6. Flow Rate Measurement

3.2.2. Pressure monitoring

The pressure sensor effectively measured the pressure levels within the pipes, with the LCD display in Figure 7 illustrating the pressure monitoring graph. The real-time pressure readings, expressed in PSI, enabled quick detection of fluctuations caused by changes in water distribution. The graph was generated using data gathered from the sensor, showcasing the successful data logging during sensor testing. This demonstrated the efficacy of the system in accurately measuring both flow rate and pressure while providing immediate feedback through the LCD display (Morchid *et al*., 2024).

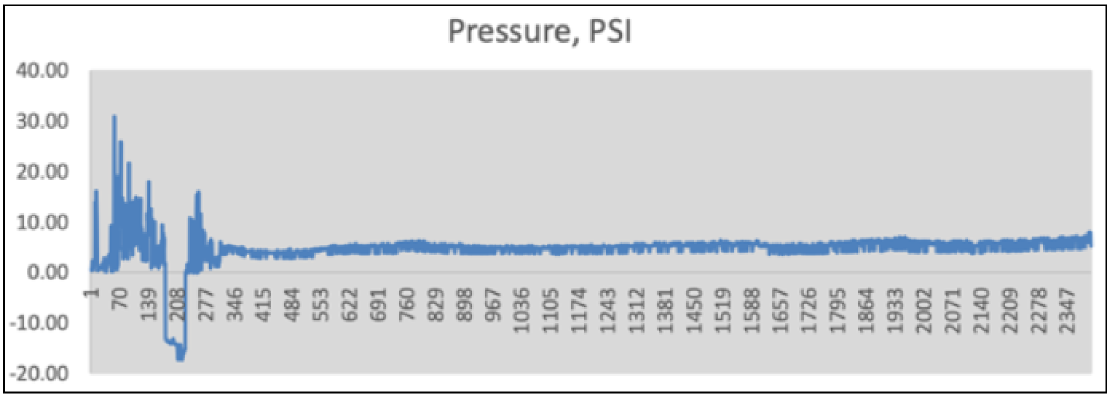

Figure 7. Pressure monitoring graph

The evaluation of the Arduino setup and real-time clock integration in data collection proved instrumental in ensuring accurate and timely information. The Arduino microcontroller facilitated seamless communication with the sensors, enabling precise data logging at predefined intervals (Louis, 2018). Furthermore, the real-time clock synchronization ensured that readings were accurately time-stamped, allowing for temporal analysis of pressure and flow rate variations. The systems instantaneous response to sensor malfunctions or connection disruptions underscored its reliability in identifying issues and assisting in swift troubleshooting. This integration highlighted the effectiveness of modern technology in enhancing data accuracy and facilitating early detection of clogging issues (Allioui & Mourdi, 2023).

4. Conclusions

In conclusion, the success of the developed sensor system in detecting clogging problems underscores its significance for Matag coconut growth and water conservation. The integration of flow rate and pressure sensors, along with an LCD display in the data logging system, proved effective in monitoring the irrigation setup. This comprehensive testing phase established the system's capability to provide accurate and timely information, enabling users to assess the proper functioning of sensors, detect connection issues, and promptly address any challenges that may arise during operation.

The successful sensor testing serves as a crucial step toward building a dependable and responsive irrigation monitoring solution. By leveraging real-time data, growers can make informed decisions, optimize water distribution, and ultimately contribute to the sustainable cultivation of Matag coconuts while conserving this vital resource.

Author Contributions: Conceptualization of study — A. S. S.S. and A.W.; Methodology, conducted the software implementation, formal analysis, investigation, and data curation, and the original draft of the manuscript preparation — A. S. S. S.; Validation — A. S. S. S., A. W., and S. A. A.; Resources were provided — A. S. S. S. and M. Y. W.; The writing, review, and editing of the manuscript were collectively performed by A. S. S. S., A. W., S. A. A., M. Y. W., and L. G. Visualization tasks were managed by A. S. S. S., while A. W., S. A. A., M. Y. W. provided supervision throughout the project. Project administration was led by A. S. S. S., and funding acquisition was facilitated by A. W. and L. G.

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