PERFORMANCE EVALUATION OF REAL-TIME PORTABLE SOIL CONDITION MONITORING SYSTEM (REPSOIL) IN ROCK MELON FERTIGATION FARM

Muhammad As Shakirin Bin Abd Aziz
Faculty of Technology and Electrical Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
76100 Durian Tunggal, Melaka, Malaysia
Email:m012210004@student.utem.edu.my

Anuar Bin Mohamed Kassim
Center of Robotics and Industrial Automation
Faculty of Technology and Electrical Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
76100 Durian Tunggal, Melaka, Malaysia

Mohd Rusdy Bin Yaacob
Center of Robotics and Industrial Automation
Faculty of Technology and Electrical Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
76100 Durian Tunggal, Melaka, Malaysia

Nur-Al-Aswad Bin Zulkefli
Faculty of Technology and Electrical Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
76100 Durian Tunggal, Melaka, Malaysia

Awangku Khairul Ridzwan bin Awangku Jaya
IngeniousCity Engineering Solutions Sdn Bhd
75260 Krubong, Melaka, Malaysia

Zuraidah Ngadiron
Industry Centre of Excellence for Railway
Institute Integrated Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM)
86400 Parit Raja, Johor, Malaysia

Takashi Yasuno
Graduate School of Technology,
Industrial and Social Sciences,
Tokushima University
Tokushima 770-8506, Japan

ABSTRACT

In the face of escalating food demands, Malaysia's agricultural sector is pivotal, with 1.6 million people engaged in activities ranging from farming to agribusiness. The sector is ripe for transformation through smart farming technologies that promise enhanced efficiency and sustainability. This study introduces the Real-Time Portable Soil Condition Monitoring System (REPSOIL), a groundbreaking innovation designed to revolutionize soil and environment parameter monitoring. Conducted at the rock melon farm of Kolej Universiti Agrosains Malaysia (UCAM), the research evaluates REPSOIL's performance, which boasts an efficiency improvement of up to 99.9% over traditional methods. The system features advanced parameters such as a Low-Power Wireless Control Protocol for data transmission and an Extensa LX-6 microcontroller architecture for processing, ensuring rapid and accurate soil analysis. With its solar-powered energy system, REPSOIL represents a sustainable solution that aligns with Malaysia's smart farming initiatives. The study's findings demonstrate that REPSOIL's precision agriculture performance significantly improves farming operations. By enabling farmers to receive real-time data on soil conditions, REPSOIL facilitates immediate and informed agricultural decisions, thereby enhancing crop productivity and contributing to national food security. The system's performance, characterized by its efficiency and sustainability, positions it as an essential tool for the future of farming in Malaysia and beyond.

Keywords: Automated Soil Sensing, Precision Agriculture Technology, Wireless Soil Data Transmission, Sustainable Farming Monitoring

INTRODUCTION

The quest for food security is a pressing concern in Malaysia, with the Department of Statistics Malaysia highlighting the nation's reliance on a trio of agricultural sub-sectors: crops, livestock, and fisheries (N. S. Abu *et al.*, 2022). Despite contributing 8.9% to the GDP in 2022, the agriculture sector experienced a slight decline due to factors such as reduced commodity production. Malaysia has turned to smart farming initiatives to address these challenges and bolster food security (Kassim, A.M., Sahak, S., *et al.* 2022). These initiatives aim to enhance domestic production, reduce import dependency, and employ technologies like the Internet of Things (IoT) for tasks ranging from soil pH control to long-distance farming (Rozenstein *et al.*, 2024). The government's commitment to this technological transformation is evident in its execution of pilot projects that integrate IoT in agriculture. These projects aim to resolve food security issues and ensure the safety and quality of food supplies (N. S. Abu *et al.*, 2022).

This research delves into the innovation and comparative performance assessment of the Real-Time Portable Soil Condition Monitoring System (REPSOIL), an automated device engineered to quantify soil and environment parameters. The study unfolds within the agricultural confines of a rock melon farm at Kolej Universiti Agrosains Malaysia (UCAM), where REPSOIL's capabilities are meticulously benchmarked against conventional manual soil testing techniques. The empirical evidence gathered from the comparative analysis underscores a substantial enhancement in the efficiency of soil data collection and the optimization of energy consumption attributed to the deployment of REPSOIL (Kassim, A.M., Kamarudin, N.A., *et al.* 2022). The findings illuminate the transformative potential of REPSOIL in streamlining agricultural practices through technological intervention.

Globally, developed countries have widely adopted smart farming technologies, leveraging them to enhance agricultural productivity and sustainability (Ratshiedana *et al.*, 2023). Nations like Japan, Indonesia, and China have become leaders in integrating technologies such as GPS-based guidance systems and yield monitors, with adoption rates reaching 60-80% by 2016 (Mandal, Ali, and Saha, 2021). In Kazakhstan, smart greenhouses equipped with IoT technology and AI are optimizing crop growth conditions. This widespread use of advanced agricultural technologies has resulted in increased efficiency, reduced environmental impact, and improved crop management (Melo, et.al, 2021). The success of smart farming in these countries serves as a model for nations like Malaysia, demonstrating the transformative power of such innovations in securing food supplies and advancing the agricultural sector (Ahmad Anas Yusof *et al.* 2022).

This research evaluates the Real-Time Portable Soil Condition Monitoring System (REPSOIL), a ground-breaking invention meant to transform the monitoring of soil and environmental parameters. The study, which is being carried out at Kolej Universiti Agrosains Malaysia (UCAM) rock melon farm, assesses REPSOIL's performance, claiming an efficiency gain of up to 99.9% over conventional techniques. The system has sophisticated technologies such as an Extensa LX-6 microcontroller architecture for processing and a Low-Power Wireless Control Protocol for data transmission to provide quick and precise soil analysis. REPSOIL is a sustainable solution that complements Malaysia's smart farming programs with its solar-powered energy system. The study's conclusions show that farming operations are much improved by REPSOIL's precision agriculture performance. REPSOIL helps farmers make quick and informed agricultural decisions by providing them with real-time data on soil conditions. This increases crop productivity and promotes national food security (Nawar, S., et al. 2022). The system's performance, which is distinguished by its sustainability and efficiency, makes it a vital instrument for farming in Malaysia and elsewhere in the future.

MATERIALS AND METHODS

Study Site: The research was conducted at a Kolej Universiti Agrosains Malaysia (UCAM) rock melon farm. An in-situ REPSOIL device and a handheld type 7-in-1 multi-soil and environment sensor were used to collect soil and environmental data from the rock melon polybag.

Figure 1. The rock melon farm in Kolej Universiti Agrosains Malaysia (UCAM)

As shown in Figure 2, the Real-Time Portable Soil Condition Monitoring System (REPSOIL) is a cutting-edge soil condition monitoring solution that leverages the Extensa LX-6 microcontroller architecture for robust performance. It utilizes the Low-Power Wireless Control Protocol (LPWCP) for efficient communication between the sensor nodes and the gateway, ensuring data integrity and timely delivery. The device is powered by a 1500 mAh battery, which is sustainably recharged via a 550 mA solar panel, making the system eco-friendly and reducing the need for manual battery replacement (Azam, M.A., et al. 2021). Additionally, the inclusion of a Type-C USB port offers a convenient alternative for charging. The system's design allows for the simultaneous operation of multiple sensors, drastically reducing the time required for data collection across several polybags. Figure 2 depicts the handheld type 7-in-1 multi soil and environment sensor used conventionally to collect the same data as the REPSOIL device (Kassim, Nawar and Mouazen, 2021). However, an operator needed to manually operate the device to collect the data from each polybag.

Figure 2: Developed multi soil and environmental sensor for agriculture

Developed in-situ REPSOIL device deployed on rock melon polybag

Developed handheld type 7-in-1 multi soil and environment sensor

Each sensor was deployed for 10 polybags, with the distance between each polybag being 80 cm, as shown in Figure 3. Table 1 tabulates the method for comparing both conventional and REPSOIL systems, and Table 2 displays the technical specifications of the REPSOIL device.

Table 1. Comparison method between handheld 7-in-1 soil sensor and REPSOIL system

Method Component	Handheld 7-in-1 soil sensor	REPSOIL System
Data Collection Procedure	Manual insertion of a 7-in-1 multi soil sensor into the soil within each polybag.	Automated embedding of REPSOIL sensors in each polybag prior to the start of the data collection.
Data Stabilization	Waiting period for the sensor to stabilize before recording data.	No waiting period required as REPSOIL sensors are designed for immediate data acquisition.
Data Recording	Manual recording of data readings from the sensor display.	Automatic logging of data in the system's online Dashboard for viewing and analysis.
Data Transmission	No electronic transmission, data is manually transcribed to a recording medium	Electronic transmission of data from sensors to the gateway node using LPWCP.
Energy Source for Sensors	Battery Powered, needed to be recharged or replaced.	REPSOIL sensors powered by a 1500 mAh battery and 550mA solar panel.
Sensor Technology	7-in-1 multi soil sensor technology requiring manual operation.	Advanced Extensa LX-6 microcontroller architecture enabling automated operation.
Communication Protocol	N/A	Low-Power Wireless Control Protocol (LPWCP) for efficient data communication.
Sensor Deployment	Manual placement and removal of sensors for each measurement.	Permanent installation of sensors allows continuous monitoring without manual intervention.

Figure 3. Experimental setup for handheld 7-in-1 soil sensor and REPSOIL system

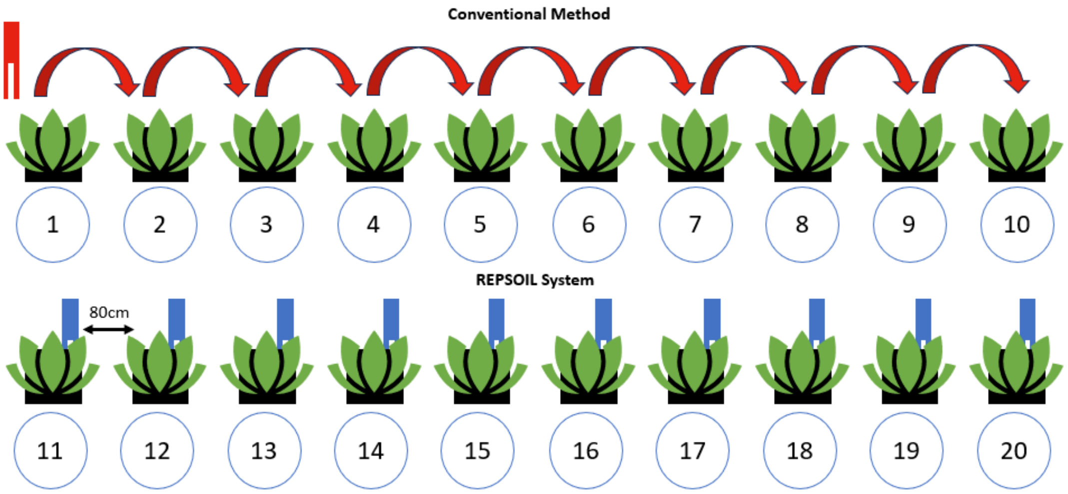


Table 2. REPSOIL technical specifications

Specification	Details
Microcontroller Architecture	Extensa LX-6
Communication Protocol	Low-Power Wireless Control Protocol (LPWCP)
Battery Capacity	1500mAh
Solar Panel Output	550mA
Charging Port	Type-C USB
Maximum Communication Range	220 meters
Data Transmission Speed	0.63 Mbps
Transmission Delay	2.4 ms
Energy Usage per Transmission	1024 Mw

PERFORMANCE EVALUATION

The performance of the REPSOIL system and handheld 7-in-1 soil sensor was evaluated. The test at UCAM Rock Melon Farm was evaluated for each method using 10 polybags. Using Equation 1, the time needed to collect data from the polybags was recorded to determine the handheld 7-in-1 soil sensor's time efficiency.

$$T_{conventional} = n \times t_{polybag} \quad (1)$$

Where:

- ($T_{conventional}$) is the total time for the handheld 7-in-1 soil sensor (s).
- (n) is the number of polybags.
- ($t_{polybag}$) is the time taken for one polybag (s).

For the REPSOIL system the time taken to collect data from all 10-polybag calculated using Equation 2 as all the sensors work simultaneously.

$$T_{REPSOIL} = t_{collection} + t_{transmission} \quad (2)$$

Where:

- ($T_{REPSOIL}$) is the total time for the REPSOIL system.
- ($t_{collection}$) is the time taken to collect data from one polybag (s).
- ($t_{transmission}$) is the data transmission time (2.4 ms).

For the handheld 7-in-1 soil sensor, energy consumption is not typically measured as it involves manual labour. The energy consumed by the system used for transmitting data from 10 polybags is calculated using Equation 3.

$$E_{REPSOIL} = P \times T_{REPSOIL} \quad (3)$$

Where:

- ($E_{REPSOIL}$) is the energy consumption for the REPSOIL system.
- (P) is the power usage per transmission (W).
- ($T_{REPSOIL}$) is the total time for the REPSOIL system (s).

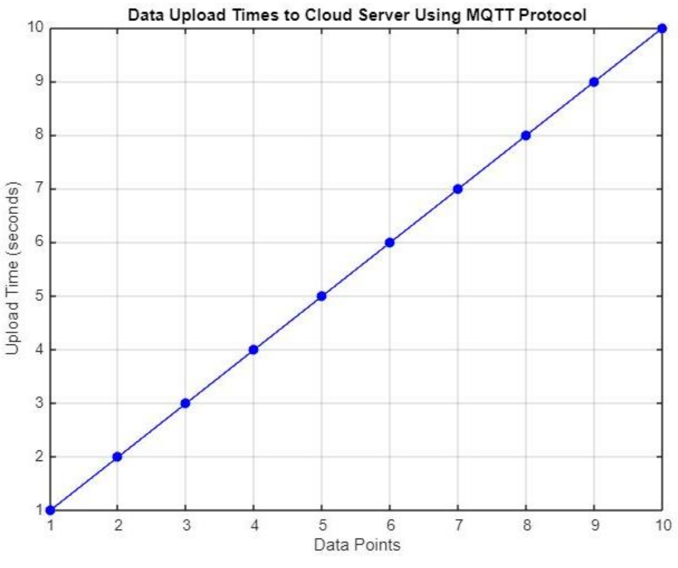
RESULT AND DISCUSSION

The study's results highlight a stark contrast in the efficiency of data collection between the handheld 7-in-1 soil sensor and the REPSOIL system as shown in Table 3. The conventional approach, utilizing a 7-in-1 multi soil and environment sensor, required a laborious 2-5 minutes per polybag for data acquisition. This translates to a total of 20-50 minutes for 10 polybags, factoring in the manual labor involved in walking to each polybag, inserting the probe, and waiting for the sensor to stabilize. In stark contrast, the REPSOIL system's automated sensors operate concurrently, taking a mere 30.0024 seconds to collect and transmit data from all 10 polybags. This data is then automatically displayed on an online dashboard for immediate viewing and analysis, as shown in Figure 6, showcasing the system's real-time monitoring and decision-making capability.

The traditional soil data collection method is time-consuming and labor-intensive, requiring significant human effort to physically interact with each polybag (Hasim, N., et al. 2012). Additionally, the 7-in-1 sensors necessitate periodic recharging or battery replacement, which adds to the operational downtime and maintenance costs. Conversely, the REPSOIL device is equipped with a built-in solar panel, enabling it to self-replenish its energy supply through solar power. This feature eliminates the need for manual recharging, thereby enhancing the system's sustainability and reducing the labor required for maintenance (Kitchen, N.R. 2008).

Precision and timeliness are paramount in agricultural decision-making, particularly when determining the need for fertilizer application or irrigation (Kassim, A.M., Sahak, S., *et al.* 2022). The REPSOIL system's ability to provide precise readings in the fastest possible time ensures that farmers can make informed decisions swiftly, optimizing plant health and yield. Field tests accentuated the REPSOIL's efficiency in data transmission. Data upload times to the cloud server ranged from 1 to 10 seconds, influenced by internet connectivity and data size. Figure 4 shows a graphical representation of the time required for data uploads to the cloud server, demonstrating REPSOIL's efficiency.

Figure 4. Data transmission efficiency



This rapid data acquisition is crucial for effectively adjusting soil parameters. It ultimately benefits the farmer by reducing resource waste and improving crop productivity. Adopting such technology could significantly advance agricultural practices, aligning with global trends toward smart farming and precision agriculture (Kumar, P., Raghvendra, P. and Souvik, K. 2021).

Table 3. Comparison of handheld 7-in-1 soil sensor with REPSOIL system

Comparison features	Handheld 7-in-1 soil sensor	REPSOIL System
Data collection method	Manual insertion and data reading	Fully automated data collection and transmission
Data collection time (per polybag)	2-5 minutes	30 seconds
Data transmission time (per polybag)	N/A (manual collection)	2.4 ms
Total time for 10 polybags	20-50 minutes	30.0024 seconds
Energy usage	Variable (manual effort)	1024 mW per transmission

Figure 5 illustrates the correlation analysis of data collection time between the handheld 7-in-1 soil sensor and the REPSOIL System, providing insights into their efficiency comparison. The graph shows a clear linear relationship between the data collection times of both methods. This means that as the data collection time increases for the handheld 7-in-1 soil sensor, there is a corresponding increase in the time required by the REPSOIL System. However, what stands out is the consistently lower data collection times of the REPSOIL System, indicated by the clustering of data points around the lower end of the graph. This highlights the REPSOIL System's efficiency and consistency in data collection compared to the handheld 7-in-1 soil sensor.

Figure 5. Correlation analysis between REPSOIL system and handheld 7-in-1 soil sensor

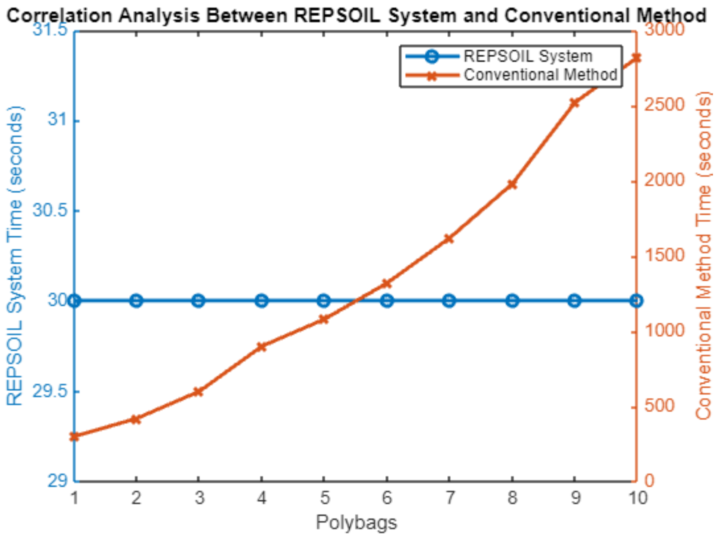
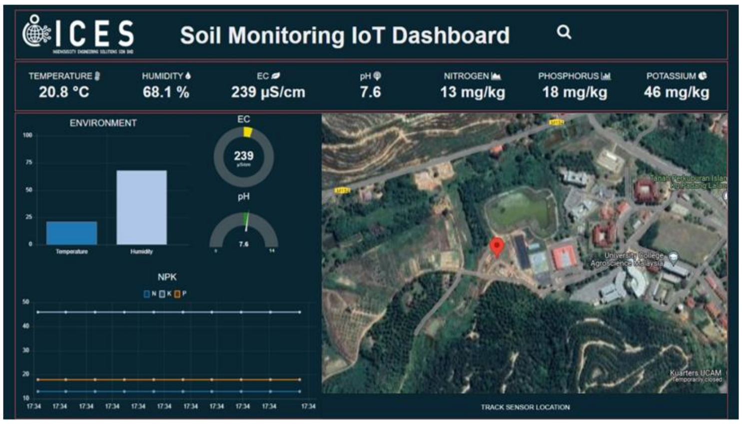


Figure 6 shows the Soil Monitoring IoT Dashboard, a pivotal tool for real-time monitoring and decision-making in agricultural operations. This dashboard integrates various sensor data, including pH, temperature, electrical conductivity, and humidity, providing farmers with comprehensive insights into soil conditions. Farmers can make informed decisions regarding irrigation, fertilization, and crop health management by visualizing this data in a user-friendly interface.

Figure 6. Soil monitoring IoT dashboard



CONCLUSION

The REPSOIL system's introduction into the agricultural landscape heralds a transformative era in soil testing methodologies. The empirical findings of this study illuminate the system's remarkable time efficiency, where the handheld 7-in-1 soil sensor's 20-50 minutes for testing 10 polybags is eclipsed by REPSOIL's brisk 30.0024 seconds. This equates to an efficiency improvement of up to 99.9%. Such a leap in productivity is not merely incremental; it is exponential, paving the way for a paradigm shift in agricultural practices. For farmers, the implications are profound: the adoption of REPSOIL can significantly enhance crop productivity by enabling rapid, data-driven decisions on fertilization and irrigation, thus contributing to the overarching goal of food security in Malaysia. By integrating this advanced system, farmers are empowered to optimize resource utilization, reduce waste, and increase yields, which are critical factors in the nation's pursuit of agricultural self-reliance and sustainability.

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