# TOWARD INTELLIGENT CROP PRODUCTION MANAGEMENT DECISION SUPPORT SYSTEM THROUGH DATA FUSION

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**ABSTRACT**

*Integration of data from various sources provide farmers with useful information and recommendations for managing their crops. Data fusion techniques can be used to combine data from different sources such as weather forecasts, satellite imagery, soil sensors, and crop growth models to create a holistic view of the crop's growing conditions. An intelligent system can use this information to provide farmers with real-time recommendations on things like irrigation, fertilization, pest control, and harvest timing. By using data fusion, the system can improve the accuracy of its predictions and recommendations, resulting in better crop yields and reduced costs for farmers. The data can also be analyzed by agronomists and researchers to improve crop management practices and develop new crop varieties. Toward this end, a system is being developed to fuse data from multiple sensors and multiple sites for two crops, namely pineapple in the open field and leafy vegetables planted indoors. It is hoped that the developed system can help farmers to make more informed decisions, improve crop yields, and increase their profits while helping to conserve resources such as water and fertilizer.*

Keywords: *Industry 4.0, Internet-of-Things, Smart agriculture, Indoor farming, Pineapple*

## INTRODUCTION

Agriculture is a crucial sector of the global economy, providing food, fuel, and raw materials for various industries. With the global population projected to reach 9.7 billion by 2050, there is an urgent need to increase agricultural productivity to meet the growing demand for food (Lowenberg-DeBoer, Franklin et al. 2021). At the same time, farmers face several challenges, such as climate change, water scarcity, soil degradation, and pests and diseases (Bregaglio, Titone et al. 2016).

To overcome these challenges and increase agricultural productivity, farmers need access to accurate and timely information on their crops' growing conditions. In recent years, there has been an explosion of data sources available to farmers, including weather forecasts, satellite imagery, soil sensors, and crop growth models. The challenge is to integrate this data from multiple sources to provide farmers with useful information and recommendations for managing their crops (Ip, Ang et al. 2018, Lioutas, Charatsari et al. 2022).

Data fusion techniques can be used to combine data from different sources and provide a holistic view of the crop's growing conditions. An intelligent system can use this information to provide farmers with real-time recommendations on things like irrigation, fertilization, pest control, and harvest timing (Busemeyer, Mentrup et al. 2013, Sa, Ge et al. 2016). By using data fusion, the system can improve the accuracy of its predictions and recommendations, resulting in better crop yields and reduced costs for farmers.

The integration of data from multiple sources has been increasingly used in various fields, including agriculture, to improve decision-making and performance. In recent years, data fusion techniques have been used to combine data from various sources, such as weather forecasts, soil sensors, satellite imagery, and crop growth models, to create a holistic view of the crop's growing conditions (Yaqoob, Hashem et al. 2016, Shakoor, Northrup et al. 2019).

Several studies have investigated the use of data fusion techniques in agriculture. For example, Zhu, Cai et al. (2018) developed a data fusion-based system for predicting rice yield and water use efficiency using data from unmanned aerial vehicles (UAVs), ground-based sensors, and meteorological data. The system achieved higher accuracy in yield prediction compared to traditional models.

Similarly, Ahmad, Nasirahmadi et al. (2022) developed a data fusion-based system for monitoring and managing crop growth and soil moisture in greenhouse agriculture. The system combined data from wireless sensor networks and crop growth models to provide real-time recommendations on irrigation and fertilization. The system achieved significant improvements in crop yield and water use efficiency compared to traditional methods.

In the field of precision agriculture, data fusion techniques have been used to optimize crop management practices. For example, Abu Bakar, Muslimin et al. (2021) developed a data fusion-based system for precision fertilization using data from satellite imagery, soil sensors, and crop growth models. The system achieved significant improvements in fertilizer use efficiency and crop yield compared to traditional fertilization methods.

The integration of data from various sources through data fusion techniques has been shown to be a promising approach to improve agricultural productivity and sustainability (Wolfert, Ge et al. 2017). The use of data fusion-based systems can provide farmers with real-time recommendations on crop management practices, optimize resource use, and reduce costs. Further research is needed to develop and refine data fusion-based systems for various crops and growing conditions to realize the full potential of this approach in agriculture.

Moreover, the data collected by the system can be analyzed by agronomists and researchers to improve crop management practices and develop new crop varieties. Thus, the integration of data from various sources can not only help farmers improve their yields and profits but also contribute to the development of sustainable agricultural practices.

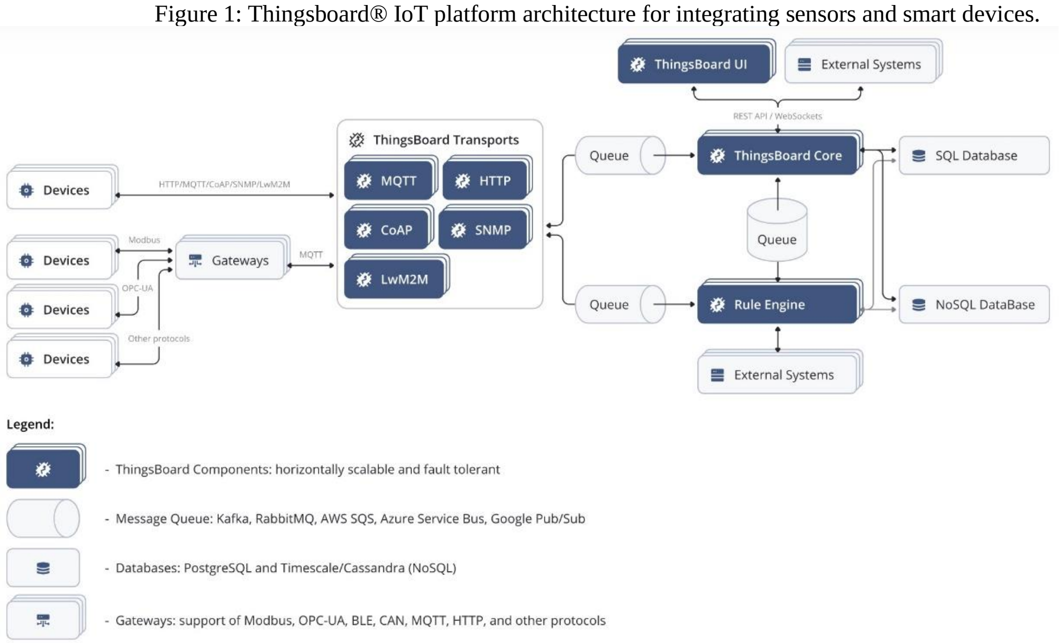
Toward this end, a system is being developed to fuse data from multiple sensors and multiple sites for two crops, namely pineapple in the open field and leafy vegetables planted indoors. The system aims to help farmers make more informed decisions, improve crop yields, and increase their profits while helping to conserve resources such as water and fertilizer.

In this work, we describe the methodology used to develop the data fusion-based system, including data collection, data fusion techniques, real-time recommendations, system testing, data analysis, and system improvement. The results of the system's performance evaluation are discussed, and the implications of the system for sustainable agriculture are examined.

## MATERIALS AND METHODS

This section describes the methodology used to develop the data fusion-based system that integrates data from multiple sensors and multiple sites for two crops, namely pineapple in the open field and leafy vegetables planted indoors. Figure 1 depicts a typical architecture for IoT systems. It shows the information exchange architecture for a Thingsboard® platform.

Figure 1: Thingsboard® IoT platform architecture for integrating sensors and smart devices.



**Data Collection:**
The first step in developing the system was to collect data from various sources such as weather forecasts, satellite imagery, soil sensors, and crop growth models. The data collection was carried out using a combination of automated systems and operator input through mobile devices that collected data from multiple sensors located at different sites. The Thingsboard® IoT platform was used to visualize the data collected by the sensors.

**Data Fusion:**
The next step was to fuse the data collected from various sources using data fusion techniques. At the moment, data fusion is only limited to the gathering of various sensors in one platform, namely the Thingsboard IoT platform.

**System Testing:**
To ensure that the system was functioning correctly, it was tested in real-world conditions. The system was tested on multiple sites for both crops, and the data collected was analyzed to evaluate the system's performance.

## RESULTS AND DISCUSSION

The developed data fusion-based crop production management decision support system was evaluated using data collected from two crops, namely pineapple in the open field and leafy vegetables planted indoors. The system was able to fuse data from multiple sensors and multiple sites, providing a holistic view of the crops' growing conditions. Figure 2 and figure 3 shows the Thingsboard® platform with the two sites from which data were gathered.

Figure 2: Farm site 1 located at a MARDI Pontian station in the state of Johor, Malaysia

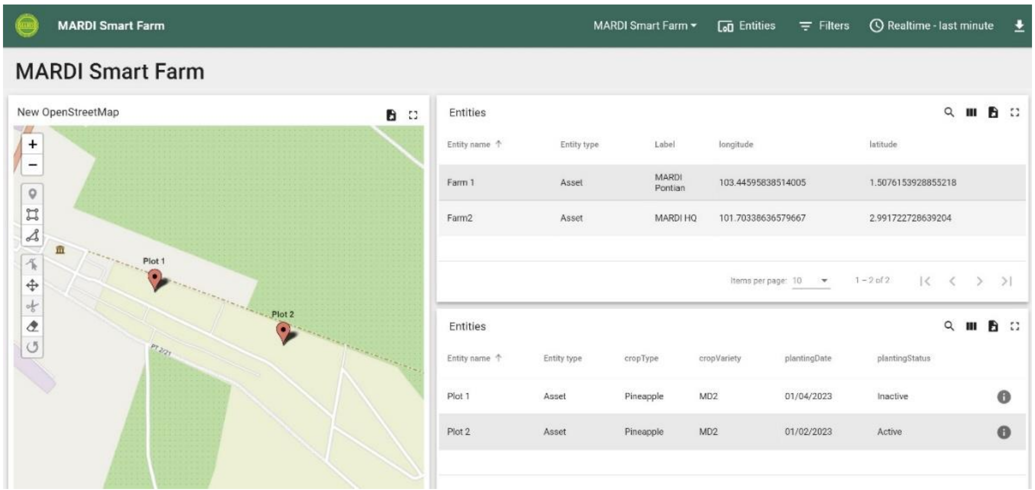



Figure 3: Farm site 2 located at a MARDI Serdang station in the state of Selangor, Malaysia

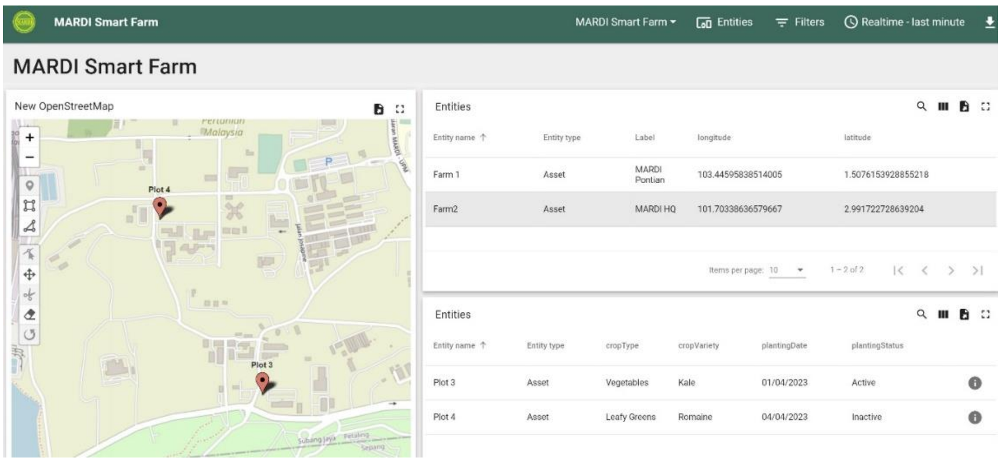
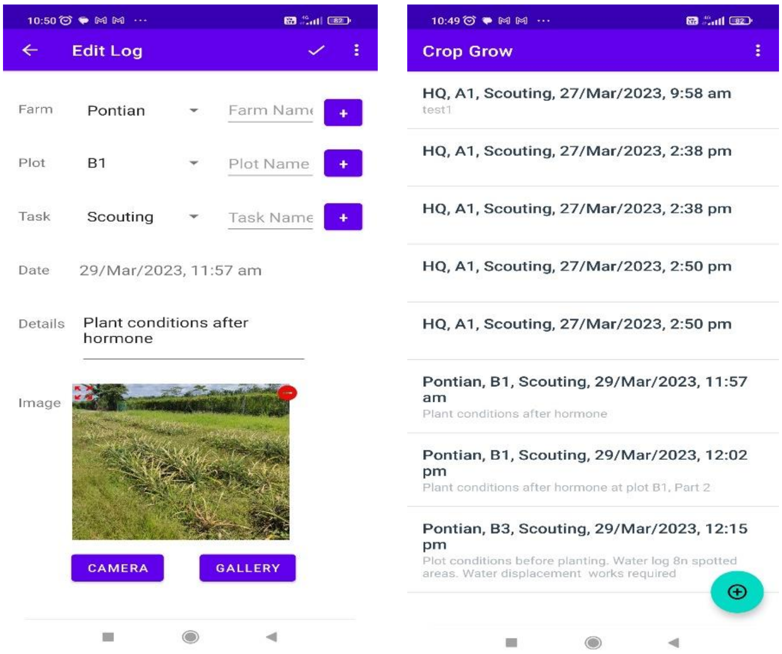



Figure 4 shows how users can input data to be sent to a Thingsboard® platform. A mobile application was developed to allow users i.e. farm workers/operators to key in related information regarding a task. After all information are entered, it is logged as a farm activity related to crop production such land preparation, scouting and fertilizer application. The log is sent automatically to the Thingsboard® platform when a connection to the internet is present. All images acquired through the mobile application are sent to a cloud storage separate from the IoT platform. Only the link is sent to thingsboard.

Figure 4. A screenshot of a worklog app developed to allow users to report and log activities related to crop production such land preparation, scouting and fertilizer application. Subfigure (a) depicts an interface for users to key in all relevant information relating to a task. Subfigure (b) shows the list of tasks or worklogs that were entered.




(a) (b)

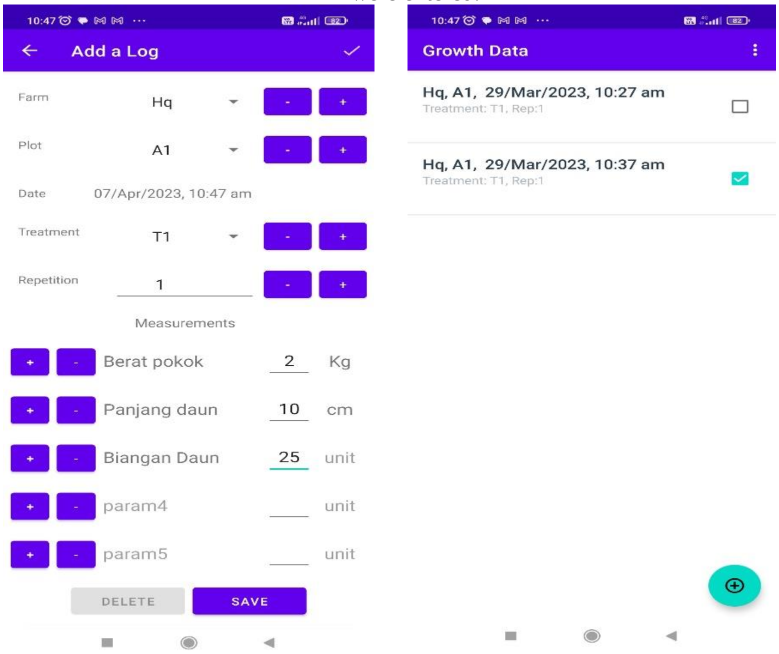
The developed mobile application also allows users to collect data relevant to crop growth parameters. The interface is shown in figure 5. Users are able to enter measurements related to crop growth parameters during field work. Once the measurements are entered, the information is saved in a list and sent automatically to the IoT platform when an internet connection is present.
All information that was sent to the IoT platform by the mobile application are saved in a server located in the cloud. Figure 6 depicts all task logs that were sent to the platform.

For the task log module as shown in figure 5, from tests done in the field it was observed that when there was a strong internet connection, on average a duration of between 1 to 10 seconds was needed to upload the data in the cloud. The time taken depended on the size of the image that had to be sent to the cloud.

The crop growth parameter data input module showed a better performance in terms of time taken to upload data to the cloud. The average time taken to upload a single data entry was only 1.5 seconds whereas multiple data upload took on average 5 seconds. This was due to the fact that only strings and numbers were transferred which only has a size of a few kilobytes as opposed to images which is a factor of 1,000 to 10,000 times bigger.

The results of this study demonstrated the potential of data fusion techniques in crop production management decision support systems.

Figure 5: A module to record Crop growth parameters while taking field measurements. Subfigure (a) shows an interface where users are allowed to enter measurements of crop growth parameters. Subfigure (b) shows a list of measurements that were entered.




(a) (b)

Figure 6: Data from mobile device that were sent to the IoT platform.

Work log
History - last 30 days

| Timestamp | farm | plot | task | date |
|---|---|---|---|---|
| 2023-03-29 13:51:16 | Mardi Pontian | crop grow 9month | pertumbuhan | 28/Mar/2023, 8:48 am |
| 2023-03-29 13:49:14 | Mardi Pontian | crop grow 9month | pertumbuhan | 28/Mar/2023, 8:48 am |
| 2023-03-29 12:22:29 | Pontian | B3 | Scouting | 29/Mar/2023, 12:15 pm |
| 2023-03-29 12:18:35 | Pontian | B3 | Scouting | 29/Mar/2023, 12:15 pm |
| 2023-03-29 12:05:02 | Pontian | B1 | Scouting | 29/Mar/2023, 12:02 pm |
| 2023-03-29 12:04:08 | HQ | B1 | Scouting | 29/Mar/2023, 12:02 pm |
| 2023-03-29 11:59:20 | Pontian | B1 | Scouting | 29/Mar/2023, 11:57 am |
| 2023-03-27 14:50:17 | HQ | A1 | Scouting | 27/Mar/2023, 2:50 pm |

This work demonstrated the system's ability to allow information/data input by human operators. This is crucial since data embedding human intuition provides more insight in the data analysis phase. In conjunction with other sensor data, the system has the potential of making more effective decisions for crop production.

## CONCLUSION AND FURTHER WORKS

The development of an intelligent system that integrates data from various sources through data fusion techniques can improve crop management practices. The system can provide real-time recommendations on irrigation, fertilization, pest control, and harvest timing, resulting in improved crop yields, reduced costs, and conservation of resources. The data analysis capabilities of the system also benefit agronomists and researchers in developing new crop varieties and improving crop management practices. The developed system can help farmers make more informed decisions, increase their profits, and help conserve resources like water and fertilizer. The ability to make informed data centric decisions could lay the foundation for a macro level economic policy by the Malaysian government regarding agriculture. It would foster Malaysia's realization of the National Agrofood Policy 2.0 in adopting smart agricultural production The current work discussed how data can be collected to enable data fusion. This step is often overlooked as most work assume that data collection is trivial which is never the case. Further work is needed to make sense of the fused data in order to fully utilize the potential of IoT platforms. A fully functional platform would be able to optimize data based crop production. Additionally, the development of user-friendly interfaces and mobile applications would improve the accessibility and usability of the system for farmers.

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