

Development of Soil Moisture Content Monitoring System for Precision Measurement of Soil Moisture in Sub-Optimal Land for Palm Oil Plantation

*A P Nugroho*¹, *N B Kusumawati*¹, *Murtiningrum*¹, *A Wiratmoko*¹, *I M Haryadi*¹, *F A Pradana*¹, *Suwardi*², *Sukarman*², *S Primananda*², *L Sutiarto*¹

¹Smart Agriculture Research Center, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jl. Flora 1 Bulaksumur, Yogyakarta 55281, Indonesia

²Wilmar International Plantation, Region Kalimantan Tengah, Indonesia

Abstract. Indonesia has 15 million hectares of palm oil plantation, making it one of the world's greatest palm oil and CPO producers. However, despite the large area of palm oil plantations, the production is not yet optimal. Soil moisture and environmental factors are the leading cause. Thus, a technology suited to monitor soil moisture, soil temperature, and microclimates needs to be developed. This research aims to develop a Soil Moisture Content (SMC) Monitoring System that can be used to monitor soil moisture, supported by soil temperature and microclimates variable and also operates automatically and in real-time. The device is also integrated with a cloud server. The implemented SMC was installed on the palm oil plantation of PT Kerry Sawit Indonesia, Wilmar International Plantation. On top of that, the SMC device can measure soil moisture up to three variations of depth. The acquired data was saved and sent to a cloud server. Then, a user can access the data to execute early water deficit anticipation. The resulting device is capable of measuring soil moisture accurately, which can be proven with these parameters, R square value of 0.9782, RMSE of 1.2%, and MAPE of 2.6%.

Keywords: Soil, Palm, Environmental Factors, Real-time Monitoring, Cloud Integration

1 Introduction

Indonesia is one of the world's largest palm oil-producing countries with a land area of 15.08 million hectares (ha) in 2021 [1]. Extensive oil palm plantations make Indonesia the world's most significant palm oil (CPO) producing country. However, the large area of oil palms still causes several problems. For example, its productivity results are not optimal. Productivity results that have not been optimal have caused the national CPO production to

¹ Corresponding author: andrew@ugm.ac.id

be constrained by approximately 33.77% [1]. Soil water content significantly affects the growth of oil palms; consequently insufficient water content is one of the causes of not optimal oil palm productivity. According to Pambudi and Bandi [2], the optimal critical point for oil palm production is the soil moisture content of 10% in dry wind conditions. In addition, environmental factors also affect palm oil production, such as rainfall, solar radiation, temperature, and humidity [3]. Therefore, optimizing oil palm production, for example, using sub-optimal land is necessary.

Sub-optimal land is land that cannot support optimal plant growth and development. The sub-optimal land area in Indonesia is estimated to be 157,246,565 hectares, but only 91,904,643 ha (58.4%) has the potential to be used as agricultural land [4], one of which is spodosols. Spodosols are soils formed from coarse and acidic sand or clay. This soil is characterized by a spodic B horizon [5]. Spodosol has two limiting factors, which are spodic layers and sandy soil texture. The spodic layer is related to the ease with which roots penetrate the soil. Sandy soil texture makes it difficult for the soil to hold water, and the chances of leaching nutrients are higher [6]. Cultivating oil palm on sub-optimal land requires applying appropriate technology and cultivation techniques to maintain productivity in the next two years. Sustainable agriculture uses technology to support production inputs so that it does not interfere with the sustainability of existing ecosystems.

One of the sustainable agricultural practices in oil palm plantations, namely the use of technology and cultivation techniques in the management of spodosol land, such as identifying the vertical extent and level of solidity of the spodic layer, improving the plant growth media, improving the microclimate, and appropriate fertilization technology [7]. The utilization of various technologies to be applied in agro- industry is mostly done through precision farming systems, usually known as Precision Farming. Precision Farming (PF) is an agricultural system that combines information and technology to identify, analyze, and manage all the variability on a specific agricultural land to obtain optimal, sustainable benefits while maintaining and protecting the environment [8, 9, 10, 11].

One method to optimize palm oil production is by land monitoring. Land monitoring is also crucial to control oil palm growth in real-time. Research related to monitoring oil palm land has previously been developed by Uktoro (2017) regarding drone image analysis for monitoring the health of oil palm plants [12]. Research by Utomo et al. (2021) regarding the monitoring and control system for oil palm nurseries based on the Internet of Things [13]. Syarovy et al. (2022) research the Utilization of Big Data in Oil Palm Plantation to Predict Production Using Artificial Neural Network Models [14]. Research Zauhariah et al. (2022) regarding determining optimal soil moisture content mapping in oil palm plantations (case study: Cikasungka plantation, PT Perkebunan Nusantara VIII, Cimulang, Bogor) [15]. Naldi's research (2023) regarding the Prototype of a Monitoring and Control System for Oil Palm Nurseries Based on the Internet of Things [16]. Vast oil palm areas need intensive observation to optimize palm oil production through Internet of Things (IoT) technology [17]. IoT, especially in the plantation sector, has great potential to enhance the quality and quantity of resilience and make production costs more effective [18].

Therefore, this research was conducted to develop a Soil Moisture Content Monitoring System for Precision Observation of Soil Moisture in Sub-Optimal Land of Oil Palm Plantations. This research aims to develop a Soil Moisture Content (SMC) Monitoring System technology that can be used for soil moisture monitoring supported by soil temperature and microclimate variables automatically and in real-time and integrated with a cloud server. The benefit of this research is that it can be used as an early warning system for water deficit. From this study, the results of monitoring soil moisture can be utilized to determine the rate of percolation of water in the soil, also, the results of environmental

monitoring can be used to determine the optimal environmental conditions for oil palm growth in order to obtain optimal production results.

2 Materials and methods

2.1 Research approach

This research focuses on observing soil moisture content, which in this observation is also accommodated by measuring soil temperature, air temperature and humidity, and sunlight intensity, which can be used to support the SMC monitoring system device. The structure for this research can be seen in figure 1.

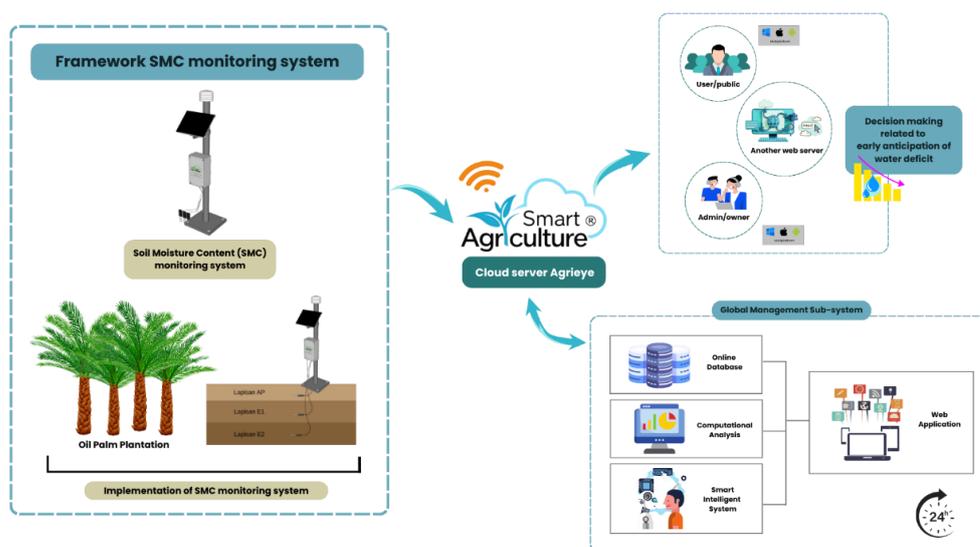


Fig. 1. Research flow diagram for SMC monitoring system

Based on figure 1, the Soil Moisture Content (SMC) monitoring system that has been designed consists of sensors for soil moisture content and soil temperature placed in the soil at three different depths in spodosols. In addition, it is equipped with environmental monitoring sensors. The implementation of the SMC monitoring system will be installed on the land of oil palm PT Kerry Sawit Indonesia, Wilmar International Plantation, Central Kalimantan. Observation results and data monitoring processes that each sensor has read will be sent and stored at Agrieye's cloud server. After that, the user can access the data through a web-based application for decision-making and initial anticipation related to water deficit.

2.2 Experiment setup

In general, the methodology of this research can be seen in figure 2.

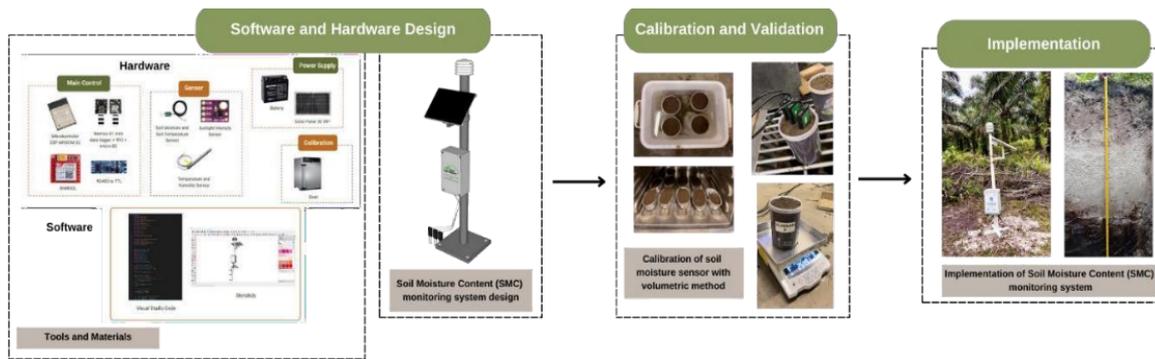


Fig. 2. Research method

Based on figure 2, there are 3 stages of development of the SMC device. The first stage is software and hardware design. Next is sensor calibration and validation. The final stage is the implementation of the devices. The SMC monitoring system device is calibrated by comparing soil moisture measurements using the volumetric method. Data obtained from calibration is said to be valid if the r square value obtained is close to 1, the RMSE value is close to 0, and the MAPE value is below 10% [14]. The equation obtained from the calibration results will then be entered into the program code for the SMC monitoring system. This is because the soil moisture value from the SMC monitoring system sensor readings can match the volumetric soil moisture value. The implementation of the SMC monitoring system will be installed on the land of oil palm PT Kerry Sawit Indonesia, Wilmar International Plantation, Central Kalimantan.

2.3 Model evaluation

The evaluation model of this study uses three methods, the linear regression test, MAPE, and RMSE. The linear regression test is a validation method by plotting the calibration data on a graph. The x-axis on the graph is the estimated data resulting from sensor readings, while the y-axis is the actual data from the volumetric method. Linear regression test is used to obtain linear equations and R square values. The R square value close to 1 implies that the system that has been designed is accurate and valid [15]. The linear regression test equation can be seen in equations (1) and (2), where the Y variable is soil moisture data using the volumetric method (%), the X variable is soil moisture data using soil moisture sensors (%), coefficient b is the linear regression coefficient, the coefficient a is a constant.

$$y = a + bx \text{ or } y = bx \tag{1}$$

$$b = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{2}$$

Mean absolute percentage error (MAPE) is a validation test to determine the error value of a system in the form of a percentage. A low MAPE percentage implies a more accurate system [20]. The MAPE equation can be written in equation (3) where \hat{y}_i is the soil moisture value using the volumetric method, y_i is the soil moisture value from the sensor after calibration, and n is the amount of measurement data.

$$MAPE = \frac{\sum_{i=1}^n \frac{|\hat{y}_i - y_i|}{y_i}}{n} \times 100\% \tag{3}$$

According to [21], the range of MAPE values can be seen in Table 1.

Table 1. Range of MAPE values

Range <i>MAPE</i>	Interpretation
< 10 %	Very good value prediction ability
10 – 20 %	Good value prediction ability
20 – 50 %	Feasible value prediction ability
> 50 %	Bad value prediction ability

Root Mean Square Error (RMSE) is a system validation test based on the predicted error value. An RMSE value close to 0 means that the system that has been designed is valid [22]. The RMSE equation can be written in equation (4) where \hat{y}_i is the soil moisture value using the volumetric method, y_i is the soil moisture value from the sensor after calibration, and n is the number of measurement data.

$$RMSE = \sqrt{\sum_{i=1}^n \frac{(\hat{y}_i - y_i)^2}{n}}$$

(4)

2.4 Software and hardware design

Software design is carried out to create programs that will be used for sensor readings of each variable, namely soil moisture sensors, soil temperature, air temperature and humidity, and sunlight intensity. The coding of this program uses visual studio code software (VSCode, Microsoft, Redmond, Washington, United States of America). The program is made to connect the SMC device to Internet, set the API so that the device can send data and set the interval for sending data to the cloud server. Hardware design is carried out to design the soil moisture content (SMC) monitoring system device that will be made. It made SMC designs using SketchUp software (@Last Software, Boulder, Colorado, USA). The hardware design of SMC monitoring system can be seen in figure 3.

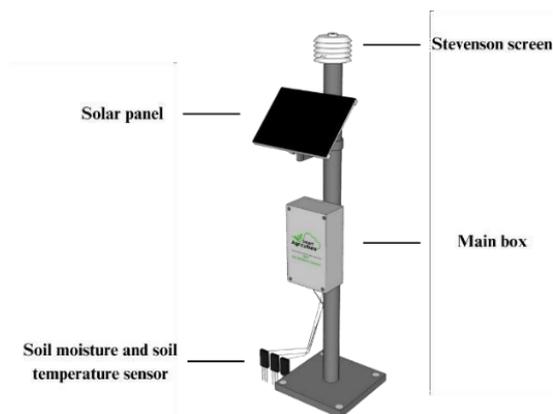


Fig. 3. Hardware design of SMC monitoring system

3 Result and discussion

3.1 Calibration and validation

Calibration and validation are done in the Laboratory of Soil and Water Engineering, Faculty of Agriculture and Biosystem Engineering, Gadjah Mada University. These process

are carried out to ensure the sensors have accurate and valid readings. The calibration is done by comparing the sensor’s reading with actual soil moisture value that was calculated using the volumetric method. Validation is carried out to prove that the applied system has good reading accuracy and consistency [23]. During the calibration process, the sensor measure soil moisture from 3 samples repeatedly. The validation are done by comparing the calibrated result and the actual value. The equation result of calibration and validation process was then implemented in the SMC’s program to correct the reading of each sensor during the implementation. The results of the linear regression test can be seen in figure 4.

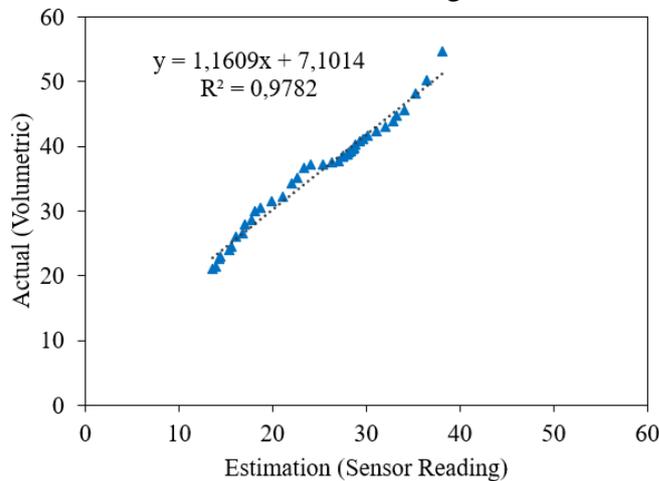


Fig. 4. Graph of linear regression test sensor readings of the volumetric test

According to the results of the regression test, it is visible that the R square value obtained is 0.9782. The R square value obtained is close to 1, meaning the sensor reading results are accurate and valid. The result of SMC Monitoring device validation is visible in Table 2.

Table 2. Result of model validation

Metode Validation	Result of validation test
Linier equation	$y = 1.1609x + 7.1014$
R square	$R^2 = 0.9782$
MAPE	2.60 %
RMSE	1.20 %

According to table 2, it can be seen that the linear equation acquired is $y = 1.1609x + 7.1014$. This equation is then used to correct the soil moisture sensor’s reading in the microcontroller’s program where the variable x of the equation results from sensor readings so that the soil moisture sensor output is in percent (%). The MAPE value obtained is 2.60%. The MAPE value is below 10%, which indicates that this sensor has excellent predictive modeling capabilities. The RMSE value obtained is 1.20%. The RMSE value is close to 0, which implies that the system that has been. designed is valid. The testing results using the MAPE and RMSE methods indicate that the designed system has accurate data reading.

3.2 Design result

The design results of the SMC monitoring system can be seen in figure 5.

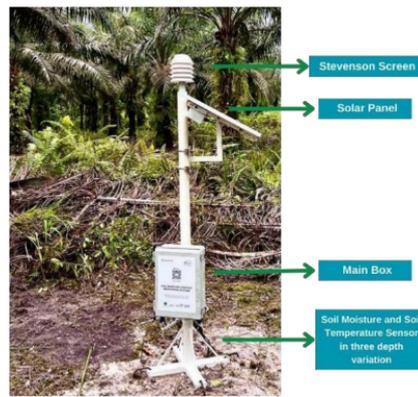


Fig. 5. Design result of SMC monitoring system

Based on figure 5, this system consists of sensors monitoring soil moisture, soil temperature, and microclimate. Sensors for microclimate monitoring consist of temperature and humidity sensors as well as sunlight intensity. This system is integrated into a cloud server and can work automatically, in real-time, and be monitored anywhere and anytime. On the top of this tool, there is a Stevenson screen. This device works automatically by utilizing solar energy. In this device, there is a main box in which there are battery and a microcontroller. Soil moisture and soil temperature sensors were placed at three different depths at oil palm plantations. The temperature and humidity sensors are placed inside the Stevenson screen, while the sunlight intensity sensor is placed above the Stevenson screen.

3.3 Implementation system

The SMC monitoring system is implemented on oil palm plantations with spodosols soil types. System implementation and the profile of the spodosols soil can be seen in figure 6.

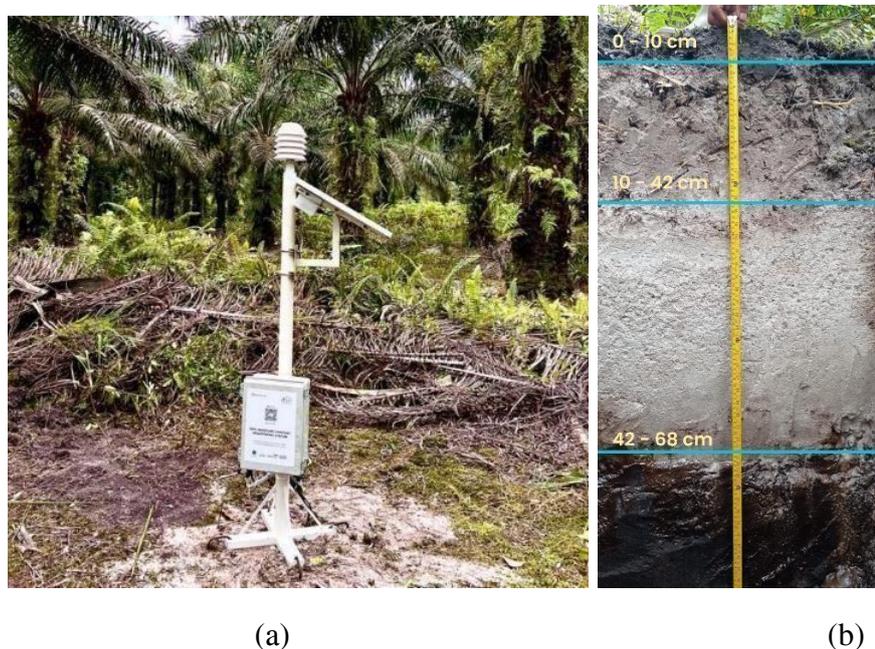


Fig. 6. Implementation system: (a) Implementation system of SMC monitoring system on palm oil land; (b) Spodosols soil profile at three depth variations

In its implementation, soil moisture and soil temperature sensors are placed at three variations of soil depth. The first layer is soil organic matter with a 0-10 cm depth. The

second layer is sandy soil with a 10 – 42 cm depth. The third layer is sandy soil that has decayed to a 42 - 68 cm depth. On spodosols, there is a hardpan layer located under the third layer. The hardpan layer is a layer that has a hard texture, making it difficult for roots and water to penetrate [7]. Monitoring of soil moisture and soil temperature can be seen in figure 7.

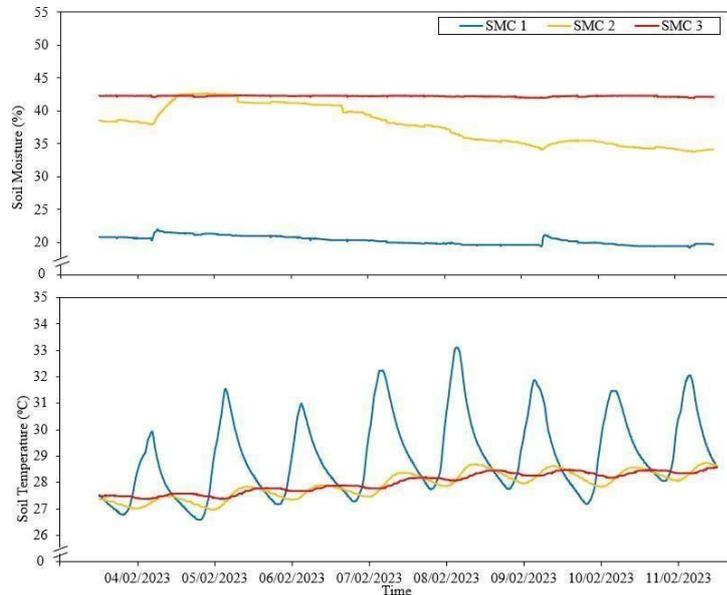


Fig. 7. Data visualization of monitoring soil moisture and soil temperature

Based on the visualization of data related to soil moisture and temperature in figure 7, label SMC 1 is the sensor that was placed in the first soil layer, label SMC 2 is the sensor that was placed in the second layer, and label SMC 3 the sensor that was placed in the third layer. In the soil moisture chart, the value of soil water content in the lower layer is relatively higher than that of the soil water content in the layer above it. This is because the water in the upper layer move down towards the layer below it, so the value of the water content in the lower layer was higher than that of the water in the upper layer. In addition, the water in the first layer will evaporate. This follows the statement of Yuniarti et al. [24], that water will move towards deeper layers after rain, while water will move upward due to evapotranspiration phenomenon then there is no rain. High water loss in the upper layers can be caused by a more significant number of roots than in the lower layers so that the plants absorb more water. The soil moisture value in the third layer tends to be stable because below the third layer is a hardpan layer. The hardpan layer or spodic layer, is a layer that has a hard texture making it difficult for roots and water to penetrate [7].

The soil temperature chart shows that the soil temperature value in the first layer is higher than the layer below it. This is because the top layer of soil is exposed to sunlight, thus the soil temperature in the top layer becomes higher than the layer below. These results follow research by Rayadin et al. [25], that soil temperature is affected by the amount of absorption of solar radiation by the soil surface, where during the day, the soil temperature is higher than the soil temperature at night. In this study, environmental conditions were also observed apart from observing soil moisture and soil temperature. The environmental conditions observed were air temperature, humidity, and sunlight intensity. Data visualization from monitoring environmental conditions can be seen in figure 8.

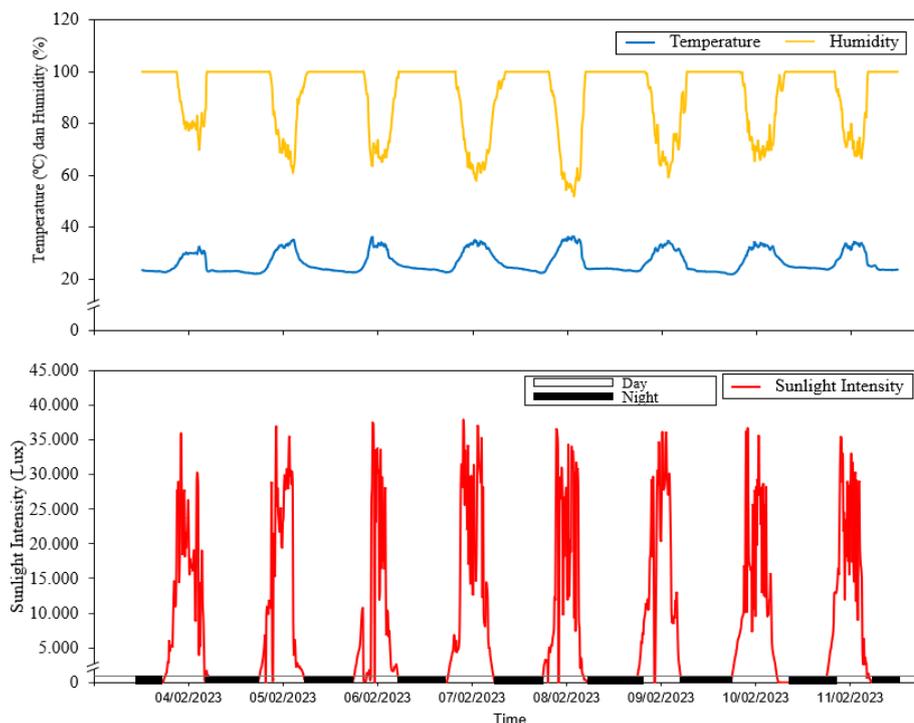


Fig. 8. Data visualization of monitoring environmental conditions

Based on figure 8, the highest temperature was 36.4°C on February 8th 2023, at 13:10:00 WIB. The highest humidity was 99.9%. The highest sunlight intensity was 37786 lux on February 7th 2023, at 9:50:00 WIB. The high air temperature value is due to the sufficient intensity of sunlight and the observation location that does not have too much shade. The value of air temperature is inversely proportional to air humidity. When the air temperature is high, the air humidity is low, and vice versa. When the air temperature is low, the air humidity is high. This is following the research of Wijayanto and Nurunnajah [26], that temperature can increase and humidity decreases, and vice versa. In addition, air temperature and humidity are affected by altitude and canopy closure. The sunlight intensity data fluctuates daily. This is because there is little shade from the palm fronds and conditions during the day and night. Based on the graph, some areas are blocked in black, which has a value of 0. This condition means night. In addition, differences in the intensity of sunlight received occur due to cloud cover. This follows Sihab [27], that solar radiation on the earth's surface varies significantly according to place and time caused by differences in latitude and atmospheric conditions, especially clouds.

4 Conclusion

Based on the performance test results of the proposed SMC monitoring system, it is known that this system has excellent data accuracy and validity. The validation test results showed that the SMC monitoring system had an R square value of 0.9782, an RMSE value of 1.20%, and a MAPE value of 2.60%.

Based on the results of soil moisture and temperature monitoring, the value of soil water content in the lower layer has a relatively higher value compared to the value of the soil water content in the layer above it. This is because the water in the upper layer move toward the layer below it. The soil moisture value in the third layer tends to be stable, because of the hardpan layer below it. The soil temperature value in the first layer is higher than the layer below it.

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