Website-based: smart goat farm monitoring cages

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ABSTRACT

Goat farming holds significant profit potential due to high community demand for goat meat and its role in supporting national food security. To optimize its development, proper and efficient farm management is essential. This study aims to design a system for monitoring and improving goat farming by observing key environmental and animal health conditions, such as feed availability, temperature, humidity, and overall livestock health. The proposed system utilizes internet of things (IoT) technology and cloud storage to create a smart farm environment. Various IoT devices, including cameras, thermal sensors, and lighting equipment, are integrated and connected via Wi-Fi. These devices collect real-time data, which is then processed into informative analytics to monitor and support farm development. Through the use of IoT and cloud-based solutions, this system is expected to enable real-time supervision and create ideal, controlled conditions for goat farming, ultimately benefiting farmers.

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1. INTRODUCTION

In the present era where technology has become a tool for humans to do all the work easily [1]. The rapid development of science has made a breakthrough in making every day human life easier [2]. One of the technologies that can be used as human infrastructure in activities is the internet of thing or often abbreviated as IoT [3], [4]. The IoT enables physical objects to see, hear, think, work, and exchange information and coordinate decisions [4]-[6]. "Thing" in the context of IoT can refer to any device with an internal sensor that has the ability to collect and transfer data over a network without manual intervention [7], [8].

Some of the problems that occur in the development of animal husbandry in Indonesia, especially in goat farming is still using a fairly traditional and primitive way such as using human labour in supervising livestock, providing feed and so on [9]. Meanwhile, in the present, Indonesia wants to participate in the application of the Industrial Revolution 4.0 in the industrial world [9]-[11]. Many industry players are competing in implementing and utilizing IoT, cloud technologies such as cloud storage, cloud computing, and big data [12]-[14].

Problems often experienced by livestock breeders, especially in Indonesia, who still use traditional methods, without/rarely utilizing technological advances. Problems often experienced by farmers, especially in Indonesia, which still uses traditional methods, without/rarely utilizing technological advances. One of the problems often experienced by farmers is the difficulty in identifying diseases experienced by livestock, centered on livestock goats. In fact, the use of technology such as the IoT such as temperature detectors using thermal cameras can help farmers identify livestock diseases through the temperature of livestock goats.

By utilizing the principles of the industrial revolution, there are many potentials that are useful for the livestock sector, especially in the field of goat farming. With the background above, researchers can create new innovations to make it easier for goat farmers to carry out monitoring activities on their goat farms. This study aims to create a goat pen that implements IoT technology in the form of a thermal camera sensor, then the IoT module is connected to a goat farming system information management website. The use of an IoT module connected to a goat farming system information management website aims to help farmers identify diseases experienced by their livestock based on the temperature of the livestock. The design that will be carried out is an initial stage, and is still experiencing trial and error. By utilizing the principles of the industrial revolution, there are many useful potentials for the livestock sector, especially in the field of goat farming. With the above background, researchers can create new innovations to make it easier for goat farmers to conduct surveillance activities in their goat farms. This study aims to create a goat cage.

2. LITERATURE REVIEW

The IoT is a concept that can connect all devices using internet technology, enabling them to have the ability to collect and transfer data over the internet via the cloud (without manual intervention). "Thing" in the context of IoT can refer to any device with any internal sensor that has the ability to collect and transfer data over a network without manual intervention [5]. The technology embedded in objects helps IoT devices to interact with internal conditions and the external environment, which in turn aids in the decision-making process.

Laravel is a PHP-based framework that is widely used for developing web applications [15]. Laravel offers very useful features such as an expressive database abstraction layer, dependency injection, and excellent scalability [16]. Research on IoT devices has many various types. Table 1 is the previous research related to IoT devices. One of the research projects is by using ESP8266 and combined with different module devices. For example, there are several previous studies that have used the ESP8266 microcontroller, and minicomputer like Raspberry Pi 3 model B [17]-[20].

Another type of ESP is ESP32. The ESP32 is a low-power microcontroller with integrated Wi-Fi and Bluetooth, designed for IoT applications. In research, the ESP32 is used for rapid prototyping and developing IoT applications that require wireless connectivity and data processing [18]. The ESP32, with its enhanced processing power and additional features such as Bluetooth, offers significant advantages over the ESP8266 for more complex IoT applications [19]. While ESP8266 provides a cost-effective solution for basic IoT applications, the ESP32's superior performance and versatility make it more suitable for advanced projects [20]. Other study aims to enhance the efficiency and accuracy of monitoring and controlling solar irradiance in photovoltaic (PV) systems through the integration of IoT technology. The proposed system employs an ESP8266 microcontroller as the central control unit, which receives input from light dependent resistor (LDR) sensors responsible for detecting both the direction and intensity of sunlight [21]. The system collects various environmental parameters, including current, voltage, and temperature, which are processed and transmitted via a Wi-Fi connection to the Blynk application, allowing for real-time remote monitoring. Experimental results demonstrate that the implemented system achieves, on average, a 65% improvement in efficiency, accuracy, responsiveness, and user convenience when compared to conventional manual monitoring methods.

Additionally, the development and implementation of IoT-based technologies have primarily focused on enhancing system efficiency and decision-making across various sectors, with a particular emphasis on smart agriculture. To support this, a robust theoretical framework is essential, which is provided by a systematic review of the application of multi-criteria decision-making (MCDM) methods in software engineering. This review highlights the challenges involved in selecting optimal solutions within complex systems, particularly those utilizing IoT [22]. This theoretical foundation is especially relevant when considering applied research, such as studies [23]-[25], which focus on the direct use of IoT in agriculture. For instance, IoT-based management and monitoring in smart agriculture [23] are explored alongside the development of information-centric approaches and dynamic data optimization strategies to address the efficiency challenges associated with real-time data processing [24]. Further enriching this approach, low-cost IoT platforms integrated with unmanned aerial vehicles (UAVs) have been proposed to enhance environmental monitoring capabilities within smart agriculture [25]. Additionally, the technical underpinnings of IoT platforms like ESP8266 and ESP32 are thoroughly examined, addressing key aspects such as programming models, security vulnerabilities, and user-friendliness [26]. In conjunction with these technical insights, other studies have contributed to bridging the gap between technical and functional considerations by proposing architectural design approaches for IoT-based agricultural management information systems, which align with the integration and scalability needs identified in the broader body of research [27].

Table 1. Previous studies

Author(s)	Title	Journal	Result and conclusion
Nagaraju and Chawla [23]	IoT implementation and management for smart farming	International Journal of Innovative Technology and Exploring Engineering vol. 8, no. 10, 2019	This research was selected grouped by various domains and subdomains related to the use of sensors, actuators, communication technologies, energy control, storage solutions, data analysis for decision making, and visualization to farmers through web applications. In this study to digitize agriculture by using IoT devices by integrating each device into a system.
Pal *et al*. [24]	Information-centric IoT-based smart farming with dynamic data optimization	Computers, Materials and Continua, vol. 74, no. 2, 2023	This research designed IoT-based smart farming centered on information with dynamic data optimization (ICISF-DDO), which improves the performance of smart farming infrastructure with minimal energy consumption and better service life. Here, the conceptual framework of the proposed scheme and the statistics of the design model have been well defined.
Litayem and Al-Sa'di [26]	Exploring the programming model, security vulnerabilities, and usability of ESP8266 and ESP32 platforms for IoT development	International Conference on Computer Systems (ICCS)	The study demonstrates that while ESP8266 and ESP32 platforms offer flexible programming models and wide compatibility with various development environments, they are also vulnerable to exploitation through freely accessible software tools. The proof of concept highlights how these platforms can be manipulated to embed malicious functionalities in IoT systems, emphasizing the potential cybersecurity risks. Through critical analysis, the discussion underscores the importance of incorporating robust security practices when deploying these devices. The research provides practical insights for developers, encouraging proactive security planning to address vulnerabilities and ensure the safe integration of ESP-based IoT solutions.
Almalki *et al.* [25]	A low-cost platform for environmental smart farming monitoring system based on IoT and UAVs	Sustain., vol. 13, no. 11, 2021	Smart agriculture involves the integration of advanced technologies into existing agricultural practices to improve production efficiency and the quality of agricultural products. The evolution of IoT and UAVs has enabled the vision of sustainable smart agriculture, where these smart technologies have been shown to improve the quality of crop yields and reduce the environmental footprint of the agricultural sector.
Köksal and Tekinerdogan [27]	Architecture design approach for IoT-based farm management information systems	Precision Agriculture, vol. 20, no. 5, 2019	The aim of this study is to contribute to the current state-of-the-art Miss by improving the current architectural design approach for IoT-based FMIS. the study aims to provide architectural design methods to design IoT-based Miss. The presented approach adopts a feature-based domain analysis approach to model the various requirements of smart agriculture.
Hussain *et al.* [28]	A framework for malicious traffic detection in IoT healthcare environment	Sensors, vol. 21, no. 9, 2021	The experimental results demonstrate the effectiveness of the proposed framework for developing efficient IoT context-aware security solutions. In addition, the proposed framework and the resulting dataset greatly help researchers to pursue the proposed methods to develop more robust context-aware security solutions, especially for IoT healthcare environments. Furthermore, with the help of the proposed framework, researchers can quickly generate traffic of other IoT use cases to develop artificial intelligent (AI)-based security solutions for other IoT use cases.

3. METHODS

The method used in this study is the software development life cycle (SDLC) method. SDLC is a methodology for creating and modifying software systems. By using the SDLC method, the benefits include facilitating programmers in developing a software application and even improving an existing software system. The SDLC model used in this study is the prototyping model. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

As shown in Figure 1, the prototyping model is a model that allows a programmer to create software using an initial representation of the software to be developed. By using this model, it is hoped that initial testing of the software can be conducted before the software is fully complete.

Initial requirements. The identification of requirements in this study involves understanding all the necessary components for system design, such as IoT devices, the server that will store data from these IoT devices, and a computer to run the system. This includes defining the software format, the costs associated with creating and developing the system, the cost of IoT devices, and preparing a broad design of the system to be developed. Table 2 is the requirements used in building the website-based IoT device system.

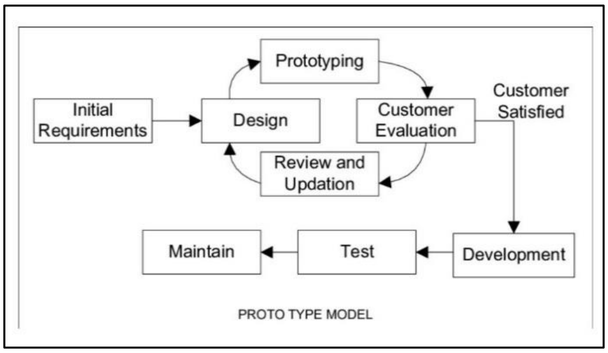

Figure 1. Flow diagram of SDLC prototype

Table 2. Device requirements

No	Required components	Types of devices	Prices (IDR)
1.	ESP32	Software	57,000
2.	MLX90640	Software	2,600,000
3.	Jumper cable female	Software	-
4.	Power micro-usb	Software	-
5.	Laravel	Software	-
6.	PostgreSQL	Software	-
7.	Visual Studio Code	Software	-
8.	DBeaver	Software	-
9.	Composer	Software	-
10.	Tailwind css	Software	-
11.	Arduino IDE	Software	-
12.	Apache	Software	-
13	PHP	Software	-

This study employs the ESP32 microcontroller and the MLX90640 thermal imaging sensor as the primary devices. The ESP32 is a versatile and low-power IoT device equipped with Wi-Fi and Bluetooth connectivity, making it ideal for real-time data acquisition and communication. It acts as the central processing unit in this system, gathering data from sensors and transmitting it to the server. The MLX90640 is an infrared thermal camera array capable of capturing temperature data across a surface with high precision. Its ability to detect temperature variations in real-time makes it particularly useful for applications in monitoring livestock conditions.

In this study, these devices are integrated to develop an IoT-based monitoring system for the livestock industry. The ESP32 processes and transmits data captured by the MLX90640 sensor, which measures the body temperature of animals. This system enables continuous monitoring of animal health, identifying potential signs of illness through abnormal temperature readings. By leveraging IoT technology, this research contributes to enhancing livestock management efficiency and ensuring better animal welfare. The implementation of such systems demonstrates the potential of IoT devices in advancing precision farming practices within the agricultural domain.

- Build prototype: this stage involves designing the prototype software system. Several aspects will be considered in designing a prototype: i) user interface: using blade to design the user interface (UI) for the website for monitoring and surveillance of livestock; ii) platform software: using a web-based application framework, Laravel, to display information about the livestock; iii) architecture: using PHP as the programming language to connect the database to the web application. Using PostgreSQL as the database management system.
- Evaluate prototype: this stage involves evaluating the previously created prototype. If it aligns with the desired workflow, it will proceed to software deployment. However, if it does not meet the requirements, revisions will be made to the prototype.
- Deployment: once the previous prototype aligns with the desired expectations, the coding process begins to develop the website application. This application will later integrate with IoT devices and connect to a server.

- Testing: in this stage, software testing is conducted, including white box testing, black box testing, and other testing methodologies. Additionally, testing is performed on the IoT devices through three experimental sessions to assess the performance of the created devices.
- Evaluate system: in this stage, an evaluation of the system and website application is conducted by examining the performance generated from the designed website, ensuring that it functions as expected. Additionally, the performance of the IoT devices is assessed to identify any potential issues. If no issues are found, further investigation is conducted to determine the cause of any device not operating optimally. To ascertain that the IoT devices operate without hindrance, several aspects are considered: i) operational time: assessing the duration the IoT devices operate without encountering problems; ii) temperature readings: verifying whether the displayed temperature on the devices corresponds accurately to the object and ambient conditions; and iii) connectivity: identifying any issues encountered when powering on the IoT devices to establish connectivity with the website.
- By examining these aspects, it becomes possible to ensure that the IoT devices operate smoothly and reliably, fulfilling their intended function within the system.
- Maintain: this stage involves maintaining the developed software. It will receive error and bug reports from users, which the programmers will address by fixing the parts of the software that are experiencing bugs and errors.

4. RESULT AND DISCUSSION

To design a website application system, it's crucial to identify the necessary components required to complete the system development. There are several requirements needed for building the goat farm monitoring website application using IoT devices, categorized into two types: software requirements and hardware requirements. These requirements cover both the hardware and software aspects needed to build the goat farm monitoring website application using IoT devices. The hardware components will facilitate the data collection and monitoring, while the software tools will enable the development, styling, database management, and overall integration of the system.

After identifying all the requirements needed to build the system, the next step is to create a prototype for the goat farm monitoring website using IoT devices. At this stage, several aspects will be considered and then addressed in the prototype development process. These aspects include:

4.1. User interface and platform software

The homepage is a feature or menu that serves as the initial display of the website application, providing introductory information. It will also include news and information channels related to goat farming. Additionally, the homepage has a login menu that functions to navigate to the login page. Below is an example of the homepage for the goat farm monitoring website system using IoT devices, as shown in Figure 2.

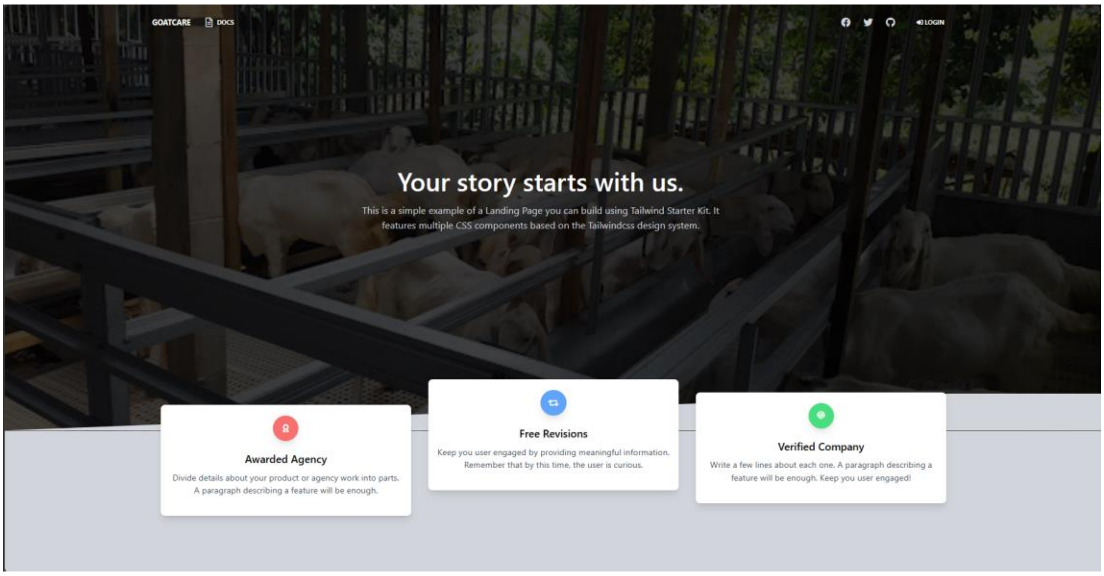

Figure 2. Landing page

The login feature is a menu that provides a screen for users to enter their email and password to proceed to the next page. The login page also includes a register link that directs users to the registration page. Below is the login page for the goat farm monitoring website system using IoT devices, as shown in Figure 3.

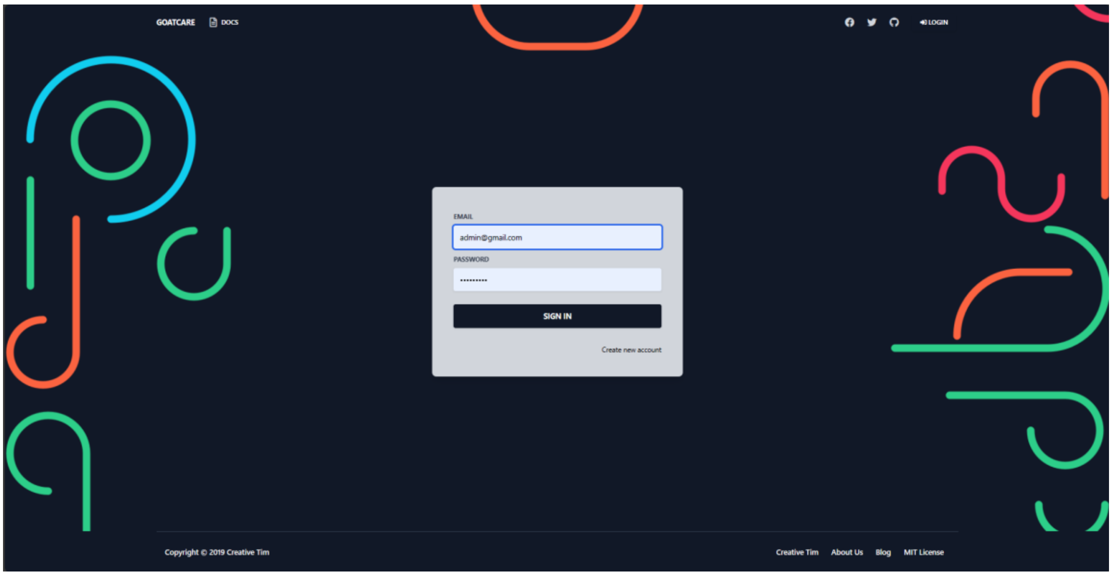

Figure 3. Login page

The register feature is a menu that provides a screen for creating a new account. The registration page contains a form that requires information such as first name, last name, address, email, password, and password confirmation. The last name and address fields are optional, while the first name, email, and password fields are mandatory. After registering, users will receive a notification to activate their account via the email they provided. Below is the registration page for the goat farm monitoring website system using IoT devices, as shown in Figure 4.

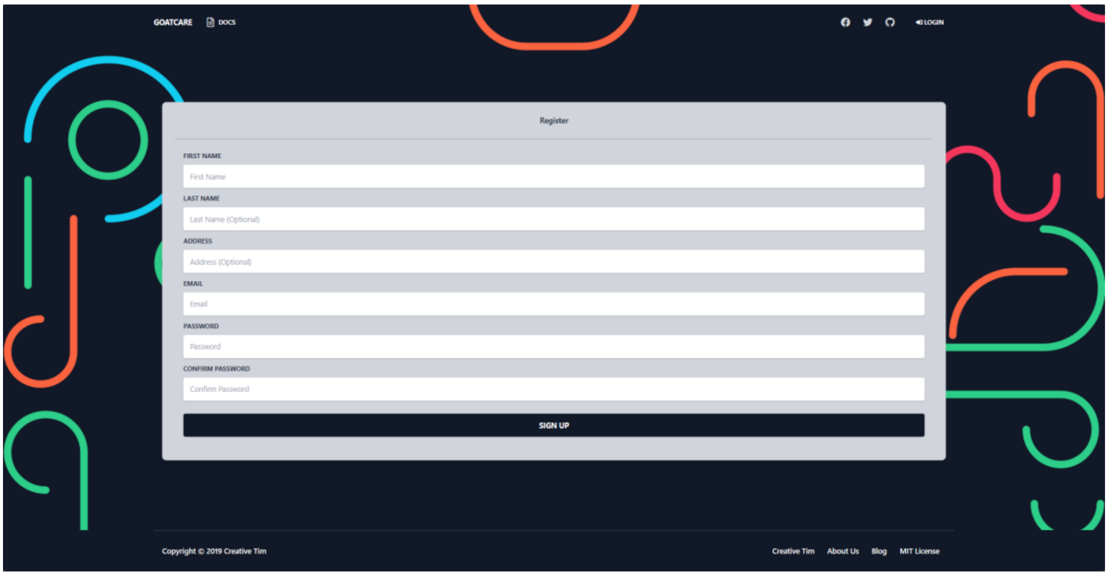

Figure 4. Register page

The dashboard is a feature or menu that displays real-time monitoring of the barn via camera, account information, the number of goats on the farm, average health information of the goats, a bar chart showing the number of healthy and sick goats, and the farm location via Google Maps. All pages accessible after logging in will have a navigation bar on the left side containing features and menus accessible for each role. Below is the dashboard page for the goat farm monitoring website system using IoT devices, as shown in Figure 5.

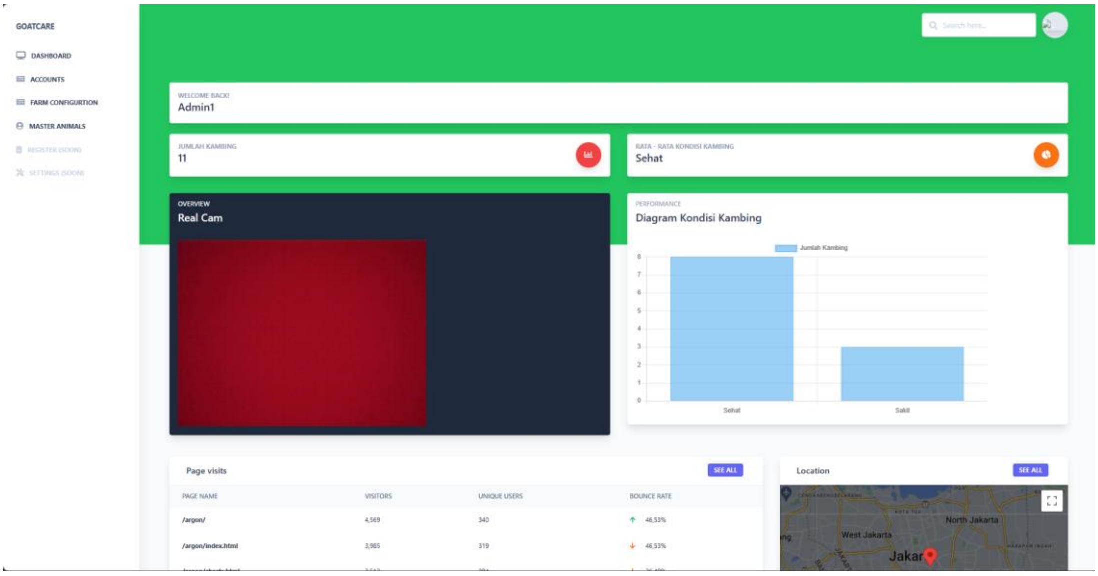

Figure 5. Dashboard page

4.2. System implementation

The system implementation phase involves the practical realization of the design and planning stages into a functional and operational system. This section covers the step-by-step process of implementing the goat farm monitoring website using IoT devices. The deployment process on IoT devices is carried out on the Arduino IDE, and later the code that has been created on the Arduino IDE will be uploaded to the ESP32 micro-controller that has been connected to the MLX90640. For the shape of the device can be seen in Figure 6.

Before uploading the code on the device, configuration is done on the device first so that the device can run. In Figure 7, there are 4 jumper cables needed to be connected to the thermal camera module. Can be seen on the white cable is placed on the port D22 then the end of the white cable is connected to the thermal camera module port in serial clock line (SCL). For the yellow cable is placed on the D21 port and then at the end of the cable is connected to the camera module port in the serial data line (SDA). Then the red cable is placed on the I port 3v3 then the end of the red cable is connected to the camera module port in the voltage input (VIN). Finally, the black cable is placed on the ground (GND) port and then the end of the cable is connected to the camera port in GND.

After configuring and installing the device, the next step is to perform testing and troubleshooting. At this stage, troubleshooting is done on IoT devices with the aim of finding problems and finding solutions to problems that arise. There are several troubleshooting sessions on IoT devices that are carried out due to the emergence of problems on the device.

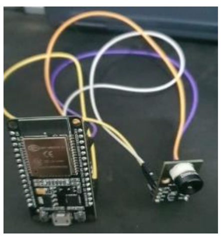

Figure 6. IoT devices

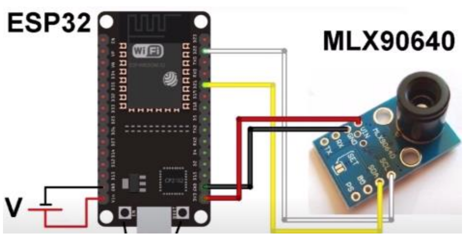

Figure 7. Configuration device

4.2.1. First session

The first session of troubleshooting is done because there are findings on the board used in the Arduino IDE application, there are differences in versions with the microcontroller board that will be used. In the application, the board in the program uses ESP32 Wroom model while the device used uses ESP wroom 32 dev module. Although it has a similar name, but at the time of testing the device after uploading, the device can not return the value of the IP Address generated in the program. After troubleshooting, it is known that the version of the board that must be used in the application is to use Sparkfun EPS32 Thing. The reason for using that version is because the code used on the device can only be supported using the board even though the hardware does not use the same version as the board version in the application.

4.2.2. Second session

The second session of troubleshooting on IoT devices was carried out because there were findings on the cable used, namely the female jumper cable was loose against the installed port. Due to the loose cable as a result at the time of the device in the test sometimes experience problems such as thermal camera device is not detected on the I2C address. After doing the troubleshooting, it is known that the right solution is to cut the jumper cable on the connector and solder the cable directly to a microcontroller port and add the PCB as a place to put both devices into one part so that soldering the device can be done easily.

4.2.3. Third session

The third session of troubleshooting on IoT devices was carried out because there were findings on the connectivity of microcontrollers with camera modules that often experience freezing. There are 2 conjectures on this problem, the first is the difference in volts from the power source to the volts needed by IoT devices, the second is a problem with the camera module experiencing corselet due to the difference in volts. The effort is to remove the solder Tin on each device and replace the power source by using a charger adapter that uses 5 volts.

After implementing the system that has been designed, to find out whether this research can be said to be successful or not can be proven by the results obtained and analyze the results whether this research is successful or not, especially for IoT devices that in conducting trials are still experiencing some problems.

To find out whether the IoT device that is made can be said to be successfully running or not, then in accordance with the research method in the previous system evaluation, there are 3 indicators of whether the device is working as expected or not. The first time that can be taken by IoT devices in a state of power on and not having problems, then the temperature results displayed on the device are in accordance with the conditions of the object and space or not, and see if there are obstacles when turning on IoT devices to be able to connect to the website.

In Table 3 there are 3 experiments with the temperature produced and displayed by the device with the object of capture is human. Testing on humans is intended to determine whether the device can work properly and in accordance with the temperature of the object to be tested before implementation to the goat pen. In the first experimental session carried out on April 12, 2024, it can be seen that the average temperature displayed ranges from 37 °C. Then in the second experimental session carried out on April 24, 2024, the average results displayed ranged from 37.5 °C. Furthermore, in the third trial session, the average results that the device showed ranged from 36.8 °C. Judging from the average results of the three experiments above, the IoT device can be said to work well to detect the temperature of the object, namely humans with normal temperatures because of the three experiments produced an average temperature range of 37 ℃.

Table 3. Temperature indicator test data

No	Trial session	Indicators	Objects	Average yield
1	12 April 2024	Temperature	Human	37 ℃
2	24 April 2024	Temperature	Human	37.5 ℃
3	05 May 2024	Temperature	Human	36.8 ℃

In Table 4 there are 3 experiments with different time ranges. In the first trial session on April 12, 2024, it can be seen that the travel time of IoT devices when they turn on is only about 10 seconds then the device freezes and reboots. From these results it can be said that in the first experiment, the device experienced problems with an unstable power supply because the power source used came from the usb port on the laptop. Then troubleshooting and revamping was carried out, an experiment was carried out again on April 24, 2024. In the second experiment, the travel time of the device can work properly increased to 8 minutes 30 seconds. The results were improved compared to the first trial session. The obstacle found was still around the unstable power supply, but at this session it was found that the solder that was planted to the device was loose with the cable that forwards the source of electrical energy to the thermal camera module. After troubleshooting and revamping the soldering of the device, an experiment was carried out again on May 05, 2024. In the third experiment, the travel time of the device can work properly increased to 2 hours 16 minutes. The results were significantly improved compared to the first and second trial sessions.

Table 4. Duration indicator test data

No	Trial session	Indicators	Connection status	Duration
1	12 April 2024	Duration	Success	10 second
2	24 April 2024	Duration	Success	8 minute 30 second
3	05 May 2024	Duration	Success	2 hour 16 minutes

5. CONCLUSION

From the data obtained during the testing process of the device, the results obtained when conducting experimental testing of the device, the resulting data can mean that the device can actually detect the temperature well, but there are constraints where the device several times stopped due to freezing and rebooting the device system where the constraints are caused because the thermal camera module can not receive electrical voltage well. If compare it with the previous studies, the effectiveness of using IoT devices for measuring the body temperature of goats is far from successful due to constraints with the MLX90640 module and differences in microcontroller usage. In theory, ESP32 is better than ESP8266 due to differences in features, but the use of different modules results in the performance of ESP32 not being optimal. From the research that has been done, it was found that the use of the MLX90640 module combined with ESP32 for the use of IoT-based goat livestock monitoring can actually run well, it's just that in its implementation there are many obstacles in assembling IoT devices, it should be noted that the IoT device module used, namely MLX90640, is a device that is relatively expensive and difficult to find in the marketplace because the item is an imported item. but using the MLX90640 is the right choice because the device provides a thermal camera that is used to take target temperatures at a distance of about 1-2 meters. From the research that has been done, it was found that the use of the MLX90640 module combined with ESP32 for the use of IoT-based goat livestock monitoring can actually run well, it's just that in its implementation there are many obstacles in assembling IoT devices.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author [Wella] on request.

REFERENCES

[1] Z. Tekic and J. Füller, “Managing innovation in the era of AI,” *Technology in Society*, vol. 73, p. 102254, May 2023, doi: 10.1016/j.techsoc.2023.102254.

[2] H. U. Khan *et al.*, “Multi-criteria decision-making methods for the evaluation of the social internet of things for the potential of defining human behaviors,” *omputers in Human Behavior*, vol. 157, p. 108230, Aug. 2024, doi: 10.1016/j.chb.2024.108230.

[3] P. Yang, N. Xiong, and J. Ren, “Data Security and Privacy Protection for Cloud Storage: A Survey,” *IEEE Access*, vol. 8. pp. 131723–131740, 2020, doi: 10.1109/ACCESS.2020.3009876.

[4] S. Choudhary and G. Meena, “Internet of Things: Protocols, Applications and Security Issues,” *Procedia Computer Science*, vol. 215, pp. 274–288, 2022, doi: 10.1016/j.procs.2022.12.030.

[5] C. Li, J. Wang, S. Wang, and Y. Zhang, “A review of IoT applications in healthcare,” *Neurocomputing*, vol. 565, p. 127017, Jan. 2024, doi: 10.1016/J.NEUCOM.2023.127017.

[6] L. Sciullo, A. De Marchi, A. Trotta, F. Montori, L. Bononi, and M. Di Felice, “Relativistic Digital Twin: Bringing the IoT to the future,” *Future Generation Computer Systems*, vol. 153, pp. 521–536, Apr. 2024, doi: 10.1016/J.FUTURE.2023.12.016.

[7] M. Saied, S. Guirguis, and M. Madbouly, “Review of artificial intelligence for enhancing intrusion detection in the internet of things,” *Engineering Applications of Artificial Intelligence*, vol. 127, p. 107231, Jan. 2024, doi: 10.1016/j.engappai.2023.107231.

[8] J. F. Cevallos M., A. Rizzardi, S. Sicari, and A. C. Porisini, “Deep Reinforcement Learning for intrusion detection in Internet of Things: Best practices, lessons learnt, and open challenges,” *Computer Networks*, vol. 236, p. 110016, Nov. 2023, doi: 10.1016/J.COMNET.2023.110016.

[9] A. Haleem, M. Javaid, R. Pratap Singh, and R. Suman, “Medical 4.0 technologies for healthcare: Features, capabilities, and applications,” *Internet of Things and Cyber-Physical Systems*, vol. 2, pp. 12–30, Jan. 2022, doi: 10.1016/J.IOTCPS.2022.04.001.

[10] S. Hutajulu, W. Dhewanto, and E. A. Prasetio, “Two scenarios for 5G deployment in Indonesia,” *Technol Forecast Soc Change*, vol. 160, p. 120221, Nov. 2020, doi: 10.1016/J.TECHFORE.2020.120221.

[11] H. Legenvre, M. Henke, and H. Ruile, “Making sense of the impact of the internet of things on Purchasing and Supply Management:A tension perspective,” *Journal of Purchasing and Supply Management*, vol. 26, no. 1, p. 100596, Jan. 2020, doi: 10.1016/J.PURSUP.2019.100596.

[12] P. Niloofar *et al.*, “Data-driven decision support in livestock farming for improved animal health, welfare and greenhouse gas emissions: Overview and challenges,” *Computers and Electronics in Agriculture*, vol. 190, p. 106406, Nov. 2021, doi: 10.1016/J.COMPAG.2021.106406.

[13] A. A. Alli and M. M. Alam, “The fog cloud of things: A survey on concepts, architecture, standards, tools, and applications,” *Internet of Things*, vol. 9, p. 100177, Mar. 2020, doi: 10.1016/J.IOT.2020.100177.

[14] A. Maia *et al.*, “A survey on integrated computing, caching, and communication in the cloud-to-edge continuum,” *Computer Communications*, vol. 219, pp. 128–152, Apr. 2024, doi: 10.1016/J.COMCOM.2024.03.005.

[15] A. Sunardi and Suharjito, “MVC Architecture: A Comparative Study Between Laravel Framework and Slim Framework in Freelancer Project Monitoring System Web Based,” *Procedia Computer Science*, vol. 157, pp. 134–141, Jan. 2019, doi: 10.1016/J.PROCS.2019.08.150.

[16] M. Laaziri, K. Benmoussa, S. Khoulji, and M. L. Kerkeb, “A Comparative study of PHP frameworks performance,” *Procedia Manufacturing*vol. 32, pp. 864–871, Jan. 2019, doi: 10.1016/J.PROMFG.2019.02.295.

[17] H. Mohamed, N. Koroniotis, F. Schiliro, and N. Moustafa, “IoT-CAD: A comprehensive Digital Forensics dataset for AI-based Cyberattack Attribution Detection methods in IoT environments,” *Ad Hoc Networks*, vol. 174, Jul. 2025, doi: 10.1016/j.adhoc.2025.103840.

[18] J. J. López and P. Lamo, “Rapid IoT Prototyping: A Visual Programming Tool and Hardware Solutions for LoRa-Based Devices,” *Sensors*, vol. 23, no. 17, pp. 1–17, 2023, doi: 10.3390/s23177511.

[19] M. Fezari, N. Zakaria, and A. Al Dahoud, “Comparative study between two Powerfull NodeMCU Circuits: ESP32 and ESP8266,” *preprint*, 2019.

[20] P. K. Malik, A. S. Duggal, S. Aluvala, R. Sahithi, Geetanjali and A. Gehlot, “Development of a low-cost IoT device using ESP8266 and Atmega328 for real-time monitoring of Outdoor Air Quality with Alert,” *2023 3rd International Conference on Advancement in Electronics & Communication Engineering (AECE)*, 2023, pp. 125-129, doi: 10.1109/AECE59614.2023.10428098.

[21] I. Anshory *et al*., “Monitoring solar heat intensity of dual axis solar tracker control system: New approach,” *Case Studies in Thermal Engineering*, vol. 53, Jan. 2024, doi: 10.1016/j.csite.2023.103791.

[22] A. A. Magabaleh, L. L. Ghraibeh, A. Y. Audeh, A. S. Albahri, M. Deveci, and J. Antucheviciene, “Systematic Review of Software Engineering Uses of Multi-Criteria Decision-Making Methods: Trends, Bibliographic Analysis, Challenges, Recommendations, and Future Directions,” *Applied Soft Computing*, 2024, doi: 10.1016/J.ASOC.2024.111859.

[23] M. Nagaraju and Dr. P. Chawla, “IoT Implementation and Management for Smart Farming,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 10. pp. 2483–2491, 2019. doi: 10.35940/ijitee.j9545.0881019.

[24] S. Pal, H. VijayKumar, D. Akila, N. Z. Jhanjhi, O. A. Darwish, and F. Amsaad, “Information-Centric IoT-Based Smart Farming with Dynamic Data Optimization,” *Computers, Materials & Continua*, vol. 74, no. 2, pp. 3865–3880, 2023, doi: 10.32604/cmc.2023.029038.

[25] A. Almalki, B. O. Soufiene, S. H. Alsamhi, and H. Sakli, “A Low-Cost Platform for Environmental Smart Farming Monitoring System Based on IoT and UAVs,” *Sustainability*, vol. 13, no. 11, 2021. doi: 10.3390/su13115908.

[26] N. Litayem and A. Al-Sa’di, “Exploring the Programming Model, Security Vulnerabilities, and Usability of ESP8266 and ESP32 Platforms for IoT Development,” *2023 IEEE 3rd International Conference on Computer Systems (ICCS)*, 2023, pp. 150-157, doi: 10.1109/ICCS59700.2023.10335558.

[27] Köksal and B. Tekinerdogan, "Architecture design approach for IoT-based farm management information systems," *Precision Agriculture*, vol. 20, no. 5, 2019, doi: 10.1007/s11119-018-09624-8.
[28] F. Hussain *et al.*, "A framework for malicious traffic detection in iot healthcare environment," *Sensors*, vol. 21, no. 9, 2021, doi: 10.3390/s21093025

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