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Iot-Based Monitoring and Alert System for Carrageenan Production in Coastal Village

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Abstract. Carrageenan is a polysaccharide compound extracted from seaweed that is widely cultivated in Sumenep waters, has a higher economic value. The process of processing seaweed into carrageenan is carried out by the extraction process at a temperature of about 80-90° C which takes several hours until the carrageenan is completely dissolved and the drying process in the oven until it becomes dry material. Both processes greatly affect the quality of the processed carrageenan. Therefore, real-time and continuous monitoring is required so that the quality can be maintained properly. With the processing site located in a coastal area far from the city centre, an Internet of Things (IoT)-based monitoring and alert system is proposed that can send real-time information. The data obtained can be used as a reference for alerts to operators in the control room through a web that can be accessed easily. The system employs ESP32 board, Thermocouple Type K sensor, SCT-013-010 sensor, which transmits data to Firebase real-time database where the data is stored. A web-based User Interface is created to display data and alerts with easier access. The system applied to carrageenan processing in coastal areas shows the usefulness of monitoring and warning against excessive temperatures.

1 Introduction

Indonesia, as an archipelagic nation, possesses immense marine and fisheries potential, with seaweed being one of its leading commodities, contributing 38 % of the global seaweed market [1]. The waters of Sumenep, Madura, are a significant center for the cultivation of *Eucheuma cottonii*, a type of red seaweed that is the primary raw material for producing carrageenan [2]. Carrageenan is a high-value hydrocolloid polysaccharide widely used in the food, pharmaceutical, and cosmetic industries as a gelling agent, thickener, and stabilizer [3]. The economic value of seaweed increases substantially when it is processed into carrageenan, making this downstream industry vital for local economies [4].

The problem with Indonesian seaweed is the low perception of product quality. The production of high-quality carrageenan is heavily dependent on precise control over the manufacturing process, particularly during the extraction and drying stages [5]. The extraction phase requires heating a seaweed slurry to a specific temperature range, typically between 80°C and 90°C, for several hours to dissolve the polysaccharide completely. Subsequently, the resulting gel is dried until it reaches a specific moisture content. Both temperature and duration are critical parameters in these stages. lower heat can lead to no gel produced because the chemical process to produce carrageenan did not take place very well, thus leaving seaweed uncooked [6]. Conversely, insufficient heat or time can lead to low yields.

Traditionally, monitoring these processes relies on manual checks by operators, which are often intermittent and prone to human error. Manual checks cannot provide the continuous data stream necessary to identify "spikes" or "drops" in temperature that occur between logging intervals [7]. Uncontrolled heat treatment for seaweed process directly affects the color and sulfate content of the final product [8]. The application of technology in the extraction

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and drying process, particularly in the heating stage, has been proven to improve the quality of the resulting carrageenan [9]. The challenge is compounded by the fact that many processing facilities are located in remote coastal areas, far from urban centers, making consistent supervision and access to advanced control technology difficult [10]. This lack of real-time monitoring not only results in suboptimal processing conditions but also eliminates the potential for data-driven evaluation, leading to variations in product quality and potential economic losses for manufacturers.

To address these challenges, modern technological solutions are required. The emergence of the Internet of Things (IoT) offers a powerful tool for real-time, continuous, and remote monitoring of industrial processes. By integrating sensors with microcontrollers and cloud-based platforms, an IoT system can provide operators with live data and automated alerts, enabling them to maintain optimal conditions and respond immediately to any deviations. Therefore, this study proposes the development of an IoT-based monitoring and alert system specifically designed for carrageenan processing. This system aims to improve quality control and operational efficiency by providing a reliable, accessible, and real-time data feed to operators, ensuring the production of high-quality carrageenan.

2 Requirement Analysis

2.1 Carrageenan Processing Workflow

Carrageenan is a natural polysaccharide extracted from the cell walls of red seaweeds. Fig. 1 show production process. The processing begins with washing the harvested seaweed using clean freshwater. This step is repeated several times to remove sand, residual sea salt, small organisms, and other contaminants. After washing, the seaweed undergoes soaking for several hours to soften its texture, facilitating easier cutting. Next, the seaweed is cut into pieces measuring 2–5 cm to increase the contact surface area during extraction. This preparation accelerates carrageenan release and optimizes heat transfer efficiency.

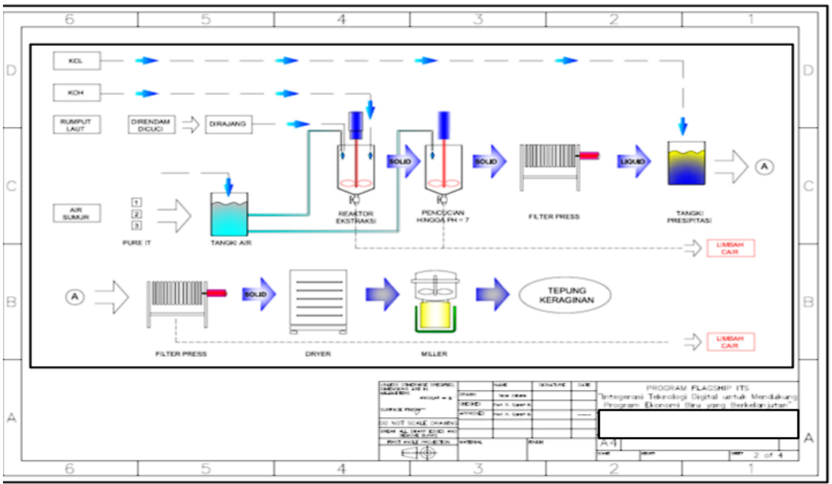


Fig. 1. Carrageenan flour processing scheme.

Extraction is carried out in stainless steel reactors to prevent corrosion and metal contamination. Water is added at a ratio of 1:10–1:20 relative to the dry weight of the raw material. Heating is maintained for approximately one hour at 80–85 °C, the optimal range for dissolving carrageenan without damaging its molecular structure. The extraction yields a mixture of carrageenan solution and solid residue. This mixture is rinsed with clean water until a neutral pH (7) is achieved. A pressing stage is then performed to separate the carrageenan-rich solution from the pulp. The solution subsequently undergoes precipitation using a designated precipitating medium to isolate the solid phase containing concentrated carrageenan. Precipitation is followed by a second pressing to significantly reduce moisture content before drying [11].

Drying is carried out in an oven at 60 °C for 48–72 hours, depending on the initial water content and ambient humidity. Strict temperature control is essential to prevent thermal degradation of the polysaccharide. Once completely dry, the carrageenan solids are ground in a high-speed milling machine into fine powder for packaging.

2.2 Monitoring System Design

Based on the production process described in the previous chapter, monitoring requirements for carrageenan production can be established. Two main units are prioritized for monitoring:

- Extraction unit – monitored parameters include extraction temperature and stirrer motor rotation speed (RPM). Temperature directly affects carrageenan solubility, while RPM influences heat distribution and prevents material clumping.
- Drying oven – monitored for internal temperature stability. Temperature fluctuations can cause uneven drying, affecting the quality, color, and gel strength of carrageenan.

Fig. 2 shows the architectural scheme of the monitoring system based on the requirements that have been established. The system architecture is divided into three main systems, namely the oven monitoring system, the extraction monitoring system, and the visual monitoring system. The oven monitoring system consists of devices for monitoring temperature and for visualizing temperature. Meanwhile, the extraction monitoring system is designed to measure the speed of the mixer machine and the temperature of the extraction chamber. Visual monitoring is also added to monitor conditions inside the seaweed processing chamber.

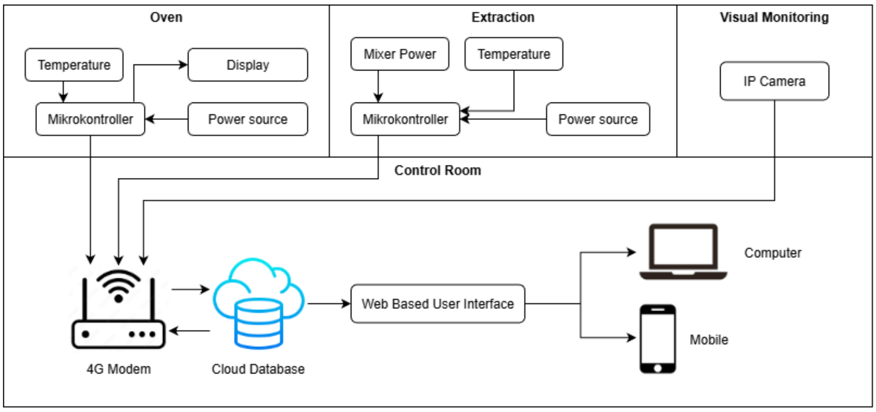


Fig. 2. Architecture of monitoring system for carrageenan process.

3 Hardware and Software Implementation

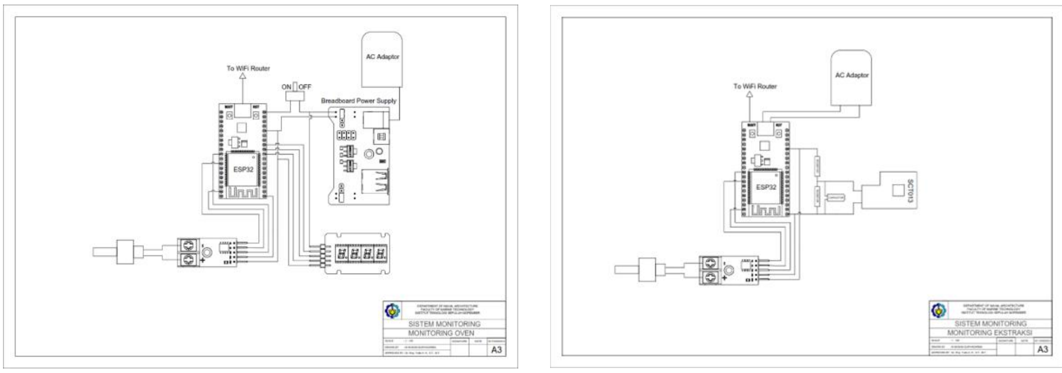
3.1 Monitoring System Design

The microcontroller used is the ESP32 DevkitC developed by Espressif Systems. One of the main advantages of the ESP32 DevkitC is its ability to connect to WiFi networks and Bluetooth devices. This allows IoT devices to communicate wirelessly with other devices, cloud servers, or smartphone applications.

Additionally, the ESP32 features a dual-core processor with high processing power for a microcontroller. However, the ESP32 is designed with a low-power mode, enabling IoT devices to operate in battery-powered or energy-constrained scenarios, making it suitable for simple applications. Another advantage is its support for various development environments, including the Arduino IDE and the Espressif IoT Development Framework (ESP-IDF). This makes it easy to use for developers with varying levels of experience [12].

3.2 Sensors

The selection of sensors is adjusted to the function based on the placement of sensors in the production process. Temperature sensor for monitoring system, a type K thermocouple sensor is used due to its wide temperature range, durability, and cost-effectiveness. This sensor was chosen because it performs well at temperatures between 25 and 100 degrees Celsius, which is suitable for drying and extraction processes [13]. The signal from the temperature sensor is first received by the max6675 module for calibration and stability of the analog signal reading from the sensor compared to the direct reading by analog-to-digital conversion on the microcontroller [14]. Meanwhile, to measure the mixer's power, an SCT-013-000 sensor is used to read the amount of current passing through a conductor to a load. The use of sensors can measure current without the need to interrupt the current path or make modifications to the main circuit. Finally, after the sensor is determined, an electronic system circuit is formed, which can be seen in Fig. 3.



(a) (b)

Fig. 3. Wiring diagram of the electronic system used; (a) oven monitoring, (b) extraction monitoring.

3.3 Database and Web Monitoring Design

The system's design is centered on an Internet of Things (IoT) framework to integrate and monitor data from various sensors in real-time. This architecture (shown in Fig. 4) involves three key stages: data transmission from the equipment, storage and processing in the cloud, and data visualization. The entire process leverages Google's Firebase platform, chosen for its powerful Realtime Database, robust authentication for security, and integrated hosting services. On the hardware side, each monitoring device is equipped with a microcontroller and a Wi-Fi module that connects to the internet via a 4G router. The microcontroller is programmed to acquire sensor data, authenticate with the Firebase system, and then transmit the information to a designated directory in the Realtime Database. Finally, this live data is presented on a simple and easy-to-understand web-based User Interface (UI), built with HTML and deployed using Firebase Hosting. This dashboard, which displays critical parameters like temperature and RPM, is designed to automatically refresh whenever new data is received, allowing all stakeholders to conveniently monitor the seaweed processing conditions.

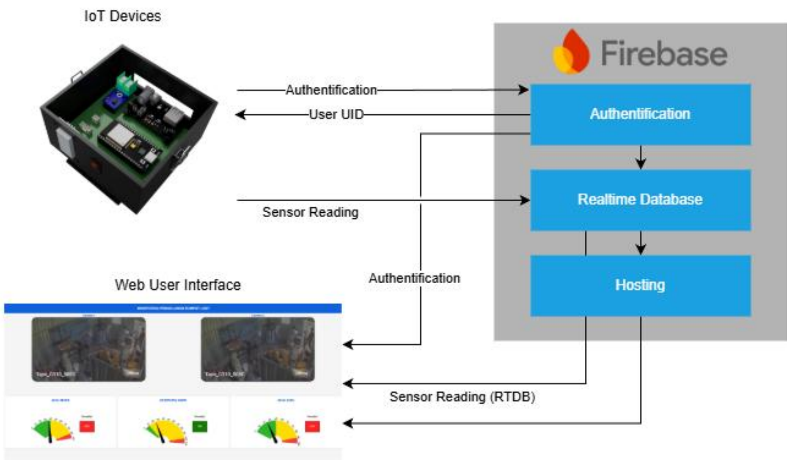
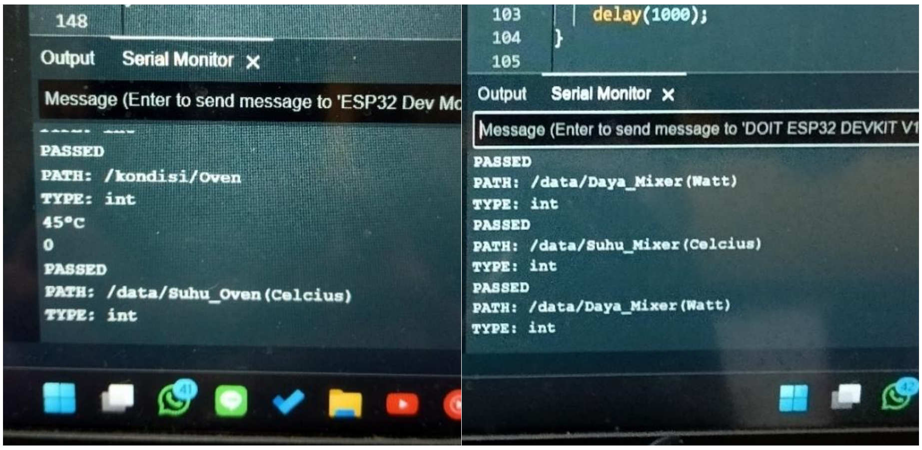


Fig. 4. Architecture of monitoring system for carrageenan process.

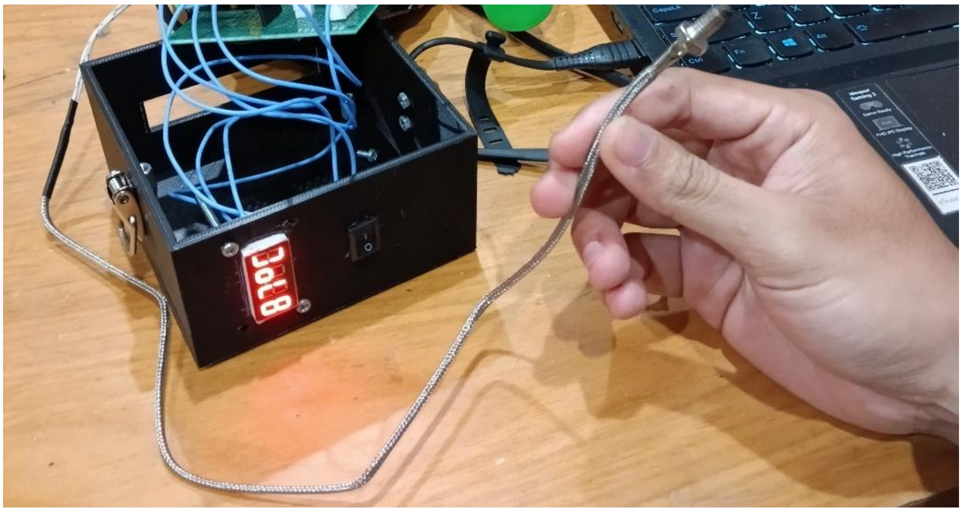
4 Results and Discussion

Preliminary testing was conducted to ensure that all electronic circuits, software components, and system connectivity operated according to the design specifications. The results indicated that the microcontroller, temperature sensor, and current sensor consistently performed accurate data acquisition. Collected data was successfully transmitted to the Firebase Realtime Database without significant delays or packet loss. The serial monitor displayed a “PASSED” status for each data transmission cycle, confirming that data integrity was maintained (Fig. 5 (a)).

The oven temperature sensor provided stable readings, with the maximum recorded value reaching 87 °C (Fig. 5 (b)). The 4-digit 7-segment display showed identical values to those transmitted to the database, demonstrating the accuracy of the microcontroller’s analog-to-digital conversion process. The SCT-013-000 current sensor successfully detected variations in the mixer’s motor load, which correlated with changes in RPM. While minor fluctuations occurred due to the instability of the drill motor used for simulation, the system was still able to record and track the overall trend with high accuracysurface.



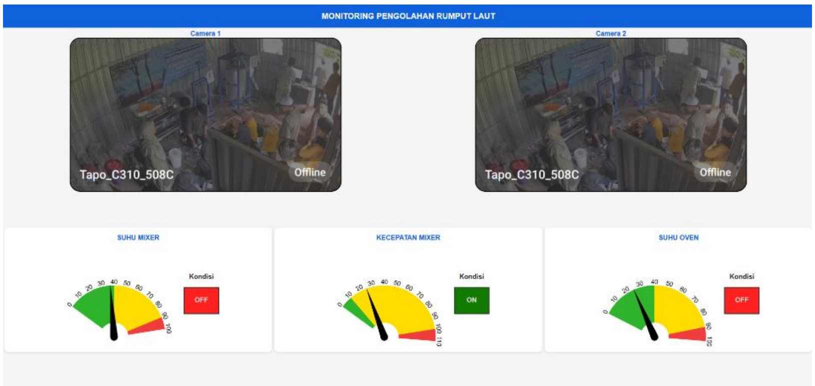
(a)



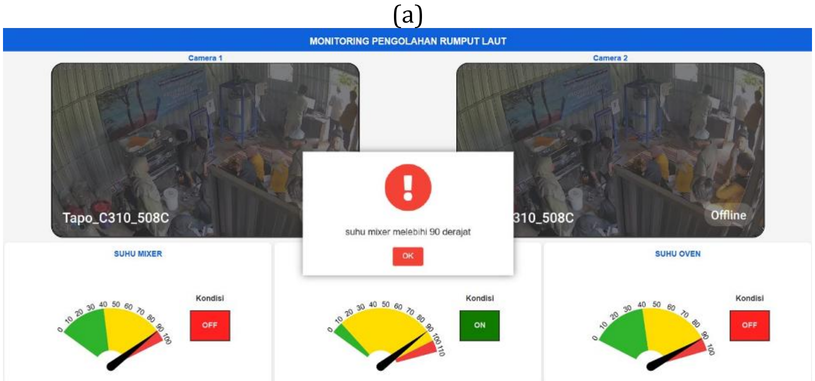
(b)

Fig. 5. IoT Device Testing; (a) passed sending data test, (b) temperature sensor test.

Data transmission was carried out via a Wi-Fi connection paired with a 4G router. A load test was performed by continuously sending data for one hour, during which no anomalies or connection failures were observed. The average update latency in the database was less than one second, meeting the requirements for real-time monitoring.



(a)



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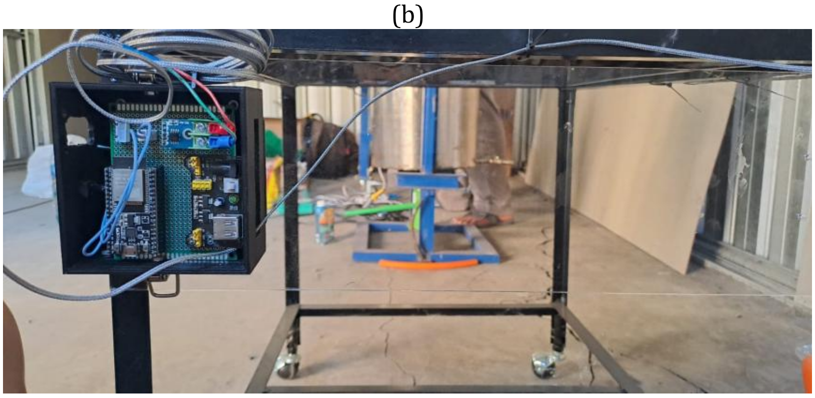
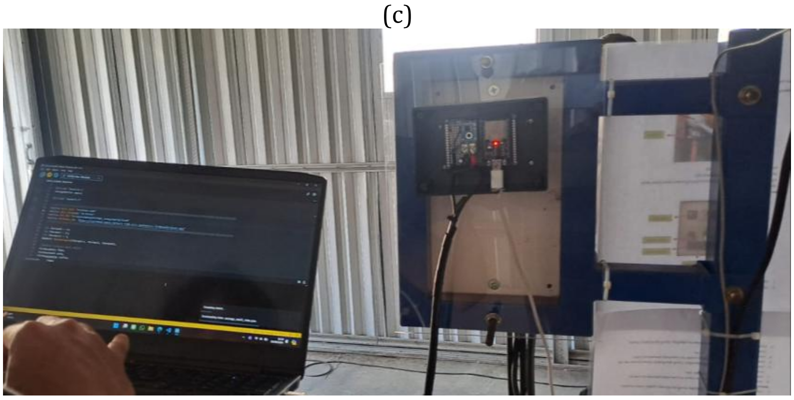


(c)



(d)

Fig. 6. Monitoring system result; (a) web user interface, (b) web alert system, (c) device installation at drying oven, (d) device installation at extraction unit.

The web-based dashboard, hosted on Firebase, successfully displayed real-time updates of oven temperature and mixer speed readings in synchronization with sensor measurements (Fig. 6 (a)). Value changes were visible almost instantly, without the need for manual page refresh. The interface's minimalistic design allowed operators to interpret results easily, even without extensive technical background. Each sensor in every process has its own safety limit determined based on the processing stage. The alert system is designed as a popup window that will appear with a notification sound if any sensor exceeds the predetermined limits (Fig. 6 (b)). This system is expected to help operators become aware of errors, thus avoiding accidents.

During implementation at the carrageenan processing facility, all sensors and electronic modules were installed without requiring major modifications to the existing machinery, seen in Fig. 6 (c, d). The oven temperature sensor was mounted through a drilled opening in the oven wall, with the electronic module positioned externally to prevent component degradation from heat exposure. The current sensor was installed non-invasively on the extraction machine's electrical panel, ensuring that the original functionality was unaffected.

5 Conclusion

The IoT monitoring system developed in this study performed successfully during both laboratory and on-site testing at the carrageenan facility. The system proved capable of accurately collecting data from temperature and current sensors and transmitting it to a cloud database in real-time with minimal delay. The web-based interface provided a clear and automatically updating display of key operational data, such as temperature and RPM. Easy to install and stable during 24-hour continuous operation, the system significantly improved the production process by enabling remote monitoring, allowing for early detection of anomalies, and enhancing overall quality control and operational efficiency.

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