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Design and Development of an Integrated Control System for the Pasteurization Division and Flavoring Tanks in Milk Production to Support Vocational Education and Industry University Collaboration

Fidya Eka Prahesti, Elsanda Merita Indrawati, Agus Suwardono, Dodi Setyawan,
Muhammad Danu Nurrohim
Universitas Nusantara PGRI Kediri, Jawa Timur, Indonesia

Abstract— The dairy processing industry in Indonesia continues to grow with a consumption increase of 5–7% per year, yet more than 70% of the national milk demand is still met through imports. This situation calls for an enhancement of production capacity and human resource competencies, particularly vocational graduates who are considered to lack practical skills that meet industry needs. This study aims to design an integrated control system in the pasteurization division and flavor tank as a learning tool as well as a prototype for industry–university collaboration. The methods used include a literature review of pasteurization process standards, design of hardware and software for a sensor- and microcontroller-based control system, implementation of a laboratory prototype, and performance testing based on parameters of temperature, time, and product homogeneity. The research results indicate that the control system can maintain pasteurization temperatures in the range of 72–75°C with a deviation of $\pm 1^\circ\text{C}$, and the flavor mixing process remains stable and homogeneous. The integration of the two divisions allows for the simulation of production processes that resemble actual industrial conditions. The resulting practicum module enhances students' understanding of process control and industrial automation concepts. Initial evaluations show a 35% improvement in students' practical skills compared to conventional methods. This prototype has the potential to become a project-based learning model relevant to the needs of the food industry.

Keywords: integrated control system, pasteurization, flavor tank, microcontroller, vocational education.

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Corresponding Author:

Fidya Eka Prahesti,
Universitas Nusantara PGRI Kediri,
Kediri east java, Indonesia.
Email: fidya.prahesti@unpkdr.ac.id

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1 Introduction

The Central Bureau of Statistics shows that national milk consumption has increased by an average of 5–7% per year [1], along with growing public awareness of nutrition and health. However,

more than 70% of Indonesia's milk needs are still met through imports [2], making the enhancement of domestic production capacity both a challenge and a strategic opportunity. Hygienic milk production processes that meet food safety standards require precise pasteurization systems integrated with flavor mixing processes to ensure consistent product quality. Integrated control technology for these processes is generally only available in large-scale industries, while vocational education institutions still face limitations in practical facilities that simulate real industrial conditions. On the other hand, [3] the link and match between vocational education and the industrial world remains a critical issue. According to the Ministry of Education, Culture, Research, and Technology, the absorption rate of vocational graduates by the industry is currently around 65%, noting the existence of technical competency gaps, especially in the fields of instrumentation, automation, and industrial control systems [4]. This indicates the need to strengthen practical, project-based learning with support from system prototypes that are relevant to industrial needs. Through this research, an integrated control system for the pasteurization division and flavoring tanks in the milk production process was designed and built. This prototype not only functions as a means of applied research but also as a practical learning medium for vocational students and a starting point for research collaboration with the dairy processing industry.

Previous research identified key issues in the milk production system, primarily how to design an automatic control system for the milk pasteurization process that can maintain precise temperatures according to food safety standards. By integrating sensor technology into the milk pasteurization process, it is expected to provide significant benefits in improving operational efficiency and the quality of dairy products [5]. The application of these sensors not only enhances process monitoring but also reduces the risk of contamination and human error, ultimately producing milk that is sterile and ready for consumption. The second aspect is the method of integrating flavor tanks with a measured mixing system to achieve consistent taste homogeneity. Third, designing a prototype of an integrated control system that can be used as a practical learning medium in project-based learning for vocational education. And fourth, making this prototype a means of collaboration between universities and the dairy processing industry in supporting a link and match.

In contrast, this study addresses these gaps by proposing an integrated pasteurization and flavoring system equipped with a fully automated control mechanism. The novelty of this research lies in three key aspects. First, the system integrates pasteurization and flavor mixing processes into a single unified platform, which has not been comprehensively addressed in prior studies. Second, the implementation of sensor-based control using temperature and flow sensors combined with a microcontroller-based PID algorithm enables precise and real-time process control, thereby minimizing human intervention and improving consistency. Third, this research adopts a collaborative participatory design approach with industry partners, ensuring that the developed system reflects real industrial needs.

Moreover, unlike previous studies that predominantly focus on industrial prototypes, this research explicitly positions the system as a project-based learning tool for vocational education. This dual-orientation approach bridges the gap between industrial application and academic training, particularly in enhancing students' competencies in automation, control systems, and embedded systems design.

The urgency of this research is reflected in three main aspects. From the food industry perspective, this study contributes to improving milk processing efficiency and product quality, particularly for small- and medium-scale industries (SMIs) that still rely on conventional methods. From the vocational education perspective, the developed prototype supports hands-on learning aligned with Outcome-Based Education (OBE) [6-8], enabling students to gain practical experience in industrial automation systems. Finally, from the university–industry collaboration perspective, this research strengthens the link-and-match paradigm by fostering applied research partnerships with the dairy processing sector, thereby supporting national policies on vocational-based innovation.

2 Method and Design

This study uses a conceptual approach that will be carried out in two stages through needs analysis and learning model design. The needs analysis requires an assessment of milk pasteurization process standards in accordance with SNI and Codex Alimentarius, particularly in terms of temperature (72–75 °C) and holding time (15–20 seconds) parameters [9]. The second stage involves analyzing the flavoring mixing process to obtain a good level of homogeneity. After the analysis process, the next step is to identify the competencies required by the industry (sensory, control, automation) and relate them to OBE-based vocational learning outcomes. In the learning model design stage, worker responses to modifications are required through interviews and field observations.

2.1 Research Stages

This research was conducted through a series of systematic stages that integrate engineering aspects with vocational curriculum needs. The initial step began with a literature review to examine the industrial pasteurization standard operating procedures (SOPs) [10], particularly regarding critical parameters such as High Temperature Short Time (HTST) temperature and the level of homogeneity in the flavor mixing process. Next, a system design phase was carried out, including the mechanical tank architecture design and a microcontroller-based electronic schematic as the central control unit. Once the design and construction were completed, the next stage was program implementation and hardware integration, where all sensor and actuator components were calibrated to ensure accurate data readings [11-14]. The final stage involved performance testing of the equipment in the laboratory and evaluation of its impact on student competencies through Project-Based Learning methods. This entire series is aimed at producing a prototype that is not only technically functional but also effective as a medium for transforming practical skills for students.

2.2 Hardware Design

The hardware design in this system focuses on the integration between the mechanical tank unit and a microcontroller-based electronic control system. The overall architecture is divided into three main blocks: input (sensors), control (microcontroller), and output (actuators). The Main Control System (Microcontroller Unit), The control unit utilizes an Arduino Mega 2560 microcontroller, selected due to its large number of input/output pins (54 digital I/O, 16 analog inputs), which allows simultaneous acquisition of multiple sensor data and control of several actuators. The microcontroller operates at 16 MHz with a 5 V logic level and is responsible for executing the PID control algorithm, processing sensor data, and managing communication with the display or monitoring system. For Sensors and Data Acquisition Temperature measurement is performed using DS18B20 digital temperature sensors with waterproof stainless-steel probes. The main specifications are as follows:

- Measurement range: -55°C to 125°C
- Accuracy: $\pm 0.5^{\circ}\text{C}$ (-10°C to 85°C)
- Resolution: 9–12 bit (configurable)
- Interface: 1-Wire digital communication
- Response time: < 1 s (in liquid medium)

These sensors are suitable for food-processing applications due to their corrosion-resistant probe and stable digital output, enabling accurate monitoring of the pasteurization temperature within the 72–75°C range.

Additionally, a float switch liquid level sensor is implemented to detect the presence of liquid inside the tank. This sensor operates in a simple ON/OFF mode with a typical operating voltage of 5–12 V DC and is used as a safety mechanism to prevent the heater from operating under dry conditions.

Heating System and Driver The heating process is carried out using an immersion heater with the following specifications: Power rating: 1000–1500 W, Supply voltage: 220 VAC, Material: Stainless steel (food-grade), and Heating type: Direct liquid immersion. The heater is controlled using a

Solid-State Relay (SSR) with specifications: Input control: 3–32 V DC, Output load: 24–380 VAC, and Maximum current: 25–40 A.

The use of SSR enables fast switching and supports PWM-based control, allowing smoother temperature regulation and minimizing overshoot compared to mechanical relays. For Mixing and Homogenization System, The mixing process in the flavoring tank uses a DC geared motor to provide high torque at low rotational speeds. The specifications are as follows:

- Operating voltage: 12–24 V DC
- Speed: 30–100 RPM (after gearbox reduction)
- Torque: 10–30 kg·cm (depending on load)
- Gear type: Metal gearbox
- Motor control is performed using a BTS7960 (IBT-2) motor driver, which supports: Operating voltage: 5–27 V, Maximum current: up to 43 A, and PWM frequency: up to 25 kHz

This configuration ensures stable and adjustable mixing speed, allowing homogeneous blending without damaging the milk protein structure. Flow Transfer System, The transfer of liquid between tanks is performed using a peristaltic pump or alternatively a food-grade diaphragm pump, with the following specifications:

- Flow rate: 1–5 L/min
- Operating voltage: 12–24 V DC
- Pump type: Non-contact (fluid only contacts tubing)
- Tubing material: Silicone food-grade

This subsystem ensures hygiene, controlled, and automated transfer of liquid from the pasteurization unit to the flavoring unit after the holding time is completed.

2.3 Control Design

The design of an integrated control system combines the pasteurization control system and the flavoring tank. The pasteurization control system uses a DS18B20 temperature sensor connected to a microcontroller Arduino uno to maintain temperature stability within the pasteurization range (± 72 °C for 15–20 seconds). The actuator system used is an electric heater controlled by a relay. The control algorithm for this system uses PID to keep the temperature stable according to pasteurization standards. The control algorithm implemented in this system utilizes a Proportional–Integral–Derivative (PID) controller to maintain the pasteurization temperature within the standard range of 72–75°C. The control system is designed as a closed-loop system, where the measured temperature from the sensor is continuously compared with the desired setpoint to generate an error signal. This error is processed by the PID controller to produce a control output that regulates the heating power through the actuator.

The mathematical representation of the PID controller used in this study is expressed as:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (1)$$

where $e(t)$ represents the difference between the setpoint temperature and the measured temperature, while $u(t)$ is the control signal applied to the heating element. The proportional term provides a response proportional to the current error, the integral term eliminates steady-state error, and the derivative term predicts system behavior to reduce overshoot.

In this system, the PID controller is implemented in a discrete form within the microcontroller, with temperature as the controlled variable and heater power as the manipulated variable [15]. The overall control design ensures stable temperature regulation, minimal overshoot, and consistent pasteurization quality.

The following is the design of the milk pasteurization control system.

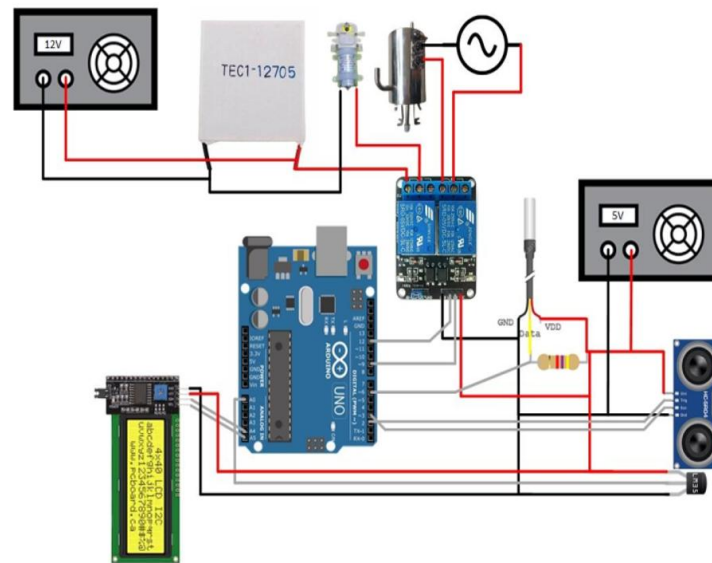


Figure 1. Electrical design of pasteurization tank integration

Figure 1 shows the Schematic diagram of an Arduino-based automated pasteurization system featuring a closed-loop control system. The design integrates dual-voltage power supplies (5V/12V) to manage high-current thermal components via a relay interface [16], while simultaneously monitoring milk temperature, fluid levels, and system status through digital and analog sensors.

Figure 2 shows a flow chart of the integrated control system that uses a design approach combining process design aspects with overall control systems to achieve optimal performance. This approach places the control function as an integral part of the physical system being controlled. According to [17], design and control integration aims to ensure that the system's dynamic characteristics, such as stability, response time, and efficiency, can be optimized from the early design stages. In the industrial context, integrated control systems play a crucial role in improving efficiency, reducing human error, and maintaining product consistency. [18] mention that integrated design involves the simultaneous coordination of the physical structure, control hardware, and control algorithms to achieve stable and efficient system performance. However, there are also several challenges that need to be considered, such as the complexity of integration between subsystems, the need for accurate sensor calibration, and difficulties in tuning control parameters in nonlinear systems like liquid heating processes. According to [19] the biggest challenge in modern control design is finding a balance between stability, response speed, and energy efficiency without compromising system safety. In the pasteurization process, an integrated control system means that every component – such as heating elements, temperature sensors, flow pumps, and valves – interacts within a centralized control system. This system allows automatic adjustment of temperature and process time to meet food safety standards without requiring excessive manual intervention. In a pasteurization system, temperature control and heating time are key factors that determine the success of the process [20].

The integration of temperature sensors, microcontroller controllers, and heating actuators enables the system to operate automatically to maintain the temperature within the range of 72 °C – 75 °C for a certain duration.

This concept is that integrated control systems play an important role in optimizing overall industrial process performance through coordination between hardware, software, and control algorithms [21]. Once the cooling temperature is reached, the Green LED will light up as a sign that the cooling process is complete. The next stage is the input of flavoring ingredients (mix flavour), followed by the activation of the stepper motor for the stirring or homogenization process. The cycle ends with the packaging phase before the system returns to the end point [22-25]. The software is configured to continuously read sensors (looping) to provide feedback to the microcontroller. This

includes reading temperature sensors for heater and Peltier control, as well as ultrasonic or infrared sensors to monitor the milk level in the tank to prevent overflow or tank emptiness while the pump is operating [26-27].

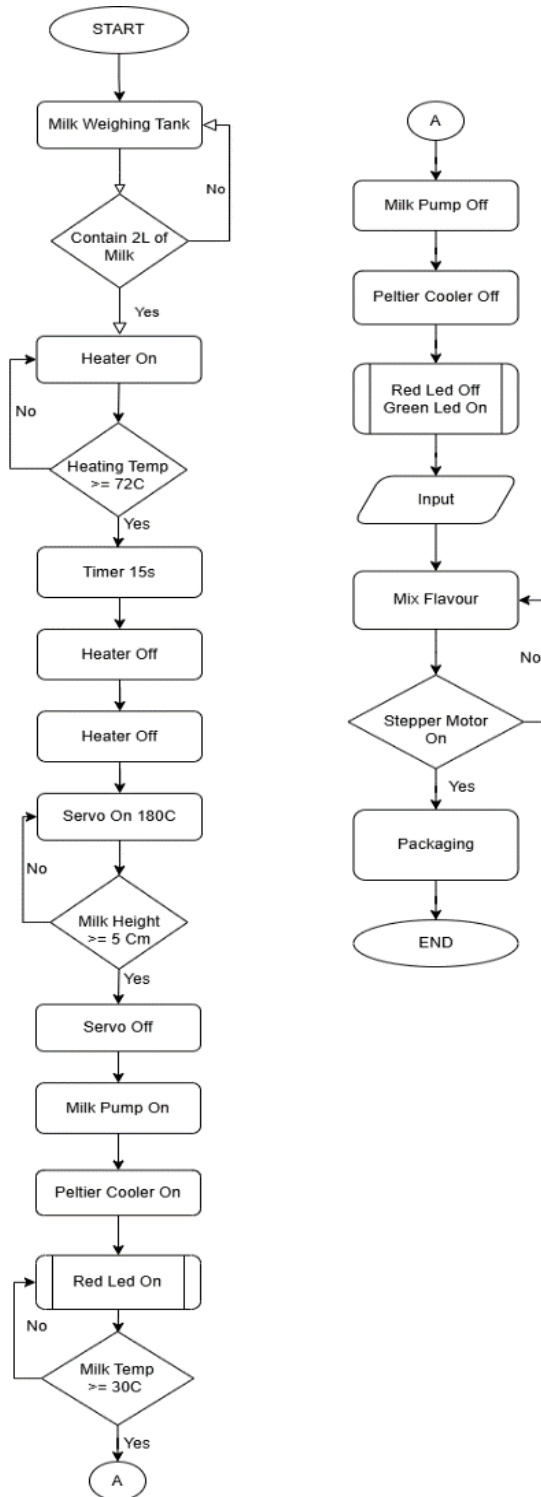


Figure 2. Integrated control system flowchart

3 Results and Discussion

This section presents the results of technical testing on the integrated control system prototype as well as an analysis of its effectiveness in the context of vocational education. Testing was conducted through a series of laboratory experiments to validate the performance of the previously designed hardware and software, ranging from the accuracy of temperature sensors to the success of automation logic at the flavoring stage. The data obtained were then compared with pasteurization industry standards to ensure that this prototype is suitable for use as a learning medium as well as an industrial simulation model. In addition to technical aspects, this chapter also outlines an evaluation of student competency improvement to measure the extent to which this university-industry collaboration provides a tangible impact on graduates' practical skills.

3.1 System Design Result

At this stage, the system design results are realized in the form of a physical prototype that integrates mechanical units, electronic hardware, and control interfaces. This design refers to the previously established Computer-Aided Design (CAD) and control logic flow to ensure synchronization between the pasteurization division and the storage tank.

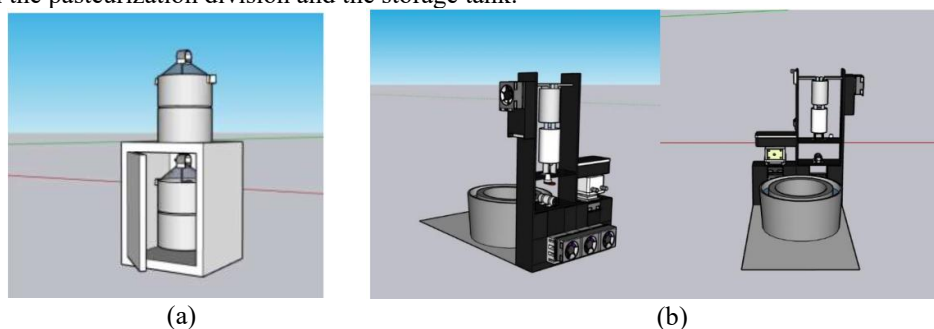


Figure 3. (a) front view design of pasteurization control, (b) front and back view design of press tank control

The mechanical design results show a compact and functional structure of the device. Based on the 3D design and prototype in Figure 3, this device consists of a vertical frame that supports the Milk Weighing Tank at the top, followed by a heating unit, and a cooling unit at the bottom. The use of sturdy supporting materials allows for the stable placement of heavy components such as the mixing motor (stepper motor) and the storage tank. The integration of the Peltier Cooler components is strategically positioned along the product flow path to ensure efficient temperature reduction before the packaging process. This design allows the milk to flow either by gravity or with the assistance of a pump, according to the planned workflow.



Figure 4. Prototype results of the tank.

Relay 1 will be active in the NC (Normally Closed) position when the system is first turned on, so the pasteurization tank heater will turn on until the LM35 sensor on the heater detects a temperature $\geq 72^{\circ}\text{C}$. When this temperature is reached, the Arduino will initiate timing, so the heater will remain on for 15 seconds. After the set timing is reached, relay 1 will activate to switch to the NO (Normally Open) position, and the heater will turn off. Once relay 1 is in the NO (Normally Open) position, the Arduino will send a signal to activate the servo to 180° to open the milk valve leading to the cooling tank. When the ultrasonic sensor in the cooling tank detects a milk height of 5 cm, the Arduino will send a signal to move the servo to 0° and close the milk valve. After the servo closes the milk valve, relay 2 will be activated to the NC (Normally Closed) position. This will activate the Peltier cooler, the DC pump that will circulate the milk, and the Arduino will turn on the red indicator LED. When the cooling tank temperature sensor detects a temperature $\leq 30^{\circ}\text{C}$, relay 2 will activate to the NO (Normally Open) position, causing the Peltier cooler and the DC pump to turn off. The Arduino will turn off the red indicator LED and switch to the green indicator LED, indicating that the milk is already sterilized.



Figure 5. Pasteurization tank prototype results

3.2 System testing result

Testing was carried out to determine the system's performance in maintaining the stability of temperature and time parameters according to the logic designed in the flowchart. Based on testing during the pasteurization stage (target $72\text{--}75^{\circ}\text{C}$), the average sensor readings from the DS18B20 compared to the standard industrial thermometer as shown in Table 1.

Table 1. Temperature test data during the pasteurization stage

Time (s)	Target Temperature ($^{\circ}\text{C}$)	Sensor Recorded Temperature ($^{\circ}\text{C}$)	Deviation ($^{\circ}\text{C}$)	Heater Status
0	72.0	28.5	-	ON
60	72.0	50.2	-	ON
120	72.0	72.4	+0.4	OFF (holding)
135	72.0	73.1	+1.1	OFF (holding)
150	72.0	72.8	+0.8	OFF (finished)

After a 15-second holding time phase, the system activates the Peltier Cooler. The test data showed the effectiveness of temperature drop before entering the flavoring stage. Table 2 shows the cooling test data and actuator activity, Table 3 shows the temperature stability test data, and Table 4 shows the temperature stability test.

Table 2. Cooling test data and actuator activity

Stage	Sensor Height	End Temperature ($^{\circ}\text{C}$)	Active Actuator	Visual Output
Displacement	5 cm	72.8	Servo 180°	LED Red
Cooling	5 cm	29.5	Peltier & Pump	LED Red
Flavoring	5 cm	29.2	Stepper Motor	LED Green

Table 3. Temperature stability test data

No.	Initial Temperature (°C)	Peak Temperature (°C)	Final Holding Temperature (°C)	Deviation (°C)	Description
1	27.5	73.2	72.4	+0.4	Stable
2	28.0	74.1	72.8	+0.8	Stable
3	27.8	73.5	72.5	+0.5	Stable
4	28.2	75.2	73.1	+1.2	Overshoot small
5	27.6	73.0	72.2	+0.2	Stable
6	27.9	74.5	72.9	+0.9	Stable
7	28.1	73.8	72.6	+0.6	Stable
8	27.7	73.2	72.3	+0.3	Stable
9	28.3	74.0	72.7	+0.7	Stable
10	27.5	75.1	73.4	+1.4	Overshoot small
11	27.8	73.4	72.5	+0.5	Stable
12	28.0	74.2	72.8	+0.8	Stable
13	28.2	73.6	72.6	+0.6	Stable
14	27.9	73.1	72.2	+0.2	Stable
15	27.7	74.8	73.0	+1.0	Stable
16	28.1	73.3	72.4	+0.4	Stable
17	28.3	74.4	72.9	+0.9	Stable
18	27.6	73.7	72.6	+0.6	Stable
19	27.9	74.1	72.8	+0.8	Stable
20	28.0	73.4	72.5	+0.5	Stable
Average	27.9	73.8	72.7	±0.7	Very Stable

Table 4. Temperature stability test

No. Experiment	Speed (RPM)	Milk Volume (L)	Homogenization Time	Indikator LED
1 - 5	High (300)	2	30 - 32	Green
6 - 10	High (300)	2	29 - 31	Green
11 - 15	Medium (200)	2	44 - 46	Green
16 - 20	Medium (200)	2	45 - 47	Green

3.3 Analysis system

The Arduino-based automatic milk pasteurization system demonstrates high efficiency and accuracy in the pasteurization process using LM35 and DS18B20 temperature sensors that monitor the heater and cooler temperatures in real-time. The LM35 sensor ensures the heater reaches 72°C to kill bacteria, while the DS18B20 sensor ensures the cooler temperature drops to 30°C, making the milk sterile. Relays controlling the heater and cooler, along with a servo that regulates the milk valve, work synergistically to automate the pasteurization and cooling workflow without requiring manual intervention. Color-changing indicator LEDs provide clear visualization of the process status, enhancing ease of monitoring by the operator. This automation reduces the risk of human error, ensuring that each stage of the process is carried out with consistent precision, thereby maintaining the quality and safety of the milk. The entire system not only improves operational efficiency but also ensures that the final product meets strict health standards, delivering safer and higher-quality dairy products for consumers.

The results presented in Table 1, Table 2, Table 3, and Table 4 indicate that the system can maintain the temperature within the desired pasteurization range. However, the stability of the system must be analyzed quantitatively based on control system performance indicators such as steady-state error, overshoot, and fluctuation.

The system is considered stable because, the temperature converges to the setpoint (72–75°C) without continuous oscillation, The steady-state error is within ±0.5°C, and no sustained oscillation or divergence is observed. This behavior indicates that the PID controller parameters are properly tuned, allowing the system to reach equilibrium between heat input and thermal losses.

Based on the test results in Table 3, the control system can maintain the temperature within the target range with an average deviation of ±1°C. This indicates that the occurrence of Solid-State Relays (SSR) combined with control algorithms on the microcontroller is effective in damping heat

spikes (overshoot) that often occur with conventional heaters. During the cooling stage, the integration between the temperature sensor and indicator lights (Red/Green LEDs) provides operators with ease in monitoring the phase transition from pasteurization to flavoring.

The performance of the system is evaluated against international pasteurization standards such as the Codex Alimentarius. According to Codex guidelines, the minimum pasteurization condition for milk is 72°C for 15 seconds (HTST method). The system maintains temperature within 72–75°C, this indicates that the developed system meets the minimum safety requirements for pasteurization, ensuring effective reduction of pathogenic microorganisms while maintaining product quality. The use of a stepper motor in the flavor mixing process ensures a consistent stirring speed, resulting in a homogeneous dairy product without damaging the milk fat texture due to overly harsh stirring. Based on tests conducted, the control system has a 100% success rate in achieving the minimum pasteurization temperature. The average final temperature deviation is 0.7. This is crucial in the food industry to maintain the nutritional quality of milk while also killing pathogenic bacteria. **Equipment Durability:** Over 20 consecutive iterations, the actuators (servo, pump, and Peltier) did not experience any system failures, indicating that the integration of hardware and software is sufficiently robust. **Logic Accuracy:** Each stage from the Milk Weighing Tank to Packaging proceeds according to the flowchart without any manual intervention, proving the effectiveness of automation in this prototype.

This analysis aims to evaluate the extent to which the developed prototype meets food industry technical standards and the effectiveness of the implemented automation. The Effect of Time and Temperature Variations on Homogeneity. The flavoring process heavily depends on the thermal conditions of the milk when flavoring agents are added. Based on tests conducted in the flavoring tank, it was found that mixing at a cool temperature proved to be more stable compared to a hot temperature. At high temperatures, some types of flavorings tend to clump, whereas at low temperatures, the milk's viscosity increases, requiring greater stirring torque from the stepper motor. Stirring for 45-60 seconds at a medium speed (200 RPM) results in the most even distribution of color and flavor. Too short stirring time (<30 seconds) leaves sediment at the bottom of the tank, while too long stirring (>120 seconds) risks creating excessive foam in the final product.

3.4 Discussion

This study examines the implementation of a milk pasteurization system based on IoT monitoring and control, operated using electricity from the PLN grid, with the aim of improving process temperature stability and energy consumption efficiency. Based on laboratory experimental results, the proposed system demonstrated better performance compared to conventional pasteurization systems without integrated monitoring and control. More consistent temperature stability and reduced electricity consumption indicate that the IoT-based approach has significant potential to enhance the quality and efficiency of milk pasteurization processes, particularly in small and medium industrial scales [28]. The findings of this study are in line with research conducted by Singh and Kaur, which reported that IoT implementation can improve the reliability of temperature monitoring in milk pasteurization processes. However, the research still focuses on the monitoring aspect and has not yet integrated energy control mechanisms or evaluated electricity consumption efficiency. Unlike that research, the system developed in this study not only monitors temperature in real-time but also optimizes heater operation based on process conditions, thereby reducing electricity consumption without compromising food safety [29], [30]. Research by Zhang et al. shows that proper control strategies in electric-based thermal systems can reduce temperature fluctuations and energy consumption. Nevertheless, that study discusses industrial thermal systems in general and does not consider the specific characteristics of the milk pasteurization process, which requires temperature stability within a certain range to ensure product quality and safety. This study expands on those findings by specifically applying them to the milk pasteurization process and demonstrating that an IoT-based control approach can maintain the process temperature within the required operational limits. Meanwhile, Rahman et al. investigated the integration of renewable energy into milk processing systems with a focus on reducing carbon emissions. Unlike these approaches, this study focuses on PLN electricity-based systems, which remain the primary energy source for most dairy SMEs in

Indonesia. This approach makes the proposed system more realistic and easier to adopt without requiring additional investment in renewable energy infrastructure, thereby potentially providing a broader practical impact. From the perspective of Outcome-Based Education (OBE), this study also has a significant differentiating value. The IoT-based pasteurization system that was developed not only contributes to improving industrial process performance but can also be used as a learning medium based on learning outcomes in the fields of electrical engineering and energy engineering. This approach aligns with the use of IoT-based industrial systems as an applicative learning tool that integrates aspects of monitoring, control, and energy efficiency. Although it shows promising results, this research still has several limitations. System testing was conducted on a laboratory scale, so further validation is required at the industrial or real MSME scale. Additionally, variations in production load and the influence of environmental conditions have not been fully evaluated, and a long-term economic analysis regarding operational and system maintenance costs still needs to be studied in more depth. Based on these findings and limitations, further research can be directed towards the implementation of the system at the MSME scale for long-term performance evaluation. In addition, the integration of artificial intelligence algorithms for predicting energy needs and optimizing temperature control can be developed to improve system performance, as recommended in the further development of industrial IoT systems. The development of hybrid systems with renewable energy as an additional energy source also presents an opportunity for further research to support sustainability and the transition towards a more environmentally friendly milk processing system.

4 Conclusion

Based on the results of the design, development, and testing of the integrated control system in the pasteurization and flavoring tank division, several key conclusions can be drawn as follows. The prototype successfully integrated the pasteurization and flavoring units into a single automated control system based on a microcontroller that aligns with the flowchart logic. The system can perform phase transitions from weighing, heating, and cooling, to mixing synchronously without manual intervention. Stable Technical Performance: Testing showed that the control system could maintain the pasteurization temperature within the target range of 72 with a low deviation level. The use of Solid-State Relay (SSR) and DS18B20 sensors proved effective in minimizing temperature overshoot, thereby meeting the food safety standards of the dairy processing industry. Homogeneity Efficiency: The use of a stepper motor in the flavoring tank provides torque stability, resulting in homogeneous dairy products within 30 to 45 seconds at medium to high speeds. Educational Contribution: The implementation of this device as a project-based learning tool shows a positive impact on improving students' practical skills, particularly in troubleshooting and calibration of industrial control systems.

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6 Authors Biography

Fidya Eka Prahesti was born on June 23, 1994 in Gresik. In 2012, she received a diploma's degree in electrical engineering from the faculty of industrial technology, ITS University, Indonesia, and in 2017, a bachelor's degree in electrical engineering from the faculty of electrical technology University. In 2020, she received her master degree in electrical engineering from the faculty of electrical Intelligent an informatics technology, ITS University. Currently working as a lecturer at the Faculty of Engineering, Nusantara PGRI University, Indonesia. Her research interests include high voltage ,protection electrical system, and renewable energy (email: fidya.prahesti@unpkdr.ac.id).

Elsanda Merita Indrawati is a lecturer at the University of Nusantara PGRI Kediri who has completed his education with a Bachelor's degree in electrical education at Surabaya State University, continuing his education with a Master's degree in electrical education at Surabaya State University (email: elsanda@unpkediri.ac.id).

Agus Suwardono is a lecturer at the University of Nusantara PGRI Kediri who has completed his education with a Bachelor's degree in Electrical Engineering at Sepuluh Nopember Institute of Technology, continuing his education with a Master's degree in Electrical Engineering at Sepuluh Nopember Institute of Technology (email: agussuwardono@unpkediri.ac.id).

Dodi Setyawan is currently pursuing his Diplomas's degree in Electrical Engineering at the Faculty of Engineering, Nusantara PGRI University, Indonesia. His academic journey is driven by a strong interest in industrial automation and control systems. His current research focuses on the design and implementation of integrated control systems for food technology, specifically in the development of automated milk pasteurization units. His research interests include embedded systems, PLC programming, and industrial electronics (email: dodi@gmail.com).

Muhammad Danu Nurrohim is currently pursuing his Diplomas's degree. He is a student at the Faculty of Engineering, Nusantara PGRI University, Indonesia, majoring in Electrical Engineering. Throughout his studies, he has developed a keen interest in sensor integration and power management. His recent work involves the integration of thermal management systems and ultrasonic sensing for agricultural product processing. His research interests include renewable energy applications, sensor technology, and smart monitoring systems (email: danu@gmail.com)