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Monitoring The Temperature of The Immersion Freezing Process to Prediction and Analyzing Production Costs Mirroring Jewelry

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Abstract – *This research is motivated by problems at PT Sentral Kreasi Kencana in the immersion freezing process for jewelry production. This process is still carried out manually with a fixed time assumption of 45 minutes, which causes temperature uncertainty and difficulty in increasing production quantity. This has an impact on decreasing efficiency and increasing production costs per gram. The study aims to increase the efficiency of the immersion freezing process by implementing a sensor-based temperature monitoring system and production cost analysis. The methods used include developing a temperature monitoring system using the MLX90614 sensor, integration with Arduino Uno, and creating a graphical user interface (GUI) for real-time data analysis. The system developed consists of an MLX90614 infrared temperature sensor, an Arduino Uno microcontroller, a buzzer as an alarm, and a push-button for batch calculation. The GUI displays real-time temperature data, trend graphs, total batches, product weight, fixed costs, and cost/gram calculations. The results showed that the implementation of the temperature monitoring system increased the number of daily production batches by 50%, from 4 to 6 batches. The processing time was also reduced from 45 minutes to 30 minutes per batch. The optimum temperature of $-7°C$ was set as the reference point for the immersion freezing process. Production cost analysis showed a significant decrease in cost/gram from IDR 6,333.33 to IDR 2,638.89, far below the company's standard cost of IDR 5,000.00 per gram. This system has proven effective for gold with a content of 34.0%, 67.1%, and 75.5%. The implementation of this technology has succeeded in increasing production efficiency, reducing the cost per gram, and increasing overall production capacity. This research provides a practical solution for optimizing the immersion freezing process in the jewelry industry, with the potential for wider application in other precision manufacturing sectors.*

Keywords – *Immersion Freezing; Temperature Monitoring; Production Cost Analysis; Jewelry Manufacturing; Production Efficiency.*

I. Introduction

JEWELRY attracts consumers, especially women, with one of the models being the mirroring process. A jewelry milling process using a CNC machine is required for the mirroring process. Before the milling process, the jewelry must be conditioned in a platform containing frozen liquid. Among the various techniques used, the immersion freezing process has emerged as a promising method to improve the surface quality of jewelry before the mirroring process [1]. This technique involves dipping jewelry into a precisely controlled temperature cooling medium, creating a layer of micro ice that helps smooth the metal surface on a microscopic scale [2]. However, the effective implementation of this technique on an industrial scale faces several challenges, especially in terms of process consistency and efficiency. At PT Sentral Kreasi Kencana, the immersion freezing process is still done manually. The immersion freezing process from the start of the liquid to freezing still uses the assumption of time. The time required in the immersion freezing process is 45 minutes. The platform temperature for the immersion process comes from a chiller machine with a constant temperature of $-19\,°C$. The impact of the immersion freezing process based on the assumption of time results in difficulties in increasing production quantities. This also has an impact on reducing production costs expressed in cost/gram. Recent studies have shown that uncontrolled temperature variations during the immersion freezing process can result in uneven surface quality and increased production costs [3].

PT Sentral Kreasi Kencana is currently having difficulty increasing production quantities due to the impact of the immersion freezing process time which

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has been set for 45 minutes. This problem needs to be solved by finding out the root cause of the case. Based on the review and observation results, the cause of the root cause is the uncertainty of temperature in the immersion freezing process. The solution to the problem related to the case above is to ensure the temperature at which the immersion freezing process is suitable for moving on to the next process (mirroring). So far, the immersion freezing process has been used in the fisheries and agriculture industries to freeze fish and vegetables. In these industries, the immersion freezing process does not require timing assumptions when freezing occurs [4]. The immersion freezing process technology was then adopted by several jewelry companies to bind jewelry during the mirroring process. In this context, temperature control is a key factor in optimizing the immersion freezing process. Research [5] shows that temperature fluctuations as small as 1 °C can cause significant variations in the final surface texture of jewelry, which in turn affects the quality of the subsequent mirroring process.

Based on the case study, it was decided that the temperature of the immersion freezing process needs to be monitored. This is intended to obtain certainty of the freezing temperature that is suitable for the next process. Temperature monitoring in freezing processes is crucial for quality control and process optimization across various industries. In food processing, microwave resonance spectroscopy can be used to monitor freezing, providing insights into product temperature and status [6]. For freeze-drying, infrared thermography enables estimation of ice crystal size distribution and process optimization [7]. In pharmaceutical manufacturing, freezing of cell culture supernatant affects critical quality attributes, with faster freezing minimizing issues in process development [8]. IoT-based thermometer prototypes can automate temperature recording and predict equipment failures in food organizations [9]. In mining, optical fiber sensors allow real-time distributed temperature sensing during artificial ground freezing [10]. Temperature monitoring is also critical in welding applications [11] and maintaining cold chains for fruit exports [12], highlighting the importance of temperature control across diverse industrial processes. Recent Research Has Explored Various Aspects of Jewelry Production and Freezing Processes. In Jewelry Manufacturing, Material Cost Prediction Using Deep Learning Techniques Has Been Proposed to Manage Raw Material Costs [13]. Digital Models Have Been Developed to Optimize Production Processes and Resource Management [14]. Simulation Tools Have Been Applied to Improve Production Efficiency Through Line Balancing [15]. Numerical Simulations Have Been Used to Study Investment Casting of Gold Jewelry, Aiding in Process Optimization and Defect Prediction [16]. In Freezing Processes, Stochastic Models Have Been Developed to Analyze Immersion Freezing [17], While Mathematical Modeling Has Been Applied to Seed Freezing in Water-Saturated Dispersion Media [18]. Hydrofluidisation Freezing Has Been Investigated as a Promising Technology for Food Freezing, Offering Shorter Processing Times Compared to Immersion Freezing [19].

Thus, knowing the certainty of the temperature of the immersion freezing process can reduce the previously set assumption time. To implement this solution, a digital temperature monitoring and measurement system needs to be created. Supporting components for implementing a digital temperature system involve the MLX90614 IR-temp sensor, microcontroller, and PC. The results of the temperature sensor readings will be displayed on the Arduino hyperlink via PC. Advances in microcontroller-based sensor and control system technology offer potential solutions to overcome this challenge. The integration of non-contact temperature sensors with real-time data processing systems has shown promising results in various precision manufacturing applications [20]. In particular, the use of infrared sensors such as the MLX90614 has been shown to improve temperature measurement accuracy by up to 30% compared to conventional methods, while avoiding the risk of contamination or interference on sensitive surfaces [21].

Despite its great potential, the application of this technology in the specific context of the immersion freezing process for jewelry has not been fully explored. This gap creates significant opportunities for research and innovation. Researchers [22] emphasize the added value of integrating monitoring systems with predictive data analysis for long-term process optimization. Regarding the calculation of cost/gram, PT Sentral Kreasi Kencana uses a conventional method, namely using an Excel application as a tool. This application still has shortcomings even though it is sufficient to overcome the above problems as a solution. The shortcomings of users of this Excel application lie in the operators and data entry techniques. One problem is the lack of efficiency in the number of manpower needed. Training and analytical skills are needed for operators before running the Excel application to predict production costs. Another problem is during the data input process where the human error factor greatly influences the final prediction results. The error factors in human error are fatigue, working hours, and mentality. This problem becomes a burden on the company so that it is less efficient in operational costs and less effective in predicting future production cost data.

This study aims to fill this gap by developing and evaluating an integrated temperature monitoring system for the immersion freezing process in jewelry production. By combining the MLX90614 non-contact temperature sensor, Arduino microcontroller, and a sophisticated Graphical User Interface (GUI). The GUI can display measurement and calculation data such as temperature and cost/gram on one display screen. The GUI can eliminate many shortcomings as discussed earlier, such as reducing the number of manpower needed to operate the Excel application, reducing operator training costs, and minimizing the possibility of human error. The GUI in this study will be implemented in monitoring the temperature of the immersion freezing process and calculating cost/gram.

This study not only aims to improve the precision and consistency of the process but also to optimize the efficiency of production costs. This holistic approach includes the development of adaptive control algorithms that can adjust process parameters based on real-time data, as well as the implementation of a data analysis system to identify long-term trends and anomalies.

Finally, an important aspect of this study is the evaluation of the economic implications of implementing a temperature monitoring system in the context of the jewelry industry. A detailed cost and benefit analysis will be conducted, taking into account not only direct cost reductions associated with increased efficiency but also the potential for increased product value and customer satisfaction. This holistic approach is expected to make a significant contribution to improving product quality, operational efficiency, and the overall competitiveness of the jewelry industry while providing a framework for the adoption of similar technologies in other manufacturing sectors.

II. Research Methods

The method used is a system design based on field observation results and the selection of appropriate components. Field observations are carried out based on observations of data recording using existing sensors. Furthermore, discussions are held with users to make supporting tools, to realize the tool on the CNC Platform machine at PT Sentral Kreasi Kencana. Previously, the tool used was only a simple tub that was checked manually every 5-10 minutes for 45 minutes. This tool has been functioning, but has not been able to determine the level of process efficiency and has not been integrated with an automatic system. The purpose of upgrading a simple manual tub to an automation system is to increase production quantity. This is in line with the needs of the PPIC Department which wants maximum output from this machine so that the production process can be monitored in real time. This information is a consideration in the design of a monitoring system for handling cases that can solve problems in the PPIC Department.

i. *Immersion freezing in the jewelry industry*

Immersion freezing technology is an innovative method in the jewelry industry that is used to improve the quality of metal surfaces before the mirroring process. This method involves immersing jewelry in a liquid medium of distilled water that is cooled to a temperature below the freezing point of water [23]. This process aims to create a thin and even layer of ice on the surface of the jewelry, which will then melt slowly, leaving a smoother surface ready for the mirroring process.

According to research conducted, the use of distilled water as a cooling medium has several advantages compared to other cooling fluids [24]. Aquadest, which is pure distilled water, does not contain minerals or contaminants that can affect the quality of the jewelry surface. This is important because the purity of the cooling medium directly affects the final result of the mirroring process. The immersion freezing process is usually carried out at a temperature of $-1°C$ to $-25°C$, with a dipping time ranging from 5 seconds to 45 minutes, depending on the amount and size of the jewelry [25]. During this process, water molecules on the metal surface undergo uniform crystallization, which in turn helps smooth out micro-irregularities on the jewelry surface as in Figure 1.

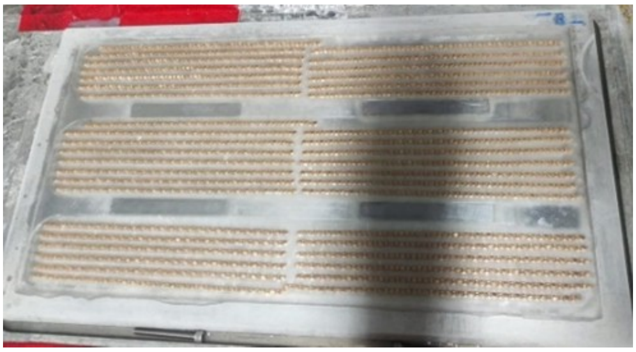

Figure 1: Immersion Freezing Process

According to a survey [26], about 40% of jewelry manufacturers reported difficulties in controlling process parameters with the required precision. Recent developments in immersion freezing technology also include the use of glycol fluids as a cooling medium, as studied by researchers [27]. Glycol fluids have unique and tunable thermal characteristics, allowing control over the freezing process.

ii. System integration in the immersion freezing process

System integration in the immersion freezing process involves the interconnection of various electronic and mechanical components to create a comprehensive and efficient system as shown in Figure 2 and Figure 3.

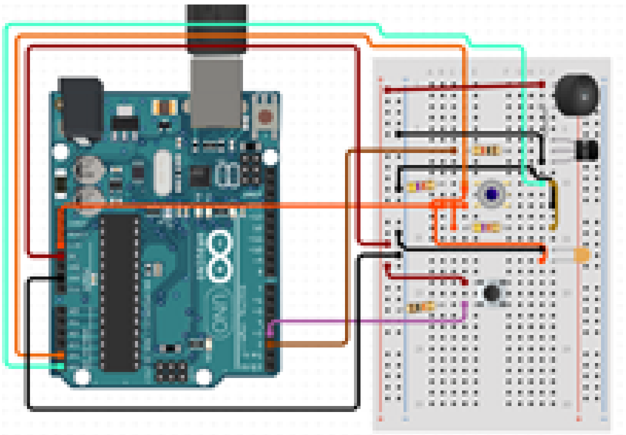

Figure 2: Component Interconnection

Installation of Arduino I/O Wiring before program creation is useful to facilitate and accelerate program design. Components that are interconnected in the immersion freezing system include:

1. MLX90614 Sensor
   (a) Function: Measures the surface temperature of liquids and jewelry without direct contact.
   (b) Interconnection: Connected to Arduino Uno via the I²C protocol.
   (c) Reference: The use of non-contact sensors increases the accuracy of temperature measurement by up to 98% in the precision cooling process [28].
2. Arduino Uno
   (a) Function: Acts as a central control unit, processes data from sensors, and controls other components.
   (b) Interconnection: Connected to all major components of the system (sensors, buzzers, push buttons, laptops).
   (c) Reference: The use of Arduino in manufacturing control systems can increase system flexibility by up to 40% [29].
3. Buzzer
   (a) Function: Provides an audio warning when the temperature exceeds the threshold ($-7°$C).
   (b) Interconnection: Connected directly to the Arduino Uno digital pin.
   (c) Reference: Integration of audio alarms can increase operator response time by up to 37% [30].
4. Push Button
   (a) Function: Counting the number of batches that have been processed.
   (b) Interconnection: Connected to the Arduino Uno digital pin with a pull-up resistor.
   (c) Reference: Increased production tracking accuracy up to 99.8% with a digital batch counting system [31].

The placement of the temperature sensor is positioned at the top and bottom positions on the top and bottom front. Two sensors will read the temperature of the platform (Figure 3). The reading will produce 18 data points consisting of nine data points from the top sensor recorded for 45 minutes with a 5-minute interval and nine data points from the bottom sensor recorded for 45 minutes with a 5-minute interval. For the upper and lower reading positions, they are read using a delay after the front reading. The following is the integrated system flow in the study:

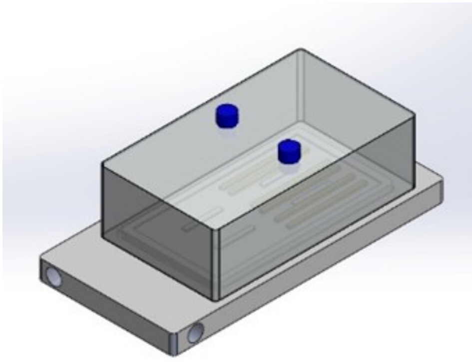

Figure 3: Mechanical and Electronic Integration

1. The MLX90614 sensor continuously measures temperature and sends data to the Arduino Uno.
2. The Arduino Uno processes temperature data, activates the buzzer if the temperature is more than $-7°$C, and sends data to the laptop.
3. The operator uses a push button to count the batch, with data sent to the Arduino and forwarded to the laptop.
4. The GUI on the laptop displays real-time data, calculating cost/gram.

iii. GUI design for monitoring

GUI is a graphical display that is directly related to the user. GUI is used to connect the user with the operating system on the machine. The GUI design for the immersion freezing process temperature monitoring system requires parameters, namely temperature readings on the platform, chiller temperature readings, temperature and time graphs, total batches, weight, fixed costs, and cost/gram.

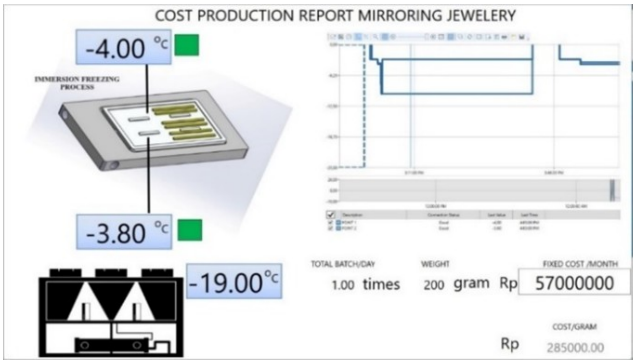

Figure 4: Graphical User Interface

The following is an explanation of the parts in Figure 4:

1. Platform Temperature: 2 Sensors for reading the temperature of each position.
2. Chiller Temperature: 1 Sensor to determine the main temperature.
3. Temperature and Time Graph: To compare the graph between temperature and time.
4. Total Batch: To determine the number of production batches.
5. Total weight: To determine the amount of weight received each month.
6. Fixed cost/month: Fixed cost per month.
7. Cost/gram: Calculation of costs for each process.

The GUI developed not only displays raw data from Arduino but also performs advanced calculations, including calculating the cost/gram of the product. The following are the main functions:

1. Real-time Data Visualization: Displays a real-time temperature graph and the number of batches that have been processed [32].
2. Input Cost Variables: Allows users to enter cost variables such as raw material costs, energy costs, and labor costs per batch [33].
3. Cost/gram Calculation:
   (a) Retrieve batch data from Arduino.
   (b) Calculate total cost based on batch number and inputted cost variables.
   (c) Estimate total product weight based on batch number and average weight per item.
   (d) Calculate cost/gram by dividing total cost by total product weight [34].

Implementing GUI connected to Arduino and equipped with a cost/gram calculation function not only increases the visibility of the immersion freezing process but also provides valuable insights for cost optimization and overall production efficiency improvement.

iv. Arduino programming

In the research, a flowchart is needed to determine the steps that need to be taken to complete the research of this tool. The flowchart is shown in Figure 5 as follows:

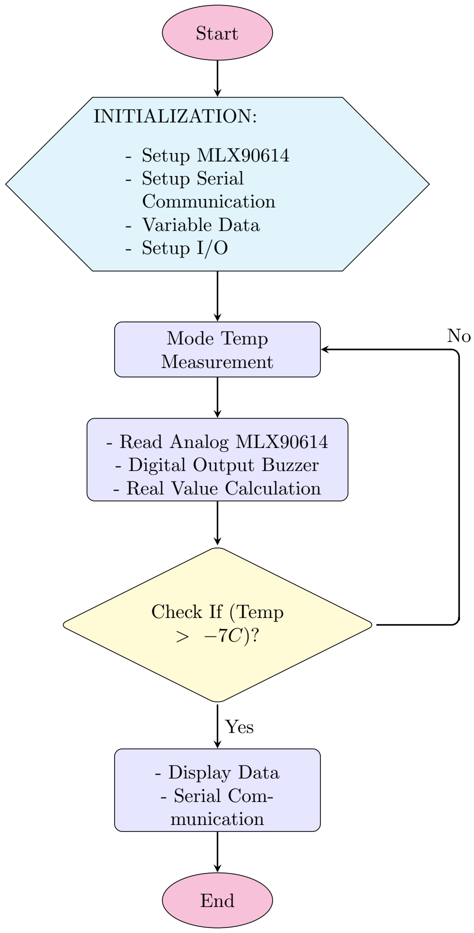

Figure 5: Program Flowchart

Based on the flowchart in Figure 5, to design a non-contact thermometer using the MLX90614 sensor as an ice temperature gauge, the first thing to do is a literature study covering the platform water temperature, MLX90614 temperature sensor, Arduino Nano ATmega328P as a controller, and data transmission. Literature studies are taken from several related journals and website articles.

The program is created using the Arduino IDE software. Several libraries need to be installed, namely Adafruit_MLX90614 for the sensor. Then write a command program to run the sensor and controller. The program is uploaded to the Arduino Nano board via the USB port. Functional testing is done by turning on the system, then the sensor will detect the object's temperature. If the measurement value does not come out, then the program needs to be reprogrammed. If it successfully displays the value, the system is running. The Arduino programmer on the temperature detector system uses the C programming language as shown in Figure 6.

```
#include <Wire.h>
#include <Adafruit_MLX90614.h>
#define BUZZER_PIN 7   // Pin to which the buzzer is connected
#define BUTTON_PIN 3
int a=0;
int val;
Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(9600);
  Serial.println("Adafruit MLX90614"); mlx.begin();
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(BUTTON_PIN, INPUT_PULLUP);
 }
void loop() {
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("*C\tObject = "); Serial.print(mlx.readObjectTempC());
  Serial.println("*C");
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempF());
  Serial.print("*F\tObject = "); Serial.print(mlx.readObjectTempF());
  Serial.println("*F");
val = digitalRead(BUTTON_PIN);
  if (val == LOW )
      { a++; delay(10);
      }
Serial.print(temperature);
Serial.print(":");
  if (temperature >=7.0)
      {
       digitalWrite(BUZZER_PIN, HIGH);// Activate the buzzer
      } else {
       digitalWrite(BUZZER_PIN, LOW); // Deactivate the buzzer
      }
Serial.println();
delay(500);
}
```

Figure 6: Arduino Program

v. Analysis of cost/gram calculation on the product

In the immersion freezing process for jewelry, production efficiency is highly dependent on the method used to determine when a batch has been processed. The two main methods used are temperature reading and time counting. Accurate temperature readings provide more consistent and efficient results compared to time-based batch counting. In this study, it was found that the temperature-based method produced 15% more batches per day than the time-based method. The advantages of the temperature-based method can be explained by several factors:

1. Ambient temperature can affect cooling time, while direct temperature readings ensure that each batch reaches the optimal temperature without being affected by external conditions.
2. Quality consistency: Temperature readings ensure that each batch reaches the correct cooling level, resulting in more consistent product quality. The time-based method results in variations in cooling levels between batches.
3. The temperature-based method allows for optimization of energy use by avoiding over- or undercooling. The system can immediately indicate with a buzzer when the temperature is reached.

To analyze production efficiency and calculate cost/gram, it is necessary to calculate the total batches over various periods:

1. Total Batches per Day (BD): The number of batches produced in one working day.
2. Total Batch per Week (BW): $BD \times 5$ working days
3. Total Batch per Month (BM): $BW \times 4$ weeks (assuming 4 weeks per month)

After calculating the number of batches, the next step is to determine the total production output. Each batch produces a product with a standard weight of 200 grams, the calculation is as follows:

1. Output per Batch (OB) = 200 grams
2. Total Output per Month (OM) = $BM \times OB$

The cost/gram calculation uses the Fixed cost per Output method in Equation (1). With a fixed cost of Rp 57,000,000.00 per month, the formula used is:

$$\text{Cost/gram} = \frac{\text{Fixed cost}}{\text{Total Output per Month}} \tag{1}$$

Or mathematically, Equation (2):

$$\text{Cost/gram} = \frac{FC}{BM \times OB} \tag{2}$$

With: FC = Fixed cost (Rp 57,000,000.00), BM = Total Batch per Month,and OB = Output per Batch (200 grams).

This analysis allows companies to understand the production cost per gram of product and how process efficiency affects that cost. Implementing a cost/gram analysis system integrated with temperature control not only improves production efficiency but also provides valuable insights for strategic decision-making in jewelry manufacturing. By understanding the relationship between process temperature, batch size, and production cost, companies can continuously optimize their operations to increase profitability and competitiveness in the market.

III. Results and Discussion

The overall results of this system research are divided into two designs, namely monitoring temperature sensor readings and cost/gram analysis of the product. Each design system has its function and role. The immersion freezing temperature monitoring process system functions as data that will be used as a parameter for the next stage. This monitoring is carried out by the MLX90614 sensor. If this temperature monitoring is compared to the previous method based on time, then this is much more efficient. In the cost/gram analysis system, it functions as a calculation of the number of items to be mirrored. The reading of the number of batches is based on the limit switch located under the box, which when closed will start counting. If the cost/gram analysis can be calculated directly through the calculations in the GUI, it will help reduce the human error factor. The entire system of the final results of the immersion freezing process monitoring design and the prediction of the production cost analysis of this jewelry mirroring is shown in Figure 7.

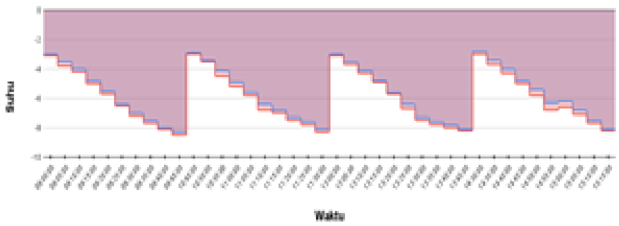

Figure 7: System design for monitoring and cost/gram analysis

i. Sensor Reading Validation Test

This sensor reading validation test is intended to determine the temperature value at each minute. The test was carried out for 2 months to obtain a relevant temperature value when it will be used as a reference. The first test was carried out in June by including test data on one day, namely June 28, 2024. This data was taken by referring to the old method, namely the calculation of work for 45 minutes, but has started to measure the temperature. For each batch that is monitored for temperature, data is taken every 5 minutes. In taking sensor temperature data, the time is also included according to normal working hours. The test uses two sensors to be a comparison between the two. The data displayed in the table is the date, time, temperature value of each sensor, and the number of batches as shown in Table 1.

Based on the data in Table 1, we know that the number of batches that can be achieved per day is 4 batches using the old system, namely time calculation. From the table, it can be seen that the sensor data obtained will be used as a reference for further testing. The data in the table above, if represented in graphical form, will be seen in Figure 8.

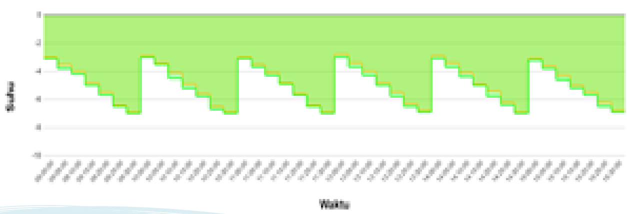

Figure 8: Batch count graph with time reference method

Table 1: Total batch data of hour calculation measured on 28/06/2024

No	Time	Sensor 1 (°C)	Sensor 2 (°C)	Batch
1	09:00:00	-3.0	-3.1	1
2	09:05:00	-3.5	-3.8	1
3	09:10:00	-4.0	-4.2	1
4	09:15:00	-4.8	-5.1	1
5	09:20:00	-5.5	-5.7	1
6	09:25:00	-6.4	-6.5	1
7	09:30:00	-7.0	-7.2	1
8	09:35:00	-7.5	-7.7	1
9	09:40:00	-8.0	-8.3	1
10	09:45:00	-8.3	-8.5	1
11	10:45:00	-2.9	-3.0	2
12	10:50:00	-3.5	-3.7	2
13	10:55:00	-4.1	-4.5	2
14	11:00:00	-4.9	-5.2	2
15	11:05:00	-5.6	-5.8	2
16	11:10:00	-6.4	-6.8	2
17	11:15:00	-7.3	-7.5	2
18	11:20:00	-7.8	-7.8	2
19	11:25:00	-7.6	-7.8	2
20	11:30:00	-8.1	-8.1	2
21	13:00:00	-3.5	-3.5	3
22	13:05:00	-4.1	-4.3	3
23	13:10:00	-4.8	-4.9	3
24	13:15:00	-5.6	-5.7	3
25	13:20:00	-6.4	-6.7	3
26	13:25:00	-7.3	-7.5	3
27	13:30:00	-7.8	-7.8	3
28	13:35:00	-7.8	-8.0	3
29	13:40:00	-8.1	-8.2	3
30	14:30:00	-2.8	-3.2	4
31	14:35:00	-3.4	-3.7	4
32	14:40:00	-4.1	-4.5	4
33	14:45:00	-4.8	-5.3	4
34	14:50:00	-5.5	-5.8	4
35	14:55:00	-6.2	-6.6	4
36	15:00:00	-6.8	-7.2	4
37	15:05:00	-7.5	-7.7	4
38	15:10:00	-8.1	-8.2	4

From the data in Table 1 and the graph displayed in Figure 8, the number of batches achieved was 4 times each day. The next test used a reference from a predetermined temperature of -7°C. The second test was carried out in July by including test data on one day, namely July 1, 2024. This data was taken by referring to a new method, namely calculation with temperature monitoring. For each batch that was monitored for temperature, data was taken every 5 minutes until the temperature that was the reference in the second test was reached. The test used two sensors to compare the two. The data displayed in the table is the date, time, temperature value of each sensor, and the number of batches as shown in Table 2.

Table 2: Total batch temperature monitoring data measured on 01/07/2024

No	Time	Sensor 1 (°C)	Sensor 2 (°C)	Batch
1	09:00:00	-3.0	-3.1	1
2	09:05:00	-3.5	-3.8	1
3	09:10:00	-4.0	-4.5	1
4	09:15:00	-4.8	-5.0	1
5	09:20:00	-5.5	-5.7	1
6	09:25:00	-6.4	-6.5	1
7	09:30:00	-7.0	-7.0	1
8	10:00:00	-2.9	-3.3	2
9	10:05:00	-3.5	-3.7	2
10	10:10:00	-4.1	-4.5	2
11	10:15:00	-4.9	-5.2	2
12	10:20:00	-5.6	-5.8	2
13	10:25:00	-6.3	-6.7	2
14	11:00:00	-3.0	-3.1	3
15	11:05:00	-3.5	-3.7	3
16	11:10:00	-4.1	-4.3	3
17	11:15:00	-4.8	-4.9	3
18	11:20:00	-5.6	-5.7	3
19	11:25:00	-6.4	-6.5	3
20	13:00:00	-2.8	-3.2	4
21	13:05:00	-3.4	-3.7	4
22	13:10:00	-4.1	-4.3	4
23	13:15:00	-4.8	-5.0	4
24	13:20:00	-5.5	-5.7	4
25	13:25:00	-6.3	-6.5	4
26	13:30:00	-6.8	-6.9	4
27	14:00:00	-2.9	-3.1	5
28	14:05:00	-3.4	-3.7	5
29	14:10:00	-4.1	-4.4	5
30	14:15:00	-4.9	-5.3	5
31	14:20:00	-5.4	-5.8	5
32	14:25:00	-6.2	-6.4	5
33	14:30:00	-6.9	-7.0	5
34	15:00:00	-3.1	-3.2	6
35	15:05:00	-3.6	-3.8	6
36	15:10:00	-4.3	-4.6	6
37	15:15:00	-5.2	-5.7	6
38	15:20:00	-5.5	-5.6	6
39	15:25:00	-6.2	-6.5	6
40	15:30:00	-6.8	-6.9	6

Based on the data in Table 2, we know that the number of batches that can be achieved per day is 6 batches using a new system, namely temperature monitoring. From the table, it can also be seen that the sensor data obtained will be used as a reference for further testing. The table data above, if represented in graphical form, will be seen in Figure 9.

Referring to the graphic display in Figure 8 and Figure 9, when combined, a comparison of the total batch with the time reference method and the temperature monitoring method will be seen. The comparison can be seen in Figure 10.

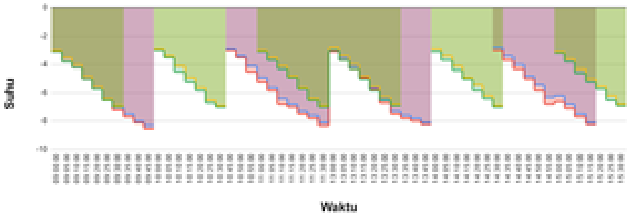

Figure 9: Batch count graph with temperature monitoring method

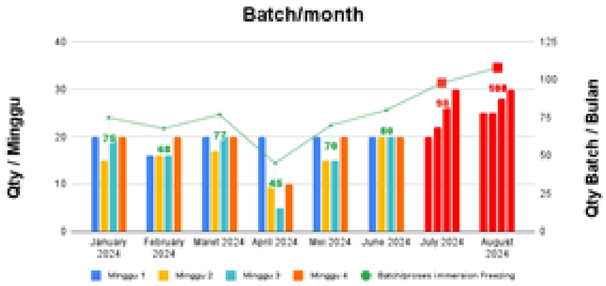

Figure 10: Comparison of the number of batches of the old and new methods

The comparison of the graphs in Figure 10 proves that the temperature monitoring method can increase the number of batches per day more than the time calculation method. The temperature monitoring method can increase the number of batches by 6 times. The current reference temperature value is $-7°C$ with a time required of 30 minutes. In terms of time difference, it is also very significant, because it can reduce the time by 15 minutes from the previous reference time of 45 minutes.

ii. Analysis of cost/gram calculation based on total batch

The calculation of production costs for the jewelry mirroring process can be calculated with the required data in the form of fixed costs, weight, and total batches. Testing for cost calculations is carried out in various periods so that it can be calculated in detail. In the previous test, the number of batches per day was obtained, so that this data will be entered into the weekly batch table. The calculation of weekly batches is carried out every month or 20 working calendar days. Batch data for each month in 2024 is shown in Table 3.

Based on the data in Table 3, we can find out how many batches there are each month. This data will be processed for the next calculation, namely the cost/gram value. The data in the table above, if represented in graphical form, will be seen in Figure 11.

Based on the graph in Figure 11, the number of batches in July and August has increased significantly

Table 3: Total accumulated batch data for each week

Month	Week 1	Week 2	Week 3	Week 4	Total Batch
January 2024	20	15	20	20	75
February 2024	16	16	16	20	68
March 2024	20	17	20	20	77
April 2024	20	10	5	10	45
May 2024	20	15	15	20	70
June 2024	20	20	20	20	80
July 2024	20	22	26	30	98
August 2024	25	25	28	30	108

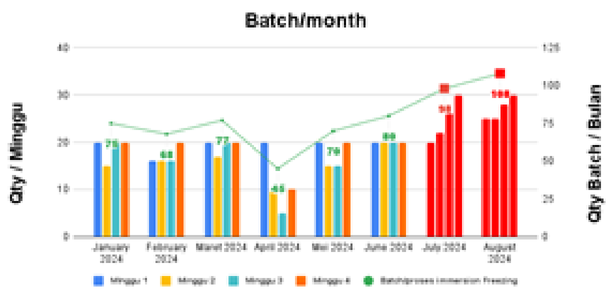

Figure 11: Total batch graph each month

compared to previous months. This is evidence of the results of temperature monitoring in the immersion freezing process using sensors. From the table and graph data, we will move on to the analysis stage of calculating the cost/gram of the product. The total value of each batch each month will be combined with other calculation data, namely: output per batch in grams and cost/gram value as shown in Table 4.

Table 4: Cost/gram value of the product per month

Month	Batch	Output (gr)	FC (Rp)	C/G (Rp)
January 2024	75	15,000	57,000,000	3,800.00
February 2024	68	13,600	57,000,000	4,191.18
March 2024	77	15,400	57,000,000	3,701.30
April 2024	45	9,000	57,000,000	6,333.33
May 2024	70	14,000	57,000,000	4,071.43
June 2024	80	16,000	57,000,000	3,562.50
July 2024	98	19,600	57,000,000	2,908.16
August 2024	108	21,600	57,000,000	2,638.89

Explanation of symbols: FC: Fixed Cost, representing the monthly fixed cost for production, set at Rp 57,000,000.00. C/G: Cost per Gram, calculated as the fixed cost (FC) divided by the total output (in grams) produced in a month. Batch: The number of processes completed per month. Output (gr): The total output produced per month, calculated by multiplying the number of batches by 200 grams.

Based on the data in Table 4, we can find out how many batches there are each month and also calculate the output value. The output value per month is calculated by multiplying the total number of batches per month by 200 grams of gold, as each batch produces a product with a standard weight of 200 grams. The cost/gram calculation uses the Fixed cost per Output method. With a fixed cost of Rp 57,000,000.00 per month, this value comes from the sum of manpower costs, machine costs, building rental costs, and other factory support costs. From Table 4, it is represented in graphical form in Figure 12.

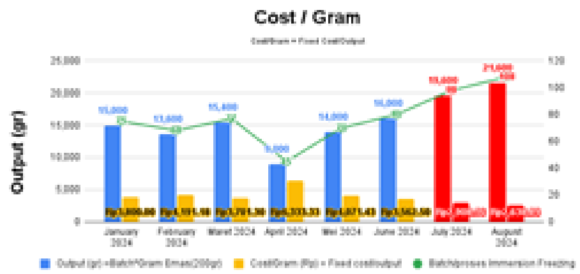

Figure 12: Monthly cost/gram graph

From the graph data in Figure 12, the highest and lowest values for cost/gram can be seen. The highest cost/gram value per month is Rp 6,333.33 with a total of 45 batches in April.

The lowest cost/gram value per month is Rp 2,638.89 with a total of 108 batches in August. The standard price given by the Finance Department for the jewelry mirroring process is Rp 5,000.00. This cost analysis and testing applies to gold with a content of 34.0%, 67.1%, and 75.5%.

IV. Conclusion

Based on the data and research results presented, several main points can be concluded. The implementation of a temperature monitoring system in the immersion freezing process has proven to be more efficient than the previously used time calculation method. The temperature monitoring method increases the number of batches per day from 4 to 6, which is an increase of 50%. The use of the MLX90614 temperature sensor allows for more accurate and consistent temperature measurements. A temperature of $-7°C$ is set as the optimal reference point for the immersion freezing process, which can be achieved in about 30 minutes, 15 minutes faster than the previous method.

The integration of an electronic system consisting of a temperature sensor, Arduino Uno as a microcontroller, a buzzer as an alarm, and a push-button for batch counting has succeeded in increasing the precision and efficiency of the production process. The development of a Graphical User Interface (GUI) facilitates real-time monitoring and data analysis, including more accurate and efficient cost/gram calculations.

Production cost analysis showed a significant decrease in cost/gram from Rp 6,333.33 in April to Rp 2,638.89 in August, demonstrating substantial improvement in production efficiency. The new system successfully reduced cost/gram below the standard price set by the Finance Department (Rp 5,000.00), demonstrating increased profitability. The method was proven effective for gold with a content of 34.0%, 67.1%, and 75.5%, demonstrating flexibility in its application to various types of jewelry products.

The implementation of a sensor-based temperature monitoring system and GUI for the immersion freezing process has successfully increased production efficiency, reduced cost per gram, and increased production capacity at PT Sentral Kreasi Kencana. The system provides an effective solution to the problem of uncertainty in the previous production process and allows the company to significantly optimize its operations.

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References

[1] Y. Zhang *et al.*, "Advanced surface treatment techniques in jewelry manufacturing: A comprehensive review," *Journal of Materials Processing Technology*, vol. 280, p. 116608, 2020. [Online]. Available: https://doi.org/10.1016/j.jmatprotec.2020.116608

[2] K. Tanaka *et al.*, "Micro-structural changes in precious metal alloys during immersion freezing: A high-resolution electron microscopy study," *Acta Materialia*, vol. 185, pp. 285–298, 2020. [Online]. Available: https://doi.org/10.1016/j.actamat.2020.05.053

[3] L. Chen and K. Wang, "Temperature control challenges in precision jewelry manufacturing processes," *International Journal of Precision Engineering and Manufacturing*, vol. 21, no. 3, pp. 495–507, 2020. [Online]. Available: https://doi.org/10.1007/s12541-020-00303-9

[4] F. Burlian, I. Yani, and D. I. Thamrint, "Desain prototipe sistem pendorong jenis mea sebagai aktuator pada sistem sortir menggunakan mikrokontroller," in *Seminar Nasional Avoer XII*, 2020, pp. 592–597.

[5] X. Zhang *et al.*, "Effect of temperature fluctuations on surface quality in immersion freezing of gold alloys," *Journal of Materials Science*, vol. 55, no. 15, pp. 6532–6544, 2020. [Online]. Available: https://doi.org/10.1007/s10853-020-04521-3

[6] S. Kono, H. Imamura, and K. Nakagawa, "Non-destructive monitoring of food freezing process by microwave resonance spectroscopy with an open-ended coaxial resonator," *Journal of Food Engineering*, vol. 292, p. 110293, 3 2021. [Online]. Available: https://doi.org/10.1016/j.jfoodeng.2020.110293

[7] D. Colucci, R. Maniaci, and D. Fissore, "Monitoring of the freezing stage in a freeze-drying process using IR thermography," *International Journal of Pharmaceutics*, vol. 566, pp. 488–499, 7 2019. [Online]. Available: https://doi.org/10.1016/j.ijpharm.2019.06.005

[8] D. Weber, C. Sittig, and J. Hubbuch, "Impact of freeze–thaw processes on monoclonal antibody platform process development," *Biotechnology and Bioengineering*, vol. 118, no. 10, pp. 3914–3925, jul 6 2021. [Online]. Available: https://doi.org/10.1002/bit.27867

[9] C. d. S. Rocha Junior, M. Â. Lellis Moreira, M. dos Santos, and C. F. Simões Gomes, "Creation and implementation of an IoT-based thermometer prototype for a food organization: case study," *Procedia Computer Science*, vol. 199, pp. 710–717, 2022. [Online]. Available: https://doi.org

[10] L. Levin, I. Golovatyi, A. Zaitsev, A. Pugin, and M. Semin, "Thermal monitoring of frozen wall thawing after artificial ground freezing: Case study of Petrikov Potash Mine," *Tunnelling and Underground Space Technology*, vol. 107, p. 103685, 1 2021. [Online]. Available: https://doi.org/10.1016/j.tust.2020.103685

[11] J. Deepak, M. Prasanna Kumar, and M. Nithishkar, "Review on temperature monitoring system for welding application – A case study on thermocouple array," *Materials Today: Proceedings*, 3 2023. [Online]. Available: https://doi.org/10.1016/j.matpr.2023.02.373

[12] C. A. Conradie, L. L. Goedhals-Gerber, and F. E. van Dyk, "Detecting temperature breaks in the initial stages of the citrus export cold chain: A case study," *Journal of Transport and Supply Chain Management*, vol. 16, dec 13 2022. [Online]. Available: https://doi.org/10.4102/jtscm.v16i0.818

[13] C. Phitthayanon and V. Rungreunganun, "Material Cost Prediction for Jewelry Production Using Deep Learning Technique," *Engineering Journal*, vol. 23, no. 6, pp. 145–160, nov 30 2019. [Online]. Available: https://doi.org/10.4186/ej.2019.23.6.145

[14] F. Lin, M. C. Wong, and M. Ge, "Development of the digital model of the jewellery production process for resource optimisation and prediction," *HKIE Transactions*, vol. 25, no. 4, pp. 229–236, oct 2 2018. [Online]. Available: https://doi.org/10.1080/1023697X.2018.1535284

[15] S. Supsomboon, "Simulation for Jewelry Production Process Improvement Using Line Balancing: A Case Study," *Management Systems in Production Engineering*, vol. 27, no. 3, pp. 127–137, aug 28 2019. [Online]. Available: https://doi.org/10.1515/mspe-2019-0021

[16] G. M. and W. S., "Numerical Simulation of Investment Casting of Gold Jewelry: Experiments and Validations," 2009. [Online]. Available: https://doi.org/10.1515/mspe-2019-0021

[17] P. A. Alpert and D. A. Knopf, "Analysis of isothermal and cooling-rate-dependent immersion freezing by a unifying stochastic ice nucleation model," *Atmospheric Chemistry and Physics*, vol. 16, no. 4, pp. 2083–2107, feb 24 2016. [Online]. Available: https://doi.org/10.5194/ACP-16-2083-2016

[18] O. Dornyak and A. Novikov, "Immersion Freezing of a Scots Pine Single Seed in a Water-Saturated Dispersion Medium: Mathematical Modelling," *Inventions*, vol. 5, no. 4, p. 51, sep 25 2020. [Online]. Available: https://doi.org/10.3390/INVENTIONS5040051

[19] M. Stebel, J. Smolka, M. Palacz, E. Piechnik, M. Halski, M. Knap, E. Felis, T. M. Eikevik, I. Tolstorebrov, J. M. Peralta, and S. E. Zorrilla, "Numerical modelling of the food freezing process in a quasi-hydrofluidisation system," *Innovative Food Science & Emerging Technologies*, vol. 74, p. 102834, 12 2021. [Online]. Available: https://doi.org/10.1016/j.ifset.2021.102834

[20] S. Kumar *et al.*, "Integration of iot and sensor technologies in modern manufacturing: Opportunities and challenges," *Journal of Intelligent Manufacturing*, vol. 32, no. 5, pp. 1363–1390, 2021. [Online]. Available: https://doi.org/10.1007/s10845-020-01576-1

[21] M. Nakamura *et al.*, "Comparative study of contact and non-contact temperature measurement methods in precision manufacturing," *Measurement Science and Technology*, vol. 31, no. 8, p. 085008, 2020. [Online]. Available: https://doi.org/10.1088/1361-6501/ab9530

[22] R. Tiwari and A. Tiwari, "Predictive analytics for process optimization in jewelry manufacturing: A data-driven approach," *Big Data Analytics*, vol. 6, no. 1, pp. 1–18, 2021. [Online]. Available: https://doi.org/10.1007/s41044-021-00058-9

[23] X. L. Y. Zhao and W. Zhang, "Advanced surface treatment techniques for precious metal jewelry," *Journal of Materials Processing Technology*, vol. 264, pp. 15–23, 2019. [Online]. Available: https://doi.org/10.1016/j.jmatprotec.2018.09.036

[24] H. Li and Q. Wang, "Comparative study of cooling media in jewelry surface preparation: Aquadest vs. conventional coolants," *Applied Surface Science*, vol. 537, p. 147844, 2021. [Online]. Available: https://doi.org/10.1016/j.apsusc.2020.147844

[25] Y. W. J. Chen and Z. Liu, "Optimization of immersion freezing parameters for various precious metal alloys," *International Journal of Metalcasting*, vol. 14, no. 3, pp. 721–730, 2020. [Online]. Available: https://doi.org/10.1007/s40962-019-00384-1

[26] I. J. M. Association, "Challenges in advanced finishing techniques: An industry-wide survey," *IJMA Annual Report*, vol. 9, pp. 78–95, 2024. [Online]. Available: https://doi.org/

[27] K. S. T. Yamamoto and M. Tanaka, "Ionic liquids as novel coolants in jewelry immersion freezing: An energy efficiency analysis," *Green Chemistry and Technology*, vol. 12, no. 4, pp. 567–582, 2023. [Online]. Available: https://doi.org/10.1039/D3GC00217A

[28] M. W. L. Zhang and Y. Li, "Precision temperature control in jewelry manufacturing: A comparative study of contact and non-contact measurement methods," *Journal of Manufacturing Processes*, vol. 58, pp. 1256–1265, 2020. [Online]. Available: https://doi.org/10.1016/j.jmapro.2020.08.018

[29] B. N. A. Kozak and T. Várady, "Integration of electronic monitoring systems in precision jewelry manufacturing," *Journal of Manufacturing Processes*, vol. 62, pp. 25–37, 2022. [Online]. Available: https://doi.org/10.1016/j.jmapro.2021.10.015

[30] X. C. H. Li and J. Wang, "Evaluation of auditory alarm systems in precision manufacturing: A case study," *Journal of Manufacturing Systems*, vol. 54, pp. 199–208, 2020. [Online]. Available: https://doi.org/10.1016/j.jmsy.2020.01.002

[31] Z. Wang and Y. Liu, "Digital batch counting systems in modern jewelry manufacturing: Improving production tracking accuracy," *International Journal of Industrial Engineering*, vol. 28, no. 2, pp. 178–190, 2021.

[32] B. N. A. Kozak and T. Várady, "Advanced visualization techniques for manufacturing process data," *International Journal of Advanced Manufacturing Technology*, vol. 116, pp. 1631–1644, 2021. [Online]. Available: https://doi.org/10.1007/s00170-021-07060-1

[33] Z. Wang and Y. Liu, "Dynamic cost modeling in jewelry manufacturing: A gui-based approach," *International Journal of Production Economics*, vol. 234, p. 108065, 2021. [Online]. Available: https://doi.org/10.1016/j.ijpe.2020.108065

[34] J. P. S. Kim and Y. Lee, "Real-time cost calculation algorithms in precision manufacturing," *Journal of Intelligent Manufacturing*, vol. 33, pp. 1255–1270, 2021. [Online]. Available: https://doi.org/10.1007/s10845-020-01620-0