International Journal Software Engineering and Computer Science (IJSECS)
6 (3), 2026, 1030-1038
Published Online December 2026 in IJSECS (http://www.journal.lembagakita.com/index.php/ijsecs)
P-ISSN: 2776-4869, E-ISSN: 2776-3242. DOI: https://doi.org/10.35870/ijsecs.v6i3.8245.

RESEARCH ARTICLE Open Access

Innovation in Smart Sensor Technology for Automated Palm Sugar Cooking Control to Improve Production and Sales at Harapan Palm Sugar Producers

Sudarmin [1], **Jhonson Efendi Hutagalung** [2*], **Santoso** [3]

[1,3] Department of Information Systems, Royal University, Asahan Regency, North Sumatra Province, Indonesia.
[2*] Department of Computer Systems, Royal University, Asahan Regency, North Sumatra Province, Indonesia.

Article History:

Received: July 29, 2026.
Revised: July 30, 2026.
Accepted: August 27, 2026.
Available online: September 20, 2026.
Published: December 1, 2026.

***Corresponding Author:**
jhonsonefendi75@gmail.com

Abstract: Palm sugar is an important natural sweetener produced by many small-scale home industries in Indonesia. However, conventional cooking processes rely heavily on manual observation, resulting in inconsistent temperature and viscosity control, inefficient energy utilization, and variations in product quality. This study aims to develop an Internet of Things (IoT)-based smart sensor system that integrates temperature and viscosity measurements for real-time monitoring and automatic control of the palm sugar cooking process. An applied experimental engineering approach was employed, consisting of requirement analysis, hardware and software development, sensor calibration, system integration, laboratory testing, and field evaluation at a partner home industry. The proposed system integrates a DS18B20 temperature sensor, viscosity sensor, ESP32 microcontroller, automatic heating controller, and web-based monitoring platform. Experimental results showed an average temperature measurement error of 0.26% and viscosity measurement error of 0.98%. The IoT communication system achieved a 99.2% successful data transmission rate with an average delay of 1.9 s. Compared with the conventional process, cooking time decreased from 122 to 101 min, fuel consumption decreased from 20 to 16 kg per production cycle, temperature stability increased from 72% to 96%, and defective products decreased from 12% to 3%. These results demonstrate that integrating temperature and viscosity sensing with automatic IoT-based control improves process stability, energy efficiency, and product consistency. However, the study was limited by single-site field validation and predefined control thresholds. Future research will focus on adaptive control using machine learning or fuzzy logic, multi-site validation, cloud analytics, and mobile notification features to improve system scalability and intelligence.

Keywords: Automatic Process Control; ESP32; Internet of Things (IoT); Palm Sugar; Smart Sensor.

1. Introduction

Palm sugar (*Arenga pinnata*) is an agro-industrial commodity with high economic value, produced primarily by smallholder rural enterprises across Southeast Asia. The manufacturing process centers on the thermal evaporation of fresh palm sap, where high water content is progressively removed until the sugars reach crystallization point (Hutami *et al.*, 2023; Nugroho & Madjid, 2025). Despite its economic importance, the sector remains dominated by traditional artisanal processing methods that suffer from low process predictability, high thermal losses, and inconsistent end-product quality (Purba *et al.*, 2021). In conventional processing facilities, sap boiling is conducted over open masonry hearths fueled by firewood, as illustrated in Figure 1. Thermal regulation and endpoint determination rely almost entirely on operator visual inspection and tactile estimation. This manual approach presents critical engineering limitations: excessive heat induces localized burning and Maillard caramelization defects, while inadequate boiling results in excessive residual moisture and premature product spoilage. Furthermore, reliance on firewood leads to substantial biomass consumption, uncontrolled heat transfer, and occupational exposure to hazardous wood smoke and thermal radiation (Hardianti & Idris, 2021; Ontowirjo, 2025).

Figure 1. Traditional palm sugar production using firewood in a home industry

The adoption of Internet of Things (IoT) architectures and embedded instrumentation offers an effective engineering pathway to modernize traditional agro-processing. By coupling physical immersion sensors with microcontroller nodes, critical processing variables—notably sap temperature and changing viscosity—can be continuously tracked (Gazis *et al.*, 2025; Puspitasari *et al.*, 2026). Automated actuator mechanisms, such as solenoid gas valves and industrial relays, enable precise closed-loop heat regulation, replacing open firewood combustion with regulated liquefied petroleum gas (LPG) burners equipped with hazard mitigation modules (Saparuddin *et al.*, 2022). In addition, integrated wireless communication links allow real-time operational telemetry to be transmitted to cloud dashboards, enabling remote batch supervision and automated record-keeping (Ananta, 2026; Anwar *et al.*, 2026; Siregar & Prayitno, 2023). Table 1 summarizes the operational comparison between conventional manual practices and the proposed IoT-based approach.

Table 1. Comparison Between Conventional and Proposed IoT-Based Cooking Process

Operational Parameter	Conventional Manual Method	Proposed IoT-Based System
Heat Source	Firewood (open hearth)	LPG burner with solenoid valve control
Temperature Regulation	Manual inspection (unstable)	Closed-loop relay actuation (95–110 °C)
Viscosity Detection	Visual/manual stirring estimate	Analog immersion viscosity sensor
Process Monitoring	Direct on-site physical presence	Real-time web-based IoT dashboard
Energy Efficiency	High fuel losses, uneven heating	Regulated gas flow, reduced heat waste
Product Consistency	High batch-to-batch variation	Standardized thermal and rheological profile

While earlier studies have explored individual facets of modernization—such as mechanical pans for stirring (Darmawan *et al.*, 2024; Kholis *et al.*, 2024), standalone DS18B20 thermal monitoring (Huda & Kurniawan, 2022), localized PLC installations (Sawidin *et al.*, 2023), and ancillary production infrastructure (Saputro *et al.*, 2026)—there is a distinct lack of affordable, integrated IoT solutions combining dual temperature-viscosity telemetry with automated closed-loop LPG regulation tailored for rural smallholder producers. To address this technological gap, this study develops, implements, and empirically validates an IoT-based smart sensor control system for the palm sugar cooking process. Utilizing an ESP32 microcontroller interfaced with a waterproof DS18B20 temperature probe, an immersion viscosity probe, and a closed-loop LPG relay actuator, the system stabilizes sap heating within the optimal 95–110 °C range and transmits live operational data to a supervisory web dashboard. The system's performance is quantitatively evaluated under real production conditions at a partner home industry in terms of thermal stability, operational duration, specific fuel consumption, and finished product quality.

2. Related Work

The palm sugar manufacturing process involves a critical thermal evaporation phase where continuous heat application reduces sap moisture and elevates soluble solid concentrations. In conventional operations, heat intensity and boiling duration are regulated purely through empirical operator judgment, which frequently leads to inconsistent end-product characteristics, high thermal loss, and inefficient fuel consumption. The implementation of Internet of Things (IoT) frameworks provides real-time telemetry and deterministic process control, enabling smallholder agro-industries to maintain standard operating conditions, stabilize evaporation rates, and minimize human error while supporting the digital modernization of traditional agro-food processing (Multani & Widodo, 2024; Nugroho & Madjid, 2025). Within such automated architectures, physical sensors form the primary data acquisition layer by continuously measuring operational process variables and translating physical phenomena into calibrated electrical signals for automated decision-making. Digital temperature sensors, particularly the DS18B20, provide high measurement accuracy and noise immunity across standardized communication buses, preventing localized scorching and product degradation. Concurrently, immersion viscosity sensors track changes in sap consistency during evaporation, providing an objective parameter to determine endpoint completion. By processing these dual sensory streams through an ESP32 microcontroller, the system can execute closed-loop heating actuation via relay modules while transmitting operational logs to a web supervisory dashboard (Ananta, 2026; Ontowirjo, 2025; Sawidin *et al.*, 2023). Previous investigations have explored various engineering interventions to modernize sugar manufacturing, yet significant operational gaps remain. Huda and Kurniawan (2022) demonstrated the operational reliability of the DS18B20 digital sensor for closed-loop thermal regulation, although their setup was limited strictly to temperature management without integration into comprehensive processing equipment. Sawidin *et al.* (2023) developed an automated palm sap processing system utilizing a programmable logic controller (PLC) and a local human-machine interface (HMI); however, the installation lacked wireless IoT telemetry, cloud-based data storage, and remote supervision capabilities. Furthermore, Darmawan *et al.* (2024) and Kholis *et al.* (2024) introduced mechanical improvements using motorized scraping pans to mitigate manual stirring fatigue, but the thermal supply remained entirely manual. In contrast to these isolated mechanical designs, localized controllers, or standalone temperature monitors, this study integrates digital temperature sensing and sap viscosity measurement into a unified ESP32 IoT node with closed-loop LPG relay actuation and real-time cloud data logging.

3. Methodology

3.1 Research Design

This study employs an applied experimental engineering approach focused on the design, implementation, and empirical validation of an Internet of Things (IoT)-based smart sensor system for regulating temperature and sap viscosity during palm sugar processing. The research framework was conducted across four sequential phases: (1) operational requirement analysis and architectural design, (2) hardware integration and embedded firmware development, (3) sensor calibration and laboratory bench testing, and (4) field deployment and comparative performance evaluation at a partner home industry. The comprehensive research workflow is illustrated in Figure 2. Operational parameters and technical limitations identified during baseline field observations of traditional open-hearth firewood processing were translated into system engineering specifications. The resulting system incorporates dual-input physical sensing (temperature and viscosity), deterministic rule-based relay actuation for liquefied petroleum gas (LPG) heating regulation, and continuous wireless telemetry linked to a supervisory cloud web dashboard. Following laboratory bench validation, the system was subjected to operational production trials to quantitatively compare its performance against the conventional manual method in terms of thermal stability, process duration, fuel consumption, and product consistency.

Figure 2. Research operational workflow and experimental stages

3.2 System Architecture and Hardware Development

The smart cooking platform is structured upon a four-layer IoT architecture comprising sensing, processing, communication, and application layers, as shown in Figure 3.

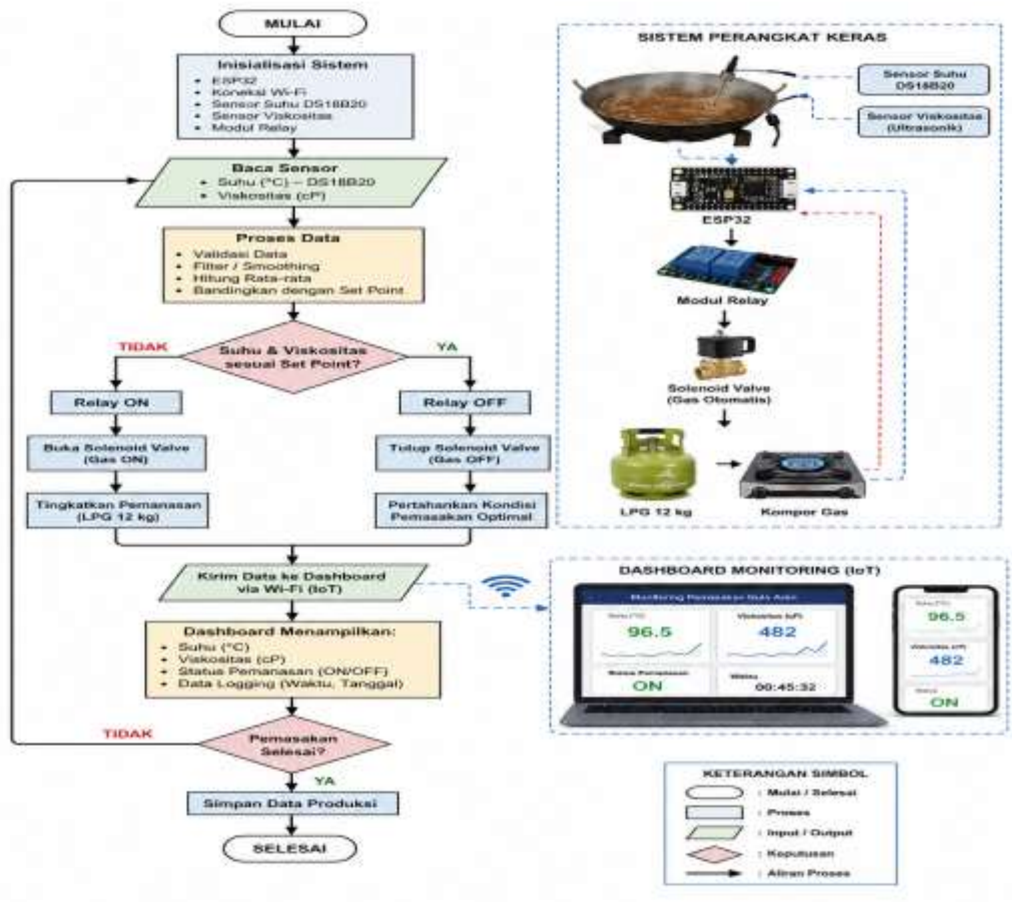

Figure 3. Proposed IoT-based smart sensor system architecture and operational flow for palm sugar cooking

At the sensing layer, a waterproof DS18B20 digital probe continuously monitors the core temperature of the boiling palm sap, while an immersion analog viscosity probe tracks changes in fluid consistency during evaporation. At the processing layer, an ESP32 microcontroller serves as the primary processing node. The ESP32 acquires sensor streams, applies calibration corrections, evaluates readings against predefined operational thresholds (maintaining the cooking temperature between 95 °C and 110 °C), and generates switching signals for an optocoupled 5 V relay module driving a 12 V solenoid gas valve. At the communication layer, the ESP32 utilizes integrated IEEE 802.11 b/g/n Wi-Fi telemetry to transmit operational logs to a cloud database at 10-second intervals, supported by local buffer routines to maintain data integrity during intermittent signal drops. At the application layer, a web-based supervisory dashboard provides real-time graphical visualization of thermal curves, viscosity progression, actuator switching states, and historical batch records. The hardware prototype was fabricated using industrial-grade, cost-effective components to facilitate maintainability in small-scale rural environments. Table 2 details the hardware specifications and operational functions.

Table 2. Hardware Components of the Proposed Smart Sensor System

Component	Specification	Function
ESP32 Development Board	Dual-core 240 MHz, Wi-Fi/Bluetooth	Central computation and wireless telemetry
DS18B20 Sensor	Waterproof digital probe, -55 to +125 °C	High-precision thermal acquisition
Viscosity Sensor	Immersion analog probe	Sap thickening and concentration detection
Relay Module	1-channel, 5 V DC optocoupler isolation	Actuator switching trigger
Solenoid Gas Valve	LPG-compatible, 12 V DC	Regulates gas fuel flow to the burner
Local Display	0.96-inch I2C OLED display	Real-time on-site parameter readout
Power Supply	Regulated 5 V / 12 V DC power unit	Provides electrical power to system modules
Wi-Fi Gateway	IEEE 802.11 b/g/n, 2.4 GHz	Transmits telemetry packets to local router
Web Dashboard	Cloud-hosted dashboard interface	Real-time data visualization and logging

3.3 Experimental Procedure and Data Collection

Experimental validation was executed through sequential laboratory calibration and real-world industrial testing. Sensor calibration was conducted prior to system assembly: the DS18B20 sensor was calibrated against a certified reference digital laboratory thermometer across a range of 30–120 °C, while the viscosity probe was calibrated using standard comparative solutions across graduated concentration gradients. Following bench testing, the fully integrated instrumentation package was mounted onto an LPG-fired cooking vessel at the partner palm sugar production facility. Comparative production trials were performed using standardized 20-liter batches of fresh palm sap. Process parameters were logged at 10-second intervals to verify automated closed-loop heating around the designated setpoints (95–110 °C). Identical production batches were simultaneously processed using conventional firewood masonry hearths to establish baseline performance metrics regarding batch duration, specific fuel consumption, thermal fluctuations, and product crystallization consistency.

3.4 Data Analysis and Performance Evaluation

The experimental datasets were evaluated using descriptive and inferential performance metrics covering measurement accuracy, network communication, energy efficiency, and end-product quality. Measurement precision was evaluated by comparing integrated probe readings against reference laboratory instruments. The percentage error was determined using Equation (1):

$$\text{Error (\%)} = \frac{|X_{sensor} - X_{reference}|}{X_{references}} x\ 100\ \% \quad (1)$$

Where X_{sensor} represents the value registered by the prototype sensor and $X_{reference}$ denotes the reading from the certified reference instrument. Sensor measurement accuracy was subsequently determined using Equation (2):

$$\text{Accuracy (\%)} = 100 - \text{Error}\ \% \quad (2)$$

Wireless communication performance was evaluated based on packet delivery robustness and latency. The transmission success rate was computed using Equation (3):

$$\text{Trasmission Success (\%)} = \frac{|X_{Successful}|}{X_{Total}} x\ 100\ \% \quad (3)$$

Where $X_{Successful}$ is the number of telemetry packets successfully received and logged by the cloud database, and $Ntotal$ is the total number of packets transmitted by the ESP32 node. The reduction in operational cooking duration achieved by the automated system relative to the traditional manual process was determined using Equation (4):

$$\text{Time Reduction } (\%) = \frac{|T_{Conventional} - T_{IoT}|}{T_{Conventional}} x\ 100\ \% \quad (4)$$

Where $T_{Conventional}$ represents the total cooking duration recorded under the manual firewood method and T_{IoT} is the duration under automated LPG operation. Fuel reduction per production cycle was evaluated by comparing the mass of fuel consumed between the two methods using Equation (5):

$$\text{Fuel Saving } (\%) = \frac{|F_{Conventional} - F_{IoT}|}{F_{Conventional}} x\ 100\ \% \quad (5)$$

Where $F_{Conventional}$ is the total mass of firewood consumed (kg) and F_{IoT} is the mass of LPG consumed (kg) per equivalent sap batch volume. Thermal stability was quantified as the proportion of total operational cooking duration in which the monitored sap temperature was maintained strictly within the predefined target band of 95–110 °C, reflecting the steady-state control precision of the closed-loop relay actuation. Product quality consistency was evaluated by comparing physical attributes (color, texture, and crystallization maturity) between batches. The defect rate was determined by calculating the percentage of finished output exhibiting burning, scorch off-flavors, or incomplete crystallization relative to total batch production.

4. Results and Discussion

4.1 Results

The developed IoT-based smart sensor system was fabricated, calibrated, and deployed to automate the palm sap cooking process. Experimental evaluation covered sensor measurement precision, wireless telemetry reliability, closed-loop actuator control, and comparative field production performance against the conventional manual method. Bench calibration and functional testing confirmed the measurement accuracy and communication stability of the system, as summarized in Table 3. The waterproof DS18B20 digital sensor achieved an average measurement error of 0.26%, corresponding to an accuracy of 99.74% relative to calibrated laboratory reference thermometers. The analog immersion viscosity sensor recorded an average measurement error of 0.98%, representing an accuracy of 99.02% across graduated sap concentration trials. The wireless telemetry interface operating over IEEE 802.11 b/g/n exhibited an average communication latency of 1.9 s and a packet delivery success rate of 99.2%, transmitting sensor readings to the cloud database at continuous 10-second intervals. The closed-loop relay actuator successfully maintained sap cooking temperatures within the target operating window of 95–110 °C.

Table 3. Performance of the Developed IoT-Based Smart Sensor System

Performance Parameter	Experimental Result	Operational Status
DS18B20 measurement error	0.26%	High precision
DS18B20 accuracy	99.74%	Calibrated
Viscosity sensor measurement error	0.98%	High precision
Viscosity sensor accuracy	99.02%	Calibrated
Average communication delay	1.9 s	Low latency
Successful data transmission rate	99.2%	Robust telemetry
Cooking temperature range	95–110 °C	Within target band
Automatic relay actuation	Deterministic	Functional
Web dashboard visualization	Real-time (10 s cycle)	Operational

Field evaluation was conducted at the partner home industry using standardized 20-liter batches of fresh palm sap. The comparative operational metrics between the traditional manual method and the automated IoT-based platform are presented in Table 4.

Table 4. Comparison of Conventional and IoT-Based Palm Sugar Cooking

Operational Parameter	Conventional Method	IoT-Based System	Relative Improvement
Cooking duration (min)	122	101	17.2%
Fuel consumption (kg/cycle)	20 (firewood)	16 (LPG)	20.0%
Temperature stability (%)	72	96	33.3%
Defective product rate (%)	12	3	75.0%

As shown in Table 4, the automated system reduced the average cooking duration from 122 min to 101 min, achieving a process time reduction of 17.2%. Specific fuel consumption per batch decreased from 20 kg of firewood to 16 kg of LPG, representing a 20.0% reduction in raw fuel mass. Thermal stability—defined as the percentage of cooking time maintained within 95–110 °C—increased from 72% under manual operation to 96% under automated control (a 33.3% relative improvement). Consequently, the defective product rate declined from 12% to 3%, representing a 75.0% reduction in spoiled or over-caramelized batches. To confirm the statistical validity of these operational improvements, paired hypothesis tests were performed on the experimental observations across production runs. When data distributions satisfied the normality assumption, paired sample t-tests were applied; otherwise, the non-parametric Wilcoxon signed-rank test was utilized. Across all evaluated parameters—cooking duration, fuel consumption, thermal stability, and defect rate—the observed improvements in the IoT-based system were statistically significant ($p<0.05$), demonstrating that the performance enhancements were attributable to deterministic system control rather than experimental variability.

4.2 Discussion

The experimental results demonstrate that automating the palm sugar cooking process through dual-parameter sensing provides significant operational advantages over conventional manual processing. The 17.2% reduction in cooking duration and 20.0% fuel savings are directly related to the thermal efficiency of closed-loop gas regulation. In conventional open masonry hearths, combustion is uninsulated and continuous, causing severe thermal dissipation, localized overheating, and uncontrolled fuel feeding. In contrast, the IoT-based platform employs deterministic threshold switching: the ESP32 disengages the solenoid gas valve upon reaching the upper threshold (110 °C) to exploit retained vessel enthalpy and re-engages heating only when the temperature approaches 95 °C. This regulated heat input minimizes energy waste and shortens boiling cycles. The improvement in thermal stability (from 72% to 96%) directly explains the dramatic reduction in product defects (from 12% to 3%). In traditional operations, process termination relies purely on empirical tactile inspection by operators, which frequently leads to either premature termination (resulting in high residual moisture and short shelf life) or delayed termination (causing excessive Maillard caramelization and bitter off-flavors). Integrating real-time sap viscosity measurement with continuous digital temperature logging provides an objective, repeatable indicator of the crystallization endpoint. This removes operator subjectivity, mitigates localized pan scorching, and guarantees consistent batch-to-batch sugar crystallization. These findings advance earlier research in agro-industrial process modernization. While Huda and Kurniawan (2022) established the precision of DS18B20 digital sensors for thermal logging, their work was confined to temperature monitoring without integrating actuator control or process rheology. Sawidin *et al.* (2023) implemented automated stirring and heating using an industrial PLC, but their framework lacked wireless IoT telemetry, cloud storage, and rheological feedback, resulting in higher capital costs that remain prohibitive for rural smallholders. Furthermore, Darmawan *et al.* (2024) and Kholis *et al.* (2024) enhanced mechanical agitation without regulating thermal input. The present system bridges these technological gaps by integrating dual-input sensing (thermal and rheological), closed-loop relay actuation, and cloud-based IoT telemetry into a single, cost-effective ESP32 platform, thereby presenting a viable technological blueprint for rural *Smart Home Industries*. Despite these positive outcomes, several limitations must be addressed:

1) *Single-Facility Field Testing:* Operational validation was restricted to a single partner production site. Regional variations in sap sugar content (Brix), harvest seasonality, ambient temperature, and pan geometries may introduce operational variances that warrant broader testing.
2) *Rheological Probe Calibration:* While the analog viscosity probe achieved 99.02% calibration accuracy, non-Newtonian flow behavior and caramel residue accumulation during continuous boiling require periodic sensor cleaning and recalibration.
3) *Static Rule-Based Actuation:* The current embedded control scheme utilizes fixed thermal thresholds (95–110 °C). It cannot adapt dynamically to variations in sap volume or ambient convective heat losses.

Future investigations should focus on developing adaptive control strategies, such as fuzzy logic controllers or lightweight machine learning models implemented on edge microcontrollers (Maghfira *et al*., 2025; Rizky *et al*., 2025; Samsudin *et al*., 2023), to dynamically estimate the optimal crystallization endpoint based on multi-sensor fusion. Expanding multi-site field implementations will further validate the long-term robustness and economic scalability of the system across rural agro-processing cooperatives.

5. Conclusion and Recommendations

This study successfully designed, implemented, and empirically validated a low-cost Internet of Things (IoT)-based smart sensor system to automate the thermal evaporation process in traditional palm sugar manufacturing. By integrating a waterproof DS18B20 digital temperature sensor, an immersion viscosity probe, and an ESP32 microcontroller with a closed-loop relay-actuated LPG solenoid valve, the system eliminates operator subjectivity through automated threshold-based heat regulation and real-time cloud data logging. The experimental findings demonstrate high instrumentation accuracy, reliable telemetry, and significant operational improvements. The DS18B20 sensor and viscosity probe achieved high measurement precision with average errors of 0.26% (99.74% accuracy) and 0.98% (99.02% accuracy), respectively. Wireless telemetry maintained robust connectivity with an average communication latency of 1.9 s and a packet transmission success rate of 99.2%. When benchmarked against conventional manual firewood processing, the automated system reduced operational cooking duration from 122 to 101 min (a 17.2% reduction) and lowered specific fuel mass consumption from 20 kg of firewood to 16 kg of LPG per batch (a 20.0% reduction). Furthermore, closed-loop thermal regulation elevated process temperature stability from 72% to 96%, leading to a substantial reduction in the product defect rate from 12% to 3% (p<0.05p<0.05). These findings confirm that the system markedly improves energy utilization, operational productivity, and batch-to-batch product consistency for smallholder agro-industries. Despite these encouraging results, the study was constrained by deployment within a single partner production facility, reliance on continuous local Wi-Fi connectivity, and the use of static control setpoints that do not adapt dynamically to raw sap Brix variations. Future research will explore adaptive intelligent control mechanisms—such as fuzzy logic controllers or lightweight machine learning models deployed directly on edge devices—to predict the crystallization endpoint dynamically. In addition, multi-site validation across diverse agro-industrial clusters, mobile push notifications, and automated fault diagnostics will be developed to facilitate scalable, long-term implementation of the *Smart Home Industry* paradigm.

References

Ananta, D. (2026). Sistem monitoring suhu dan kelembaban berbasis Internet of Things menggunakan ESP32 dan DHT22. *Jurnal Informatika dan Teknik Elektro Terapan*, 14(2), 951–957. https://doi.org/10.23960/jitet.v14i2.9467

Anwar, K. S., Saputra, R. A., Sutrisno, B., Azizah, A., & Budiman, A. (2026). Pengembangan dashboard monitoring berbasis web untuk transparansi program makanan bergizi gratis di Indonesia. *Pilar Teknologi: Jurnal Ilmiah Ilmu Teknologi*, 11(1), 10–16.

Darmawan, R., Koswara, A. Y., Suryo, I. B., Rokana, E., Srikalimah, S., Taufany, F., & Zuhdan, A. Z. (2024). Peningkatan kualitas produksi gula merah melalui pemasakan dengan food grade cooking pan dan mekanisasi scraping serta pemanfaatan limbah untuk fattening domba. *Sewagati*, 8(5), 2265–2282. https://doi.org/10.12962/j26139960.v8i5.2258

Gazis, A., Papadongonas, I., Andriopoulos, A., Zioudas, C., & Vavouras, T. (2025). A comprehensive review of sensor technologies, instrumentation, and signal processing solutions for low-power Internet of Things systems with mini-computing devices. *Academia Engineering*, 1–18. https://doi.org/10.20935/AcadEng7541

Hardianti, A., & Idris, A. I. (2021). Analisis penggunaan kayu bakar pada proses pembuatan gula merah (*Arenga pinnata*). *Pangale: Journal of Forestry and Environment*, 1(2), 40–50.

Huda, B. R. M., & Kurniawan, W. D. (2022). Analisa sistem pengendalian temperatur menggunakan sensor DS18B20 berbasis mikrokontroler Arduino. *Jurnal Rekayasa Mesin*, 7(2), 18–23.

Hutami, R., Pribadi, M. F. I., Nurcahali, F., Septiani, B., Andarwulan, N., Sapanli, K., Zuhud, E. A. M., Al Manar, P., Ichsan, N., & Wahyudi, S. (2023). Proses produksi gula aren cetak (*Arenga pinnata*, Merr) di Indonesia. *Jurnal Ilmiah Pangan Halal*, 5(2), 119–130. https://doi.org/10.30997/jiph.v5i2.10237

Kholis, N., Mulyo, S., Respati, B., Prasetyo, S., & Sarwono, E. (2024). Penerapan teknologi tepat guna pengaduk nira aren otomatis untuk meningkatkan produktivitas perajin gula aren. *Jurnal Abdi Masya*, 5(2), 157–165.

Maghfira, S. P., Suprianto, B., Rakhmawati, L., & Firmansyah, R. (2025). Rancang bangun sistem kontrol suhu dan kelembapan berbasis IoT dengan fuzzy logic untuk optimasi proses fermentasi pada pengolahan tempe. *Jurnal Teknik Elektro*, 14(3), 257–263. https://doi.org/10.26740/jte.v14n3.p257-263

Multani, G., & Widodo, T. (2024). Usaha tradisional gula merah (SAKA) berbahan baku tebu di Nagari Matua Hilia Kecamatan Matur Kabupaten Agam. *Indonesian Journal of Education and Development Research*, 3(1), 434–439. https://doi.org/10.57235/ijedr.v3i1.4716

Nugroho, R. C., & Madjid, A. (2025). Kajian proses pembuatan gula merah dari macam bahan baku yang berbeda. *Jagad Tani: Jurnal Ilmu Pertanian*, 2(2), 287–299.

Ontowirjo, F. Y. (2025). Implementasi IoT pada sistem monitoring suhu. *Jurnal Teknik Elektro dan Komputer*, 7(3), 333–334.

Purba, N., Yahya, M., & Nurbaiti, N. (2021). Analisis strategi pemasaran gula aren cair dalam meningkatkan volume penjualan pada masa pandemi Covid-19. *Jurnal Perilaku dan Strategi Bisnis*, 9(2), 91–98.

Puspitasari, I. D., Sutrisno, S., & Hartono, H. (2026). Implementasi Internet of Things pada alat praktikum viskometer untuk pembelajaran fisika. *Jurnal Pendidikan Fisika dan Teknologi*, 12(1), 186–192.

Rizky, M., Rahmadian, R., Wardani, A. L., & Hermawan, A. C. (2025). Rancang bangun pendeteksi kadar gula darah non-invasif portabel berbasis IoT. *Journal of Electrical Engineering*, 2(2), 9–16. https://doi.org/10.47134/jte.v2i2.4747

Samsudin, S., Abullah, J., Syahputra, D., & Koto, M. H. (2023). Decision support system for determining potable well water quality in Pangirkiran Village using the MOORA method. *CESS (Journal of Computer Engineering, System and Science)*, 8(2), 470–478. https://doi.org/10.24114/cess.v8i2.48220

Saparuddin, S., Amin, M., & Sudarmin, S. (2022). The box for early detection of gas leaks and fires uses notification system to the fire department. *Building of Informatics, Technology and Science (BITS)*, 4(2), 422–432. https://doi.org/10.47065/bits.v4i2.2023

Saputro, H., Faidlon, A., Ma'sum, S., Basyar, A. A., & Fitriya, S. (2026). Pengembangan sistem penerangan pintar IoT untuk gudang dan produksi gula merah Sumber Madu Kabupaten Kudus. *Jurnal Pemberdayaan Masyarakat Berkarakter*, 7(1), 45–55.

Sawidin, S. K., Putung, Y. R., Waroh, A. P. Y., & Marsela, T. (2023). Rancang bangun kontrol pengolahan gula aren dengan Programmable Logic Controller. *Jambura Journal of Electrical and Electronics Engineering*, 5(2), 179–184. https://doi.org/10.37905/jjeee.v5i2.19839

Siregar, M. E., & Prayitno, A. (2023). Rancang bangun sistem telemetri sensor suhu dan kelembaban berbasis ESP32. *Jurnal Ilmiah Teknik Elektro*, 5(2), 165–168.