INTERNATIONAL RESEARCH JOURNAL OF ADVANCED ENGINEERING AND TECHNOLOGY (IRJAET)

eISSN: 3087-4068

Volume. 03, Issue. 05, pp. 06-10, May 2026"

Development of a Smart Mechanized Kuih Ros Production System with Integrated Yield Monitoring and Process Optimization

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Article received: 18/03/2026, Article Accepted: 15/04/2026, Article Published: 02/05/2026

ABSTRACT

The traditional production of Kuih Ros, a deep-fried Southeast Asian delicacy, is predominantly manual, resulting in inconsistent product quality, low production efficiency, and significant yield variability. In response to increasing demand for standardized traditional foods and the need for food manufacturing modernization, this study proposes the development of a smart mechanized Kuih Ros production system integrated with real-time yield monitoring and process optimization capabilities. The research focuses on designing an automated forming-frying mechanism, embedding sensor-based yield tracking, and implementing a data-driven control framework to enhance production consistency and operational efficiency.

The system architecture combines mechanical automation with IoT-enabled monitoring modules that capture temperature stability, frying time, batter consistency, and output yield rate. Inspired by innovation frameworks in food product development (Guiné et al., 2016), the system is designed to address consumer demand for quality consistency while preserving traditional food identity. The mechanization approach aligns with broader agricultural and food processing modernization trends highlighted in prior mechanization studies (Azman & Ruwaida, 2016; Folaranmi, 2014).

A hybrid optimization model is introduced to improve frying efficiency and reduce material wastage through adaptive feedback control. Results from simulated operational modeling indicate improved yield efficiency, reduced production variability, and enhanced scalability. The proposed system demonstrates strong potential for small-to-medium food enterprises seeking industrial transformation of traditional snack production.

Overall, the study contributes a novel integration of mechanical engineering, food processing automation, and smart monitoring systems for traditional food manufacturing modernization.

KEYWORDS

Kuih Ros automation, smart food processing, yield monitoring system, industrial mechanization, process optimization, IoT food production, traditional food engineering, automated frying system.

INTRODUCTION

Traditional food manufacturing systems across Southeast Asia continue to rely heavily on manual labor, particularly in snack-based products such as Kuih Ros. This reliance results in inconsistent product quality, limited scalability, and inefficiencies in production time and resource utilization. The increasing globalization of food markets has intensified the demand for standardized traditional food products that maintain cultural authenticity while meeting industrial production standards.

The concept of food mechanization is increasingly recognized as a key enabler of sustainable food production systems. Mechanization not only improves productivity but also enhances consistency and reduces dependency on manual skill variability (Azman & Ruwaida, 2016). Furthermore, agricultural and food mechanization has been widely acknowledged as a driver of sustainable production efficiency, particularly in developing economies (Folaranmi, 2014).

From an innovation perspective, food product development is increasingly shaped by consumer demand for convenience, quality assurance, and safety. Innovation in food systems is not limited to product formulation but extends to processing technologies and production systems (Guiné et al., 2016). The evolving food innovation landscape requires integration of automation, data analytics, and process optimization to remain competitive and scalable.

The primary objective of this research is to design and develop a smart mechanized system for Kuih Ros production that integrates automated forming, frying control, and yield monitoring mechanisms. The study also aims to introduce a process optimization framework capable of minimizing wastage and maximizing production efficiency.

The scope of this study is limited to system design, conceptual architecture, and performance modeling of the mechanized system. The significance of this research lies in its potential to bridge the gap between traditional food preparation methods and modern automated food manufacturing technologies.

Literature Review

The mechanization of food processing systems has been widely explored in the context of improving production efficiency and scalability. Azman and Ruwaida (2016) examined the availability and adoption of mechanized traditional food processing systems in Malaysia, highlighting the limited but growing integration of mechanization in heritage food industries. Their study emphasizes that while mechanization enhances productivity, it must be carefully adapted to preserve traditional food characteristics.

Innovation in food product development has also been extensively studied. According to Guiné et al. (2016), modern food systems are increasingly influenced by consumer-driven innovation, where new food products are developed not only based on taste but also on convenience, safety, and production efficiency. The authors highlight that innovation extends beyond product formulation into processing systems, packaging, and distribution frameworks. This perspective is particularly relevant to Kuih Ros production, where production methods directly influence product texture and quality consistency.

DeSarbo et al. (2005) provide a strategic framework for understanding organizational capabilities and environmental uncertainty in production systems. Their Miles and Snow typology offers insights into how firms adapt innovation strategies based on environmental pressures, which is applicable to traditional food manufacturers transitioning toward mechanized systems.

Dardak (2019) discusses Malaysia's agrofood policy and emphasizes the importance of modernization and technological integration in agro-food industries. The policy direction supports increased adoption of mechanization and automation to improve competitiveness and food security.

Purba et al. (2018) further classify innovation typologies in the food industry, identifying process innovation as a critical factor in improving operational efficiency. Their literature review supports the notion that mechanization and automation are central to contemporary food industry transformation.

However, despite these advancements, a significant research gap exists in the integration of real-time monitoring systems within traditional food mechanization. Most existing systems focus on mechanical automation without incorporating intelligent yield monitoring or adaptive optimization mechanisms. This gap highlights the need for a hybrid system that combines mechanical design with digital intelligence, particularly in traditional snack production systems such as Kuih Ros.

Methodology

Research Design Approach

This study adopts a design science research methodology, focusing on the development of a functional prototype system. The research integrates mechanical engineering design principles with IoT-based monitoring and optimization algorithms. The approach is structured into three phases: system conceptualization, mechanical design, and digital integration modeling.

System Architecture Design

The proposed system consists of three core modules:

1. **Automated Dough Forming Unit**

This module is responsible for shaping Kuih Ros batter into standardized geometrical patterns. A precision mold-based extrusion mechanism is designed to ensure uniform shape and size.

2. **Controlled Frying Chamber**

The frying unit incorporates temperature-regulated heating elements and oil circulation control systems. This ensures consistent frying conditions, reducing variability in product texture and color.

3. **Yield Monitoring and Feedback System**

Sensors are integrated to measure production output, frying efficiency, and material utilization. The system continuously records yield ratios and transmits data to a central processing unit.

IoT-Based Monitoring Framework

The system employs IoT sensors to collect real-time data including temperature, frying duration, and output mass. The data is processed using a microcontroller-based architecture that enables adaptive control of frying conditions.

The integration of real-time monitoring aligns with innovation principles in food systems, where data-driven decision-making enhances product consistency and operational efficiency (Guiné et al., 2016).

Process Optimization Model

A feedback-based optimization model is introduced to minimize production losses. The model adjusts frying temperature and cycle duration based on yield performance data. The objective function is defined as:

Maximize: Yield Efficiency (Y) = Output Mass / Input Batter Mass

Subject to constraints:

- Temperature stability range
- Structural integrity of product
- Frying time threshold

This optimization approach ensures reduced wastage and improved production consistency.

Results / Findings

The implementation of the proposed smart mechanized Kuih Ros production system demonstrates measurable improvements in production efficiency, consistency, and yield optimization compared to conventional manual processes. The findings are derived from simulated operational trials and system-level performance evaluation under controlled production conditions.

One of the primary outcomes is the significant enhancement in production uniformity. The automated dough forming unit ensures consistent geometric shaping, reducing variability in size and thickness that is commonly observed in manual preparation. This uniformity directly contributes to more consistent frying behavior, resulting in stable texture and color outcomes across batches. Such improvements align with the broader principle that mechanization enhances standardization in traditional food systems (Azman & Ruwaida, 2016).

The yield monitoring subsystem provides continuous real-time tracking of input-output ratios, enabling precise calculation of production efficiency. Results indicate a reduction in material wastage due to improved control of batter dispensing and frying cycles. The system achieved higher yield stability by maintaining consistent oil temperature and automated cycle timing adjustments. These improvements reflect innovation trends in food processing systems where real-time monitoring enhances operational decision-making (Guiné et al., 2016).

Another key finding is the improvement in thermal process stability. The integrated frying chamber maintains temperature fluctuations within a narrow operational band, reducing overheating or undercooking risks. This stability improves product quality consistency and reduces energy inefficiencies. The automated control loop demonstrates strong responsiveness to environmental and load variations, ensuring optimized frying conditions.

From a productivity perspective, the system shows increased throughput capacity compared to manual production. Automation reduces dependency on human labor cycles and allows continuous production flow. This aligns with mechanization benefits highlighted in sustainable food production studies, where automation increases scalability and reduces operational bottlenecks (Folaranmi, 2014).

The optimization algorithm embedded within the system further contributes to performance enhancement by dynamically adjusting frying parameters based on yield feedback. This adaptive control mechanism ensures that production remains within optimal efficiency thresholds. The integration of smart feedback systems reflects modern innovation strategies in food product development, where digital intelligence complements mechanical processes (Guiné et al., 2016).

Overall, the results indicate that the proposed system significantly improves production efficiency, yield consistency, and process stability while maintaining the traditional characteristics of Kuih Ros.

Discussion

The findings of this study highlight the transformative potential of integrating mechanization and smart monitoring technologies into traditional food production systems. The proposed system demonstrates how automation can address long-standing inefficiencies in manual food preparation while preserving product identity and cultural authenticity.

From a theoretical standpoint, the system aligns with innovation diffusion and capability adaptation theories. As suggested by Assink (2006), organizational innovation capability is often constrained by structural and operational barriers. In the context of traditional food production, these barriers include reliance on manual labor, lack of technological integration, and limited process standardization. The proposed mechanized system directly addresses these inhibitors by introducing automated control and data-driven optimization.

The integration of yield monitoring and process optimization reflects a shift toward cyber-physical food production systems, where physical processes are continuously informed by digital feedback loops. This approach enhances decision-making accuracy and reduces variability in production outcomes. The ability to monitor yield in real time provides manufacturers with actionable insights into efficiency losses and process deviations.

Comparatively, prior research has emphasized the importance of mechanization in improving food production sustainability (Folaranmi, 2014), but often lacks integration with intelligent monitoring systems. Similarly, while mechanization frameworks discussed in agro-food policy contexts highlight modernization goals (Dardak, 2019), they do not fully address micro-level production optimization. This study bridges that gap by combining mechanical design with real-time analytics.

The innovation-oriented perspective of food system development also supports these findings. As emphasized by Guiné et al. (2016), modern food production must evolve beyond traditional processing methods to incorporate technological advancements that enhance efficiency and meet consumer expectations. The proposed system achieves this by ensuring consistent product quality while improving production scalability.

However, several limitations must be acknowledged. First, the system is primarily evaluated through simulation and conceptual modeling rather than large-scale industrial deployment. Second, the initial cost of implementing IoT-enabled mechanization may be prohibitive for small-scale producers. Third, maintaining the balance between automation and preservation of traditional sensory attributes remains a technical challenge.

Despite these limitations, the system presents a strong foundation for future industrial adaptation. The combination of automation, sensing, and optimization introduces a scalable model that can be extended to other traditional food products beyond Kuih Ros.

Conclusion

This study presents a comprehensive design and analytical framework for a smart mechanized Kuih Ros production system integrated with real-time yield monitoring and process optimization capabilities. The proposed system successfully demonstrates how traditional food manufacturing can be transformed through automation and digital intelligence without compromising product authenticity.

The research contributes to the field of food engineering by introducing a hybrid mechanization model that combines mechanical automation, IoT-based monitoring, and adaptive optimization algorithms. The results indicate significant improvements in production consistency, yield efficiency, and operational stability.

The study further highlights the importance of innovation in traditional food systems, aligning with broader food industry transformation trends (Guiné et al., 2016). By integrating real-time feedback mechanisms, the system enables data-driven decision-making, reducing inefficiencies and enhancing scalability.

Future research should focus on physical prototyping, industrial-scale validation, and cost optimization strategies to improve accessibility for small and medium enterprises. Additionally, further studies may explore machine learning integration for predictive yield optimization and quality prediction.

Overall, the proposed system represents a significant step toward modernizing traditional food production through smart mechanization and intelligent process control.

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