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Original Article

Design and Performance Evaluation of a Semi-Automated Packaging Machine for Traditional Fragrant Rice Meals

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Abstract - *Traditional Malay fragrant rice meals, commonly prepared with coconut milk and pandan leaves, require efficient packaging solutions to meet the needs of modern consumers with busy lifestyles. The design, development, and performance evaluation of a semi-automated packing machine appropriate for this meal are examined in this study. An Arduino Mega 2560 microcontroller configured for input-output operations is used to operate the device. To manage the packing process, it integrates sensors, appropriate motors, and preprogrammed control algorithms. Experimental tests were conducted by varying both meal weight and packaging duration to assess the system's operational performance. The evaluation considered electrical parameters such as voltage, current, and power consumption, alongside packaging accuracy. Results indicate that increased product weight and extended packaging time lead to higher power requirements while maintaining consistent packaging performance. The study demonstrates that the proposed semi-automated packaging machine is technically viable and offers a practical solution for small- to medium-scale food production industries. Its application can support the modernisation of traditional meal packaging, improving efficiency, convenience, and potential scalability in food processing.*

Keywords - *Arduino, Automated machine, Packaging machine, Vending machine, Fragrant rice meals.*

1. Introduction

Time-saving has become a top concern in modern lifestyles. Thus, this encourages the wider use of automation in routine tasks. In the food sector, packaging is essential for preserving food quality and enhancing customer convenience. As a consequence, automated and semi-automated packaging solutions are rapidly being embraced by retail outlets, shopping malls, and small-scale food enterprises to facilitate quicker and more sanitary production of ready-to-eat meals. Traditional aromatic rice dishes made with pandan leaves and coconut milk are still quite popular in Malaysia. But the majority of these meals are still packed by hand, which takes a lot of time and effort and often yields uneven serving sizes. Such limits might restrict manufacturing capacity and impair product uniformity, eventually reducing consumer satisfaction. More effective and dependable packaging methods are obviously needed to facilitate the increased distribution of traditional meals in light of the growing demand for convenient food choices. Previous studies have reported various applications of microcontroller-based automation in food processing and packaging [1]. The Arduino Mega 2560 microcontroller, in particular, offers a flexible and low-cost platform for developing automated systems that integrate motors, sensors, and programmed control logic. However, most existing research focuses on standardised or single-material food products, such as beverages or dry items, giving limited attention to traditional multi-component rice meals. In addition, systematic evaluations linking packaging performance to electrical power consumption under varying operating conditions are rarely reported.

To address these gaps, this study proposes a low-cost, semi-automated packaging machine specifically designed for traditional Malaysian fragrant rice meals. To the best of the authors' knowledge, this work represents one of the first attempts to integrate multi-component meal packaging with a systematic evaluation of electrical performance. This proposed system studied the relationship between meal weight, packaging time, and electrical parameters to assess operational efficiency.

The objectives of this study are threefold: (i) to design a semi-automated packaging machine that is user-friendly and capable of consistent operation, (ii) to develop the hardware and software integration for the machine using the Arduino Mega 2560 platform, and (iii) to evaluate the machine's performance under varying operating conditions, particularly in relation to meal weight, packaging time, and electrical power consumption.

Hence, to evaluate operational efficiency, the link between electrical factors, packing time, and product weight is investigated. The results contribute to the development of semi-automated food packaging technologies and provide useful insights for enhancing conventional meal processing in small-to medium-scale production settings.

2. Literature Review

2.1. History of Automated Dispensing Systems

Hero of Alexandria created a coin-operated mechanism to dispense holy water in the first century, which is when vending technology first emerged [2]. Tobacco dispensers were first introduced in England in the 17th century, and more sophisticated, fully automated systems were created in the 19th century. These developments reflect humanity's long-standing pursuit of automation in daily life. However, research has improved from simple dispensing mechanisms to sophisticated systems that prioritise accuracy, reliability, and efficiency [3]. Modern innovation is presently largely focused on applications in the food and packaging sectors, where the use of automated solutions helps fill the increased demand for convenience, uniformity, and productivity in both small and major organisations.

2.2. Types of Vending and Packaging Machines

Vending machines, which provide quick access to beverages, snacks, frozen meals, and other commonplace items, have become a commonplace aspect of everyday consumer life in recent years. Coffee makers, soft drink manufacturers, and snack or frozen food producers are all widespread in Malaysia. These systems are generally handled by a microprocessor, which synchronises input and output operations to assure dependable operation. However, there are a variety of packaging machines, such as those used for capping, filling, sealing, and labelling. Filling machines are especially crucial to the food sector since they regulate the quantity of product provided while maintaining hygienic requirements. Both successful production and consumer happiness depend on this.

2.3. Limitations of Manual Packaging

Packing tasks are still done by hand in a lot of small and medium-sized food firms. The habit of hand-filling servings of rice, sauces, and side dishes is especially prevalent while preparing traditional Malay fragrant rice meals. However, hand packing often leads to lengthier processing times, more human error, and unequal portions. Additionally, it involves significant labour input, which reduces the efficiency of manufacturing.

According to earlier research, automated food packing may increase efficiency, speed, and uniformity. Specifically, semi-automatic methods contribute to lower labour costs and improved quality control [4]. Although automated and self-service packaging devices are becoming more and more popular in the beverage and snack sectors, they are still not widely used in traditional Malaysian cuisine [5]. In order to improve accuracy and operational dependability, this project focuses on developing and testing a semi-automatic packing system that combines an effective filling mechanism with microcontroller-based control.

2.4. Recent Advances in Food Packaging Automation

Industry 4.0 elements like Machine Learning (ML), the Internet of Things (IoT), and sanitation design principles are being applied more and more in recent innovations in food packaging automation. IoT-based systems provide real-time monitoring of crucial process parameters through connected sensors and controllers. For example, operation timing, equipment status, and environmental conditions. Machine learning and machine vision technologies are widely studied for quality control and inspection in food packaging, specifically for tasks such as defect identification, package integrity verification, and process optimisation. In contrast to manual operation, these technologies may give quicker and more reliable findings.

Despite these developments, most current systems focus on standardised food products or completely automated, high-throughput applications. However, far less effort has been made on low-cost, application-specific semi-automated packaging systems that can handle multi-component meals while guaranteeing energy efficiency, sanitary conditions, and portion consistency. The recent project, which focuses on the design and performance evaluation of a semi-automated packaging system created for traditional Malaysian fragrant rice dishes, is motivated by this gap.

2.5. Smart Manufacturing, Food Safety, and User Experience Perspectives

In the wider context of smart manufacturing, food packaging automation is increasingly seen as an aspect of flexible, human-centered production systems rather than entirely autonomous industrial solutions. Research on smart manufacturing has a primary focus on resource efficiency, scalability, and flexibility, especially for small and medium-sized enterprises. In the meantime, research on food safety highlights the necessity for hygienic design, uniform portioning, and regulated handling.

Furthermore, current research on user experience in automated and semi-automated systems has concentrated on effective human-machine interaction, ease of use, and reduced physical and mental strain, particularly in food preparation settings. For traditional food operations, semi-automated systems that assist workers rather than completely replace them are increasingly seen as practical and suitable. These viewpoints offer a significant framework for the current research, which focuses on a low-cost, semi-automated packaging system aimed at increasing operational efficiency, cleanliness, and usability in conventional food production settings.

3. Methodology

The technique used to complete this project has been divided into six primary phases. The flowchart outlining the general experimental stages is shown in Figure 1. In addition to being helpful for planning, this graphic was also a convenient way to refer to it as it was being implemented. SolidWorks 2013 (x64 version) was used to design the machine's hardware, allowing precise component and assembly modelling before construction. The Arduino Mega 2560 platform was used to create the control system, and the Arduino 2010 Genuino edition software was used to program it. Sensor inputs, motor functions, and overall process time were all managed by the program logic.

Once the programming had been completed, the design was implemented to use on real hardware in order to confirm system performance and guarantee that the mechanical and electrical components were integrated correctly. Lastly, the machine was run with different meal weights and packing times to assess performance. To evaluate dependability and efficiency, electrical characteristics including voltage, current, and power consumption were monitored. The machine's operating capabilities and appropriateness for small-scale food packaging applications were shown by the test results.

SolidWorks 2013 (x64 version) was used to design the semi-automated packing machine's mechanical parts. The separate components created during the design process are depicted in Figure 2. The filling unit, packing frame, and supporting structures were among the components that were modelled in accordance with the system's functional requirements. After each component was finished, SolidWorks was used to put them together to produce a complete machine model.

After that, the model was analysed to assess its basic stability, usefulness, and goal alignment. If the design did not fulfil the functional criteria, the model was adjusted and developed until it was well-performing. This iterative procedure guaranteed that the final design was practical and could be built. The prototype, which served as the foundation for hardware implementation and experimental testing, was produced using the completed SolidWorks model after the design process was concluded.

3.1. Experimental Design and Performance Evaluation Criteria

This study's experimental approach assesses the performance of the proposed semi-automated packing machine using a controlled laboratory-based approach. The purpose of the study was to assess, under certain operating conditions, the relationship between electrical characteristics, packing time, and meal weight. Throughout the experiments, meal weight and sensor-based packing time were considered independent variables, whereas package length, voltage, current, and power consumption were examined as dependent variables. The main factors for food packaging applications, such as energy economy, operational stability, and portioning consistency, were used to evaluate performance. While operational performance was evaluated based on repeatability and consistent dispensing behaviour across many trials, energy performance was examined using electrical power usage. Using this methodology allows the reported findings to represent the regulated performance of the proposed system accurately.

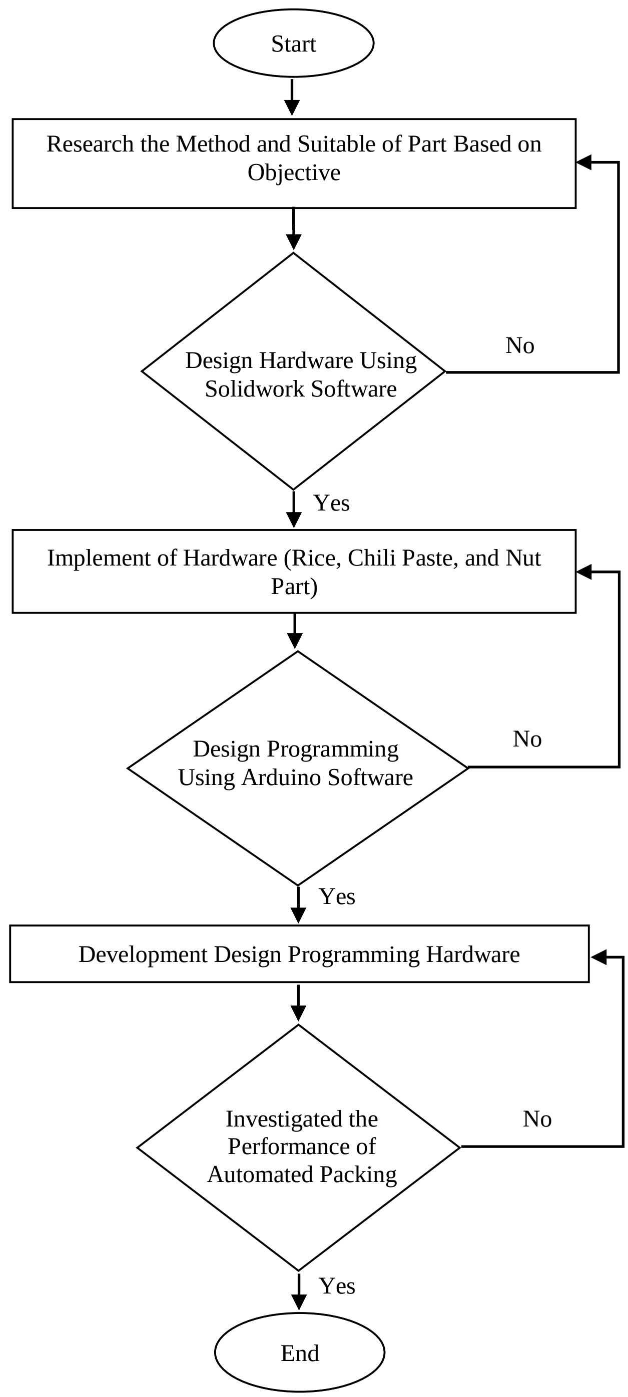

Fig. 1 Flowchart project

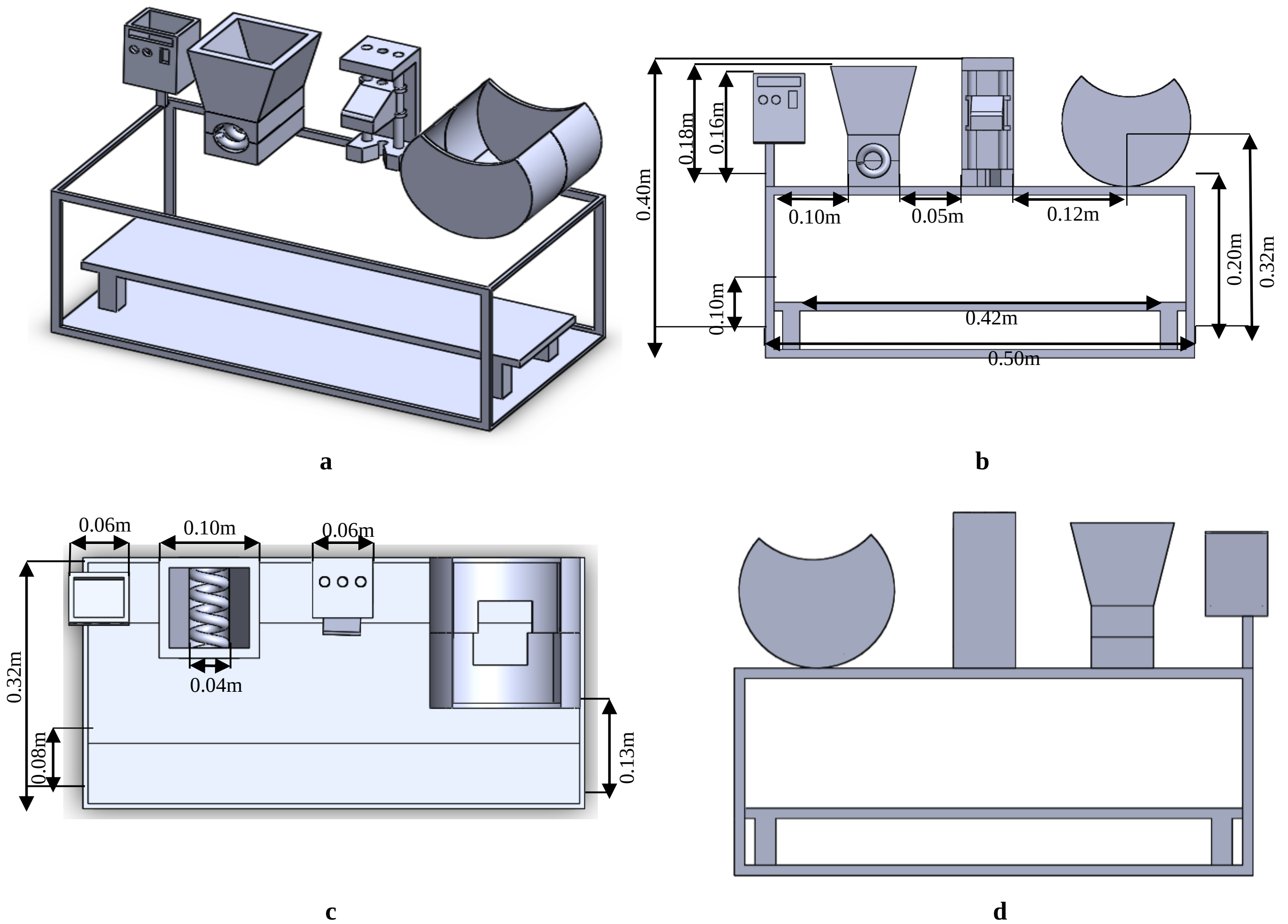

Fig. 2 Project design, (a) Side view, (b) Front view, (c) Top view, and (d) Rear view with hidden line.

3.2. Statistical Validation and Reproducibility

All tests were carried out under controlled laboratory circumstances and performed three times for each operating state, utilising the same system configuration, power supply, packaging materials, and ambient environment in order to verify the experimental findings and evaluate measurement repeatability. In order to reduce experimental uncertainty and guarantee consistency of the observed trends, this repeated-measurement strategy was used. Packing time, voltage, current, power usage, and dispensing weight were all noted throughout each attempt.

The findings reported in this research are the average values derived from the repeated experiments. The system performed consistently and reliably under all testing situations, with very little change between repeats. Since the creation and performance assessment of a prototype-scale system is the main focus of this research, repeatability and consistency are prioritised above sophisticated inferential statistics in the statistical analysis. Given the minimal variability seen in the repeated measurements, graphical uncertainty indicators such as error bars were not included, since they would not give any valuable information beyond the established repeatability. This method is enough to verify the suggested semi-automated packing machine's durability and dependability under the examined circumstances.

4. Hardware Development

During the hardware development phase, the necessary components of the semi-automated packaging machine had to be assembled. Figure 3 depicts the system's main parts, which include the Arduino Mega 2560 microcontroller, sensors, motors, power supply unit, and mechanical frame. Every part was chosen according to how well it would meet the machine's functional needs. As the central control unit, the microcontroller processes sensor input data and produces output signals that power the motors [6]. The motors control the filling and sealing processes, while the sensors identify the packing material's location and presence. Both mechanical and electrical components are guaranteed to operate steadily by the power source. The prototype operated easily and reliably during testing and evaluation because the hardware was painstakingly put together to ensure component compatibility.

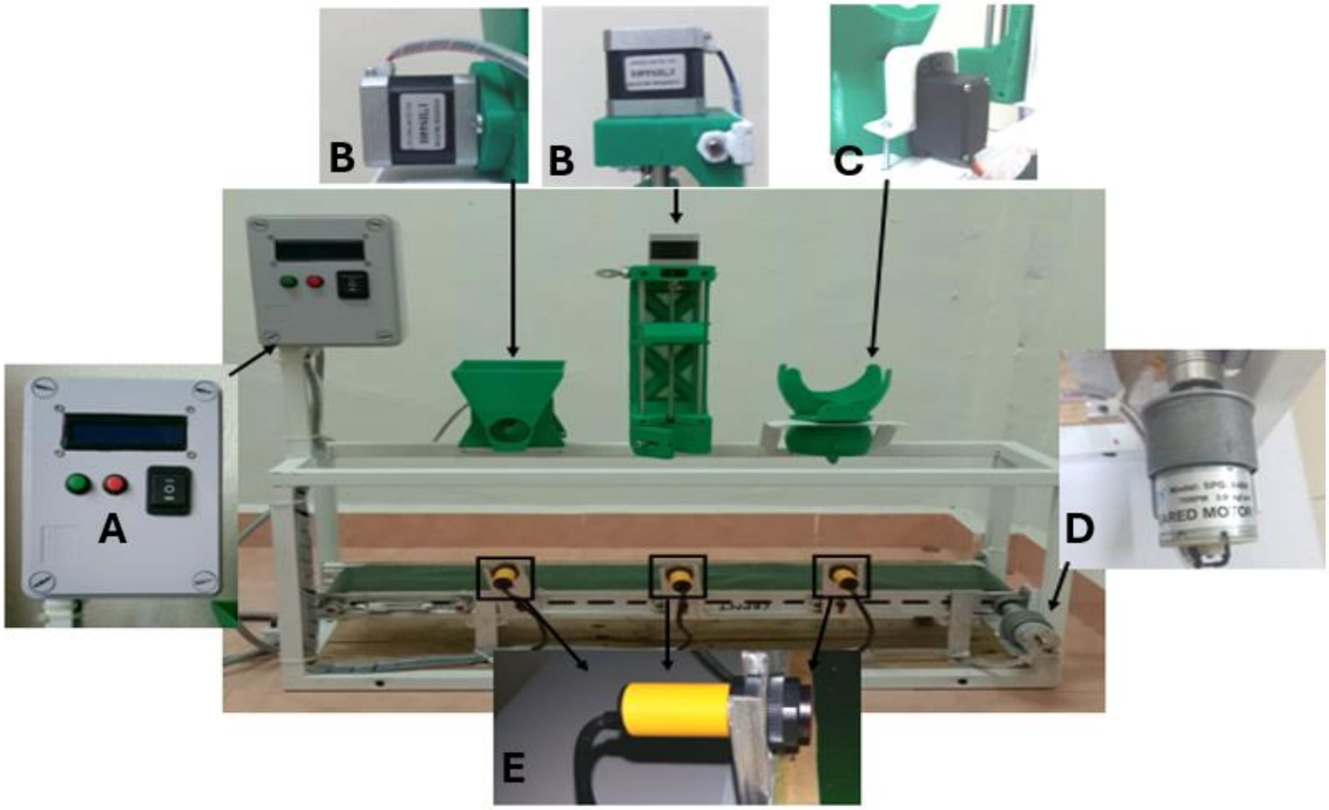

Fig. 3 Hardware project design, (a) Power supply box, (b) Stepper DC motor, (c) Servo DC motor, (d) DC gear motor, (e) Infrared sensor.

4.1. Power Supply

An ADPATN-S1203A module is used by the power supply unit, seen in Figure 4, to transform the AC mains input into a regulated 12V DC output. Since low-voltage DC is necessary for the safe and effective functioning of the machine's parts, such as the gear motor and control circuits, this conversion is crucial. The system operates dependably because of the TNK module's steady output and low ripple, which also guards against voltage swings that would compromise sensor accuracy or motor speed. Therefore, choosing a regulated 12V DC supply was essential to ensure the semi-automated packing machine operated consistently.

Fig. 4 Power supply ADPATN-S1203A

The motor driver, seen in Figure 5, is a current amplifier that runs at 5V. The Arduino Mega 2560 microcontroller sends it a low-current control signal, and it responds by producing a proportionately greater current signal that is enough to power the motor. The motor driver serves as a crucial link between the control system and the mechanical actuator since the microcontroller by itself is unable to provide the necessary current [6]. A transistor may be used as a switch to operate a motor in one direction in its most basic form [7]. However, the semi-automated packing machine in this project operates consistently because of the steady and dependable motor control provided by the specialised motor driver module [8].

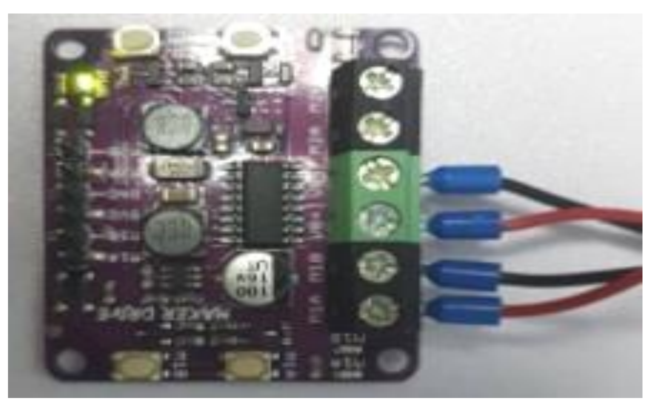

Fig. 5 Motor Driver

This project uses the Arduino CNC Shield, as shown in Figure 6, to make motor control easier. It is designed to work with the Arduino Mega 2560 and provides a useful interface for connecting and controlling stepper motors. The open-source firmware of the shield enables precise motion control with simple programming instructions. This system's CNC shield ensures reliable and well-coordinated packing mechanism performance by enabling the simultaneous operation of two stepper motors [9].

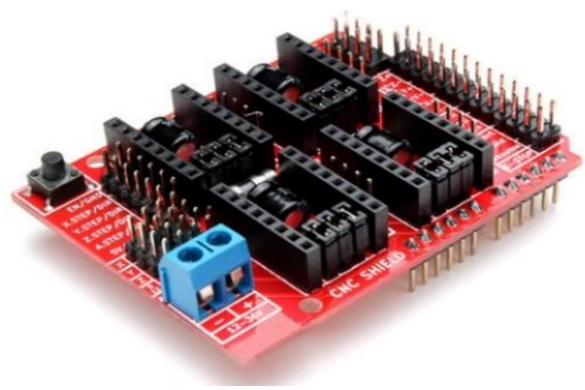

Fig. 6 CNC Shield [9]

The Arduino Mega 2560, seen in Figure 7, was selected as the primary microcontroller for this project because it has more input-output (I/O) connectors and a bigger memory capacity than standard Arduino boards. These features allow it to be used in applications that need complex circuitry and multitasking [10]. The Arduino Mega 2560 is often used in sophisticated systems that need a large amount of code storage and several concurrent connections, such as multi-motor controllers and 3D printers [11]. The CNC shield, motor drivers, and sensors for the semi-automated packaging machine may all be combined on the board used in this study.

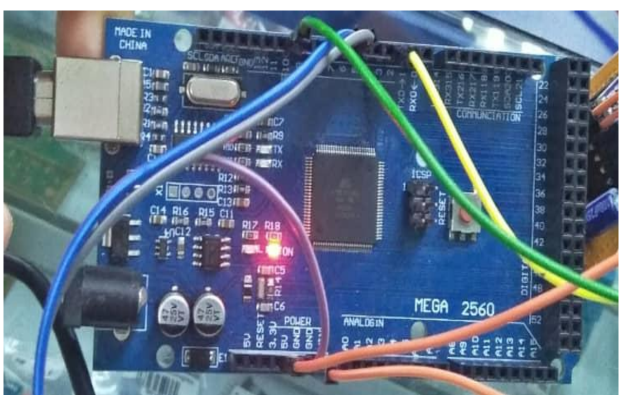

Fig. 7 Arduino Mega 2560

As shown in Figure 8, the Liquid Crystal Display (LCD) serves as the primary user interface in this project for showing system information. The LCD makes advantage of liquid crystals' light-modulating properties, which control the flow of a backlight rather than producing light directly, to produce viewable characters [12]. Through the provision of real-time feedback [13], including timing, process status, and operating directions, the LCD in this system enhances human interaction with the semi-automated packing machine. Because it can display alphanumeric characters, it is a helpful tool for machine monitoring and control [12].

Fig. 8 Liquid-Crystal Display (LCD)

As shown in Figure 9, an I2C interface was added to the 16×2 LCD module to streamline wiring and minimise the number of pins needed. For microcontroller-based systems, the I2C (Inter-Integrated Circuit) protocol is very effective since it only requires two wires (SDA and SCL) to transmit data. Since the Arduino Mega 2560 already supports I2C connection, the LCD may be attached without requiring extra I/O resources. Even when many devices share a communication bus, this design keeps the pin count low while allowing the display of real-time process information.

Fig. 9 I2C LCD

4.2. Electric Motor

For this project, the 12V brushless DC motor (Figure 10) was chosen because of its extended lifetime, high efficiency, and dependability during continuous operation. Due to their widespread availability, affordability, and low maintenance requirements, brushless motors are especially well-suited for prototype development [13]. The motor in this system provides the torque required to move and support the mechanical parts of the rice section and the chilli paste chamber. The semi-automated packing machine operates consistently and efficiently thanks to its mix of performance and durability.

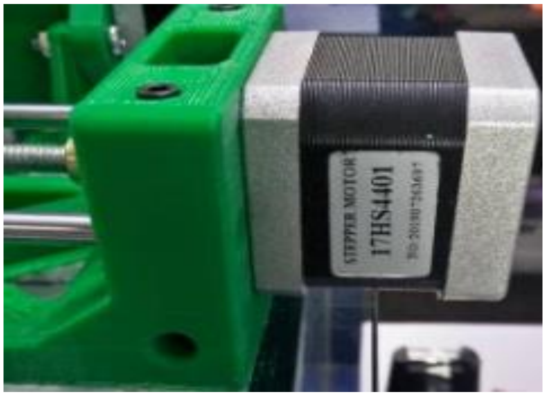

Fig. 10 Stepper Motor 17HS4401

In order to provide exact control over item placement and rotational movement, this project makes use of the 6V servo motor, as shown in Figure 11. With a closed-loop feedback system, a servo motor's precision is maintained by continually monitoring the shaft's position. Because the control signal controls the rotational angle, it may be used in applications requiring a high degree of accuracy. The servo motor is especially used in the semi-automated packaging machine to regulate and manage the positioning of the food ingredients as they are being packaged [14, 15].

Fig. 11 Servo motor MCG946R

The conveyor system used to package the fragrant rice dish from Malaysia is powered by a DC gear motor. For transferring products steadily on a conveyor, this kind of motor combines a gearbox with the DC motor to provide more torque at a lower speed. The motor is driven by the regulated DC supply and runs at a rated voltage of 12V. The DC gear motor was chosen for prototype development because of its cost-effectiveness, efficiency, and dependability under load [16].

4.3. Sensor

The 6V Infrared (IR) sensor used in this study to identify items without physical touch is shown in Figure 12. Infrared light is emitted by IR sensors. It measures the reflection from surrounding objects. This concept makes it very effective in detecting the presence or absence of objects. The precision and reliability are very important in automated systems [16]. Besides, non-contact features can reduce mechanical wear and support stable operation.

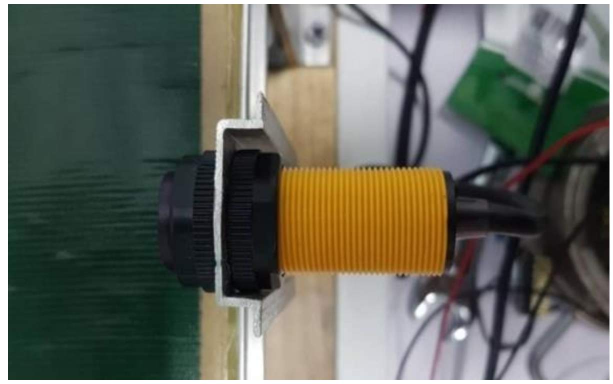

Fig. 12 Infrared Sensor

This semi-automated packaging machine consists of three digital programs of infrared proximity sensors. Sensors 1 and 2 were used to identify the rice and nut component, and to monitor the chilli paste, respectively. Together, these sensors ensured precise sequencing and control of the packing process [17].

5. Result and Analysis

5.1. Performance of the Machine at Various Sensor Distances

By altering the distance between sensors, the performance of the semi-automated packing machine was investigated in this study. The voltage, current, and power consumption measurements taken at different sensor spacings are summarised in Table 1. A clear trend emerged: voltage and current increased progressively with increasing sensor spacing, which increased power consumption. For example, at the shortest spacing of 0.10m, the system only consumed 1.904W, but at 0.18m, the power needed rose to 3.094W, a more than 60% increase.

Table 1. Performance of the machine for various sensor distances

Distance (m)	Time (s)	Voltage (V)	Current (A)	Power Consumption (W)
0.10	5	11.2	0.17	1.904
0.12	10	11.43	0.184	2.103
0.14	15	11.6	0.21	2.134
0.16	20	11.73	0.235	2.756
0.18	25	11.9	0.26	3.094

The longer working time needed when sensors are placed further apart may be used to explain the observed increase in electrical demand. The conveyor system must operate for a longer period of time to carry the cup between sensors when the separation is greater. Consequently, this raises the torque demand on the DC gear motor, which raises the current draw and power consumption. Even though the current increases were somewhat slight, when paired with the increased voltage levels, even little increases had a substantial contribution to the total power usage. This demonstrates how the location of the sensors affects the machine's energy efficiency.

The optimal sensor spacing from a performance standpoint was found to be 0.14 meters. The system recorded a voltage of 11.6 V, current of 0.21 A, and power consumption of 2.134 W at this distance in order to strike a compromise between operational precision and efficiency. While longer distances needlessly raised power consumption and lengthened operation, shorter lengths shortened process time but ran the risk of impairing detection accuracy.

Figure 13 illustrates how voltage and process time are directly impacted by increasing the sensor spacing. Shorter lengths (0.10-0.12 m) are characterised by lower process durations of 5-10 seconds and a relatively constant voltage range of 11.2-11.43 V. However, these factors become much more important as the interval increases. At 0.18 m and 11.9 V, the process takes 25 seconds to finish. This pattern suggests that longer conveyor operating durations and hence higher voltage needs are caused by longer distances. Interestingly, the graph shows that the system maintains a fair trade-off between process speed and power usage at an ideal spacing of 0.14 m. Efficiency declines after this because of needless delays and increased voltage use.

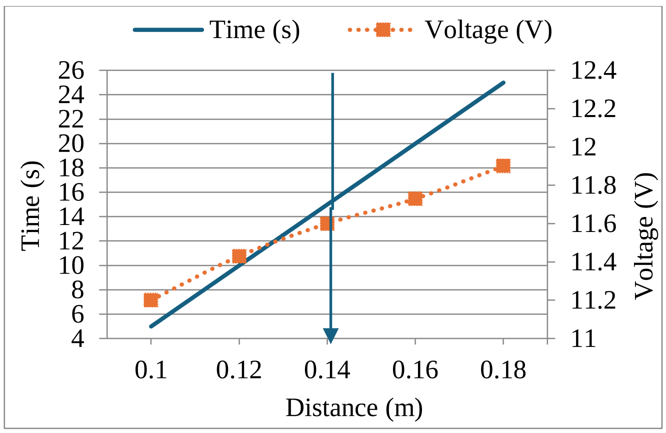

Fig. 13 Time and voltage versus distance

Additionally, Figure 14 shows how closely voltage, current draw, and sensor spacing are related. Both voltage and current progressively increase with distance. The voltage is 11.2 V at 0.10 m and 0.26 A, and 11.9 V at 0.18 m. 0.17 A of current is flowing. The DC gear motor encounters more torque demands over longer distances, resulting in an increased current draw, as seen by the linear rising trend. As previously shown in Table 1, a little increase in current results in a considerable increase in power consumption when combined with higher voltage. The balanced point, when voltage (11.6 V) and current (0.21 A) remain within acceptable ranges and ensure efficacy without overtaxing the system, is once again determined to be 0.14 m.

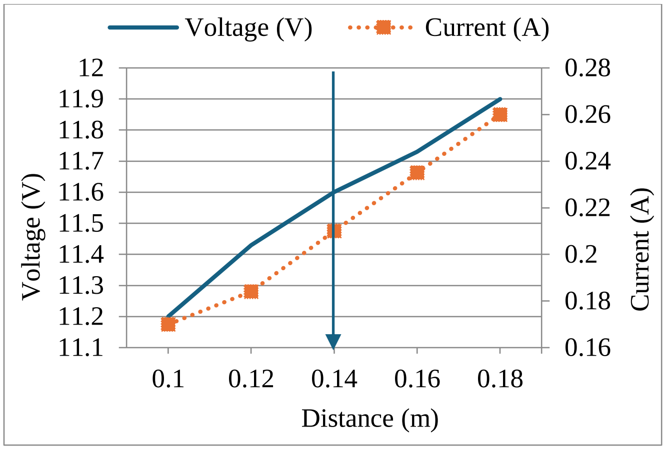

Fig. 14 Voltage and current versus distance

Furthermore, Figure 15 illustrates the relationship between sensor distance, current draw, and power consumption of the semi-automated packaging machine. The findings indicate that while the current progressively rises with distance, the increase is less noticeable than the growth in power usage. For instance, the current only increases somewhat, from 0.17 A at 0.10m to 0.26 A at 0.18 m. But in the same time frame, power usage almost doubles, rising from 1.904 W to 3.094 W.

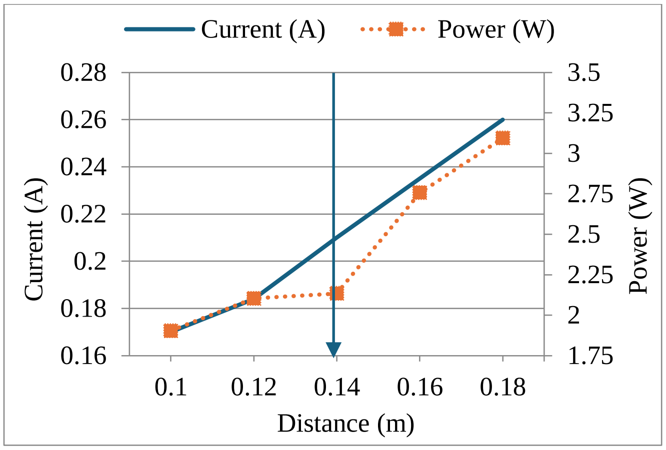

Fig. 15 Current and power versus distance

Given that power is a multiplicative function of both voltage and current, this large increase in power emphasises how sensitive the system's energy consumption is to both factors together. The conveyor and motors must run for longer periods of time when the sensor distance is longer, which disproportionately increases energy usage. According to the statistics, operating over 0.14 m results in needless power loss, which lowers the system's efficiency. Because it strikes a compromise between current stability and modest power usage, 0.14 m is determined to be the ideal sensor distance. While larger distances put a greater electrical strain on the system without enhancing efficiency, shorter distances save time but run the risk of sacrificing detection accuracy.

The semi-automated packing machine was tested to see whether it could distribute plain rice, rice with chilli paste, and rice with nuts in it, among other classic Malay fragrant rice dinners. The machine's constant functioning is shown in Table 2. The results show a steady development in dispensing weight over time. At 1 second, the weight of regular rice was 0.024 kg. Meanwhile, at 5 seconds, it was 0.103 kg. Over the same time period, the amount of rice containing chilli paste increased to 0.120 kg from 0.027 kg. This shows a significantly higher rate. The heaviest weight at 5 seconds was 0.164 kg of rice, which was filled with chilli paste and nuts.

Table 2. Operational performance based on rice dish weight

		Time (sec)				
		1	**2**	**3**	**4**	**5**
Weight (Kg)	**Rice**	0.024	0.041	0.060	0.083	0.103
	Rice and Chilli Paste	0.027	0.046	0.069	0.096	0.120
	Rice and Chilli Paste with Nut	0.035	0.063	0.093	0.128	0.164
Voltage (V)		11.2	11.45	11.6	11.76	11.9
Current (A)		0.18	0.185	0.19	0.195	0.2
Power Consumption (w)		2.016	2.118	2.204	2.293	2.380

The equipment operated steadily in terms of electrical performance. While the voltage stayed within a small range of 11.2 V to 11.9 V, the current only marginally rose from 0.18 A to 0.20 A as the load grew in weight. As anticipated, power usage increased from 2.016 W at startup to 2.380 W after five seconds. Continuous operation benefits from the virtually linear trend, which displays energy efficiency with minimum deviations.

All things considered, the outcomes show how dependable, energy-efficient, and flexible the semi-automated packing machine is in handling a variety of food situations. These properties make it excellent for small-scale food companies and commercial traditional meal preparation, where consistency and cost-effectiveness are critical.

6. Discussion

The need for efficiency, standardisation, and cost reduction in small-scale firms is pushing the development of semi-automated food processing systems. The semi-automated packaging equipment used in this research was specifically designed to make traditional Malay fragrant rice dinners, which are gourmet dishes produced with plain rice and a range of toppings, including chilli sauce and nuts. Figures 16 to 20 summarise the machine's performance under different operating conditions, paying special emphasis to dispensing weight, voltage stability, current draw, and power consumption. These results are thoroughly examined in the discussion that follows, which also offers insights into the machine's efficacy and its industrial use.

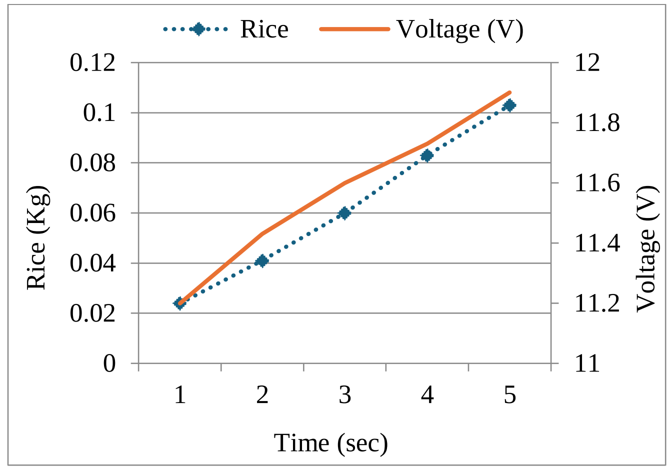

Fig. 16 Relationship between rice weight and voltage over time at fixed sensor distance (0.14 m)

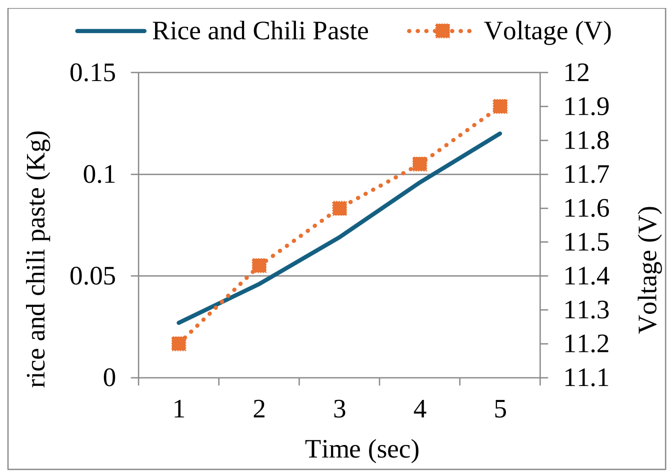

Fig. 17 Relationship between rice–chilli paste weight and voltage over time at a fixed sensor distance of 0.14m

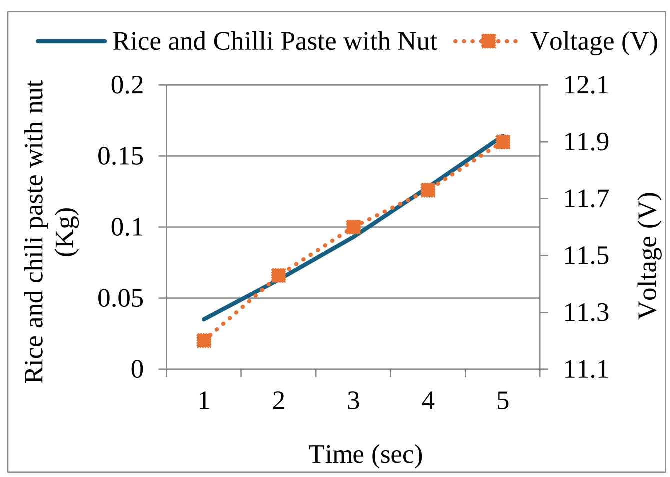

Fig. 18 Effect of rice, chilli paste, and nut weight on voltage at various times with sensor distance fixed at 0.14m

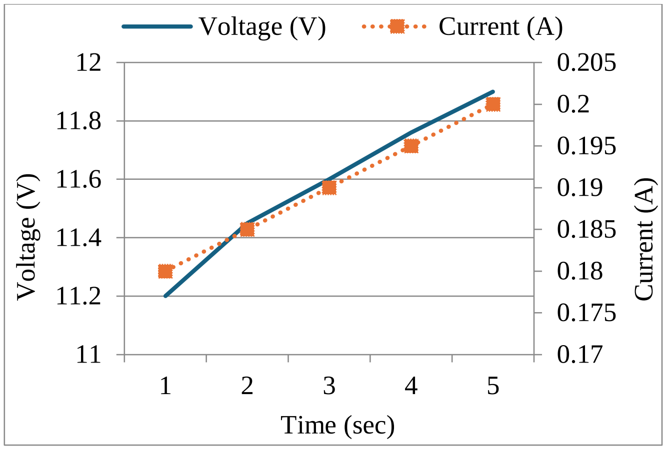

Fig. 19 Voltage–current characteristics over time at 0.14m sensor distance

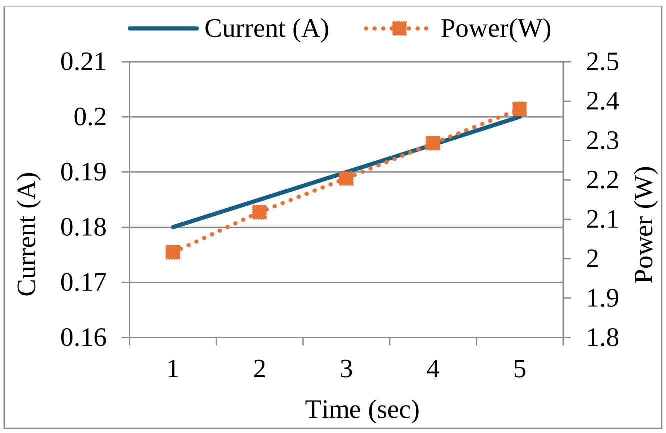

Fig. 20 Power–current characteristics across time with sensor distance maintained at 0.14m

6.1. Weight Dispensing Characteristics

The ability of a packing machine to precisely and consistently distribute food amounts is its primary performance indicator. The dispensing time and the total weight of food supplied for the three categories of plain rice, rice with chilli paste, and rice with nuts obviously have a linear connection, as shown in Figures 16 to 18. This linearity demonstrates that the mechanical parts, more especially, the hopper, auger, or feeding mechanism, are in sync with the timing system and that the dispensing system is correctly calibrated.

At one second, the delivered weight of plain rice is 0.024 kg; at five seconds, it is 0.103 kg. This result is consistent with what would be expected from a granular food ingredient that flows freely and has no resistance. Over the same time period, rice with chilli paste showed somewhat higher dispensing weights, rising from 0.027 kg to 0.120 kg. This implies that the addition of chilli pastes increases mass density. Then, the machine can dispense more weight for the same amount of time. Finally, the combination of rice, nuts, and chilli pastes makes the heaviest weight dispensing. It rises from 0.035 kg at 1 second to 0.164 kg at 5 seconds.

6.2. Electrical Performance and Stability

The electrical performance is shown in Figures 19 and 20. Based on the results, the voltage was maintained within the range of 11.2 to 11.9 V throughout each test conducted. This consistency indicated that the machine's motor and power supply operate successfully for the operation. Besides, the voltage changes could cause inconsistent motor action, thus affecting the accuracy of filling. Given that the voltage remains consistent under diverse scenarios, it implies that the electrical system is well-suited to the mechanical demands.

The current values increased gradually from 0.18 A at 1 second to 0.20 A at 5 seconds. The little increase, however, suggests that even when working with sticky or irregular mixes, such as rice with almonds and chilli sauce, the machine is not put under a lot of mechanical strain. This result indicates strong long-term durability and emphasises the machine's drive system's efficiency.

Figure 20 illustrates how power usage rose from 2.016 W to 2.380 W in a linear fashion with dispensing time. For continuous industrial usage, a predictable and controllable relationship between current and power is ideal. The machine is ideal for small-scale or household-level activities when energy saving is essential because of its very low total wattage when compared to bigger, fully automated packing systems.

6.3. Integration of Mechanical and Electrical Systems

The machine's ability to work in combination with electrical operation and mechanical dispensing is one of its main advantages. Current and power usage increased proportionately and steadily with the linear rise in dispensed weight for all meal categories. This shows that there are no indications of overloaded or irregular behaviour, and the machine runs within a balanced performance envelope.

It is particularly vital to be able to maintain the electrical properties stable when delivering thick or sticky food ingredients. Semi-solid or sticky ingredients are difficult for many dry food packing machines to handle, which often leads to blockage, uneven portioning, or higher energy use. This problem is resolved by the new system, indicating that the dispensing unit's design and motor specifications were carefully chosen to meet the operating requirements.

6.4. Practical and Impact Assessment

From a financial standpoint, the proposed semi-automated packaging machine offers a less expensive solution to fully automated industrial packaging systems. Because the system employs widely accessible components and a straightforward control architecture to reduce both initial and continuing expenses, it is suitable for small and medium-sized food enterprises that mostly depend on manual packaging operations. Under the tested operating circumstances, the machine uses less electricity. The system's low energy consumption contributes to decreased running costs.

Furthermore, in contrast to standard automated packaging equipment, it facilitates continuous use in small-scale food production circumstances.The technique enables employees to do repetitive packaging operations in a semi-automated manner. This demonstrates that human work will not be entirely replaced by technology. While enhancing output, working conditions, and cleanliness, this strategy may preserve employment opportunities in standard food preparation facilities.

6.5. Benchmarking and Cost Analysis

High capacity and complete automation are the main goals of many contemporary automated systems. Nevertheless, they often call for larger capital expenditures, higher energy use, and more complex control systems. However, the suggested semi-automated packing machine shows consistent and continuous performance at a reduced energy usage of around 2-3 W while maintaining dependable portioning for multi-component standard meals.

The proposed technique provides greater portioning uniformity and quicker packing times compared to manual packaging. Besides, the manual packaging requires less initial capital but leads to high labour costs and irregular production. Fully automated systems, while capable of great throughput and accuracy, usually need large initial and continuous expenses. Therefore, this system provides a solution by combining inexpensive hardware and small energy usage. The suggested technology's economic viability for small to medium-sized conventional food packaging applications is shown by this cost-performance balance.

6.6. Comparative Analysis with Manual and Automated Packaging Systems

To better position the proposed semi-automated packaging machine within existing food packaging approaches, a comparative analysis is presented against manual packaging practices and reported semi- and fully-automated systems. The comparison in Table 3 focuses on key aspects, including cost, operational efficiency, portioning consistency, scalability, and power consumption, based on experimental results obtained in this study and findings reported in the literature. Beyond performance comparison, it is also important to consider the broader economic, energy, environmental, and social impacts of the proposed system.

Table 3. Qualitative comparison of packaging approaches

Aspect	Manual packaging	Fully automated systems (Literature)	Proposed system
Capital cost	Very low	Very low	Very low
Labor dependency	High	Low	Moderate
Portioning consistency	Low	High	Improved
Throughput	Low	High	Moderate
Scalability	Limited	High	Suitable for SMEs
Power consumption	None	High	Very low (≈2–3 W)

6.7. Environmental and Social Impact Considerations

From an energy standpoint, the semi-automated packing machine runs at a very low power level of roughly 2-3 W under the tested circumstances. The system may be used continuously in small-scale food production settings. This is because it utilises low operational expenses and power usage. Reducing energy use results in fewer related emissions from an environmental perspective. Furthermore, compared to human packing methods, the enhanced portioning regularity achieved by semi-automation may help reduce food waste, promoting more environmentally friendly food processing processes.

In terms of social impact, the suggested strategy promotes a semi-automated approach that helps workers with repeated packing tasks rather than completely replacing human labour. While maintaining job opportunities in conventional food preparation and small food businesses, this method may improve working conditions, increase cleanliness and uniformity, and promote production.

6.8. Regulatory and Food Safety Considerations

Strict food safety and hygiene regulations must be maintained by any equipment used in food packaging that has direct contact with food. Although formal certification was outside the scope of this prototype-based research, the design of the recommended semi-automated packing machine was informed by fundamental sanitary design considerations often utilised in food processing equipment. These guidelines include avoiding exposed joints and crevices, adopting designs that are simple to clean, and selecting materials that are appropriate for food contact to decrease the risk of contamination. Regular portioning and regulated dispensing also support sanitary packing practices by avoiding needless manual handling.

From a regulatory aspect, this technique aligns with the fundamental objectives of food safety management systems, including ISO 22000 and HACCP-based standards. These frameworks prioritise risk minimisation and controlled processing conditions when handling and packaging food. Although formal compliance testing and certification would be required for commercial deployment, the design demonstrates thorough consideration of hygiene and regulatory aspects critical to small-scale food packaging applications.

6.9. Modularity and System Adaptability

The proposed semi-automated packing machine's modular design enables flexible adaptation to different food varieties and operating requirements. The dispensing mechanism, sensor placement, and control settings are examples of major system components that may be altered independently without substantially changing the overall design.

In addition, the dispensing mechanism may be changed to handle varied food textures, including dry granular materials, semi-solid items, or blended ingredients, due to the modularity characteristics. Additionally, operational factors like sensor thresholds and dispensing duration are adjusted using software updates rather than hardware replacements. This is because the system utilises microcontroller-based control logic.

As a result, the system can be customised for a wide range of small-scale food packaging applications while maintaining low system complexity and cost. This modular and flexible design also facilitates scalability and future upgrades, making the suggested technique appropriate for increasing production demands and product variants.

6.10. Digital Integration and Data-Driven Capabilities

Even while the proposed system presently operates as a stand-alone semi-automated packaging machine, its microcontroller-based architecture provides a solid foundation for future digital integration. Sensor data pertaining to packing time, electrical parameters, and operational status may be maintained locally or transferred with other devices for monitoring and record-keeping purposes.

Basic communication modules can be integrated into the system to enable Internet of Things (IoT) connectivity. Besides, it can support remote monitoring of system performance and energy consumption. Then, the operational data can be used to support predictive maintenance by detecting unexpected operating issues, such as excessive power consumption or irregular dispensing behaviour. This is to prevent component failure from occurring. Even though the current prototype does not include these digital components, they are feasible future additions that are in line with smart manufacturing principles.

6.11. User Experience and Ergonomic Considerations

For semi-automated food packaging systems intended for traditional, small-scale food processing plants, user experience is crucial. Because of its easy control logic and minimal setup requirements, the recommended system enables operators with minimum technical skill to manage the machine effectively.

By eliminating repetitive manual tasks associated with portioning and packaging, the semi-automated process reduces operator fatigue and physical strain. The system displayed consistent and dependable performance throughout the experiment, allowing for seamless operator-machine interaction without the need for ongoing human adjustment.

Qualitative observations demonstrate that the recommended approach improved ease of use, portion consistency, and cleanliness when compared to manual packing techniques, even if formal usability testing was beyond the scope of this prototype-based research. These results highlight how vital user-centred design is to produce feasible and efficient semi-automated food packaging systems.

6.12. Future Prospects

As shown by the performance assessment in Figures 16 to 20, the semi-automated packing machine reliably distributes food quantities of different types. These results indicate the machine’s robustness, adaptation, and flexibility for small-scale food operations, especially those that focus on traditional cuisine. Beyond its technological advantages, the system might develop into a widely available, sustainable technology that promotes industrial productivity and environmental responsibility. Although the technique has exhibited good results, more developments might widen its use. For example, adding more advanced sensors might significantly improve accuracy, particularly for blends that are very viscous. The device may be easily customised to accommodate traditional cuisines other than fragrant rice dinners.

By combining thorough performance evaluation, electrical-mechanical interaction analysis, repeatability assessment, and benchmarking against current packaging techniques, the study’s analytical scope goes beyond simple prototype validation. The study is positioned as a significant addition to semi-automated food packaging research, especially for small to medium-scale food production contexts and conventional multi-component meals, thanks to these thorough evaluations.

7. Conclusion

The design and development of a semi-automated, user-friendly packaging machine for the aromatic rice dish from Malay culture successfully achieved the project’s objectives. The apparatus demonstrated that semi-automation may be effectively integrated into traditional food packaging and operated effectively. Performance evaluation showed reliable functioning by showing a correlation between increases in meal weight and increases in voltage, current, and total power consumption. For example, in only 5 seconds, the delivered weight of plain rice climbed progressively from 0.024 kg to 0.103 kg, and for rice with nuts and chilli sauce, it increased to 0.164 kg. The power usage increased predictably from 2.016 W to 2.380 W as the voltage stayed constant between 11.2 and 11.9 V and the current increased marginally from 0.18 A to 0.20 A. The results demonstrate that the system that was developed is ideal for small enterprises and consumer applications due to its efficiency, affordability, portability, and ease of use. Food stalls, workplaces, and other high-demand settings may use the machine because of its low power consumption and straightforward operation. This approach has a great chance to supplement or replace traditional manual packing techniques as digital and automated technologies develop further. This would increase the food industry's productivity, standardisation, and competitiveness, especially in traditional meal preparation. The originality of this study lies in the development and experimental evaluation of a low-cost, semi-automated packaging system tailored for traditional multi-component rice meals. By systematically analysing the relationship between dispensing weight, packaging duration, and electrical performance, this work extends existing food packaging automation studies that largely focus on standardised products or fully automated systems.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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