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Original Article

Development of An IoT-Based Smart Billing System for A Multipurpose Machine

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Abstract *- The evolution of energy consumption tracking has witnessed a notable transition from traditional meters to digital smart meters, providing detailed insights into electricity usage. These smart meters not only enable precise billing but also empower consumers to monitor and optimise their energy consumption. However, challenges persist in the billing systems of most developing nations, e.g. Kenya. These existing billing systems may not work if implemented in small-scale workshops, considering their inefficiencies, including manual intervention, billing errors, delays, and lack of awareness regarding tariffs. All these affect billing accuracy, customer satisfaction and the economy. Small-scale workshops, like those in Kenya, are crucial to society but face obstacles due to the slow adoption of modern technology. The proposed system, with its transformative potential, is set to revolutionise the way small-scale workshops operate. Incorporating IoT into billing procedures plays a pivotal role in enhancing billing accuracy, transparency, and revenue generation, offering clients personalised access to real-time billing information. The system architecture includes real-time monitoring of energy usage, client notifications through SMS and email, and automated billing based on factors like power consumption and operational variables. The research strives to develop and implement an IoT-based automated billing system for small-scale multipurpose machines, enabling individual client billing without human intervention. The system provides a user-friendly interface, client login access, and post-payment options, enhancing operational efficiency and customer experience. By integrating IoT technology and AI, the system streamlines billing processes, enhances accuracy, and aligns with the Industry 4.0 paradigm, contributing to sustainable development goals. The incorporation of Internet of Things (IoT) and Artificial Intelligence (AI) technologies into small-scale workshops using an automated billing system is notable progress in enhancing operational efficiency, generating revenue, and satisfying customers. This aligns with the transformative goals of the fourth industrial revolution and sustainable development agendas.*

Keywords *- Smart energy meter, Billing, Automation, IoT, Raspberry Pi board, Python.*

1. Introduction and Background

In the past, energy consumption tracking was limited to traditional meters that provided basic information on electricity usage. However, with the advancement of technology, digital smart meters have been developed to offer more detailed insights into energy consumption [1]. These smart meters not only enable accurate billing but also allow for the monitoring and analysis of electricity usage at the consumer level.

The billing system, which dates back to medieval times, has evolved over the centuries to keep pace with changing consumer needs and technological advancements. Energy meters have traditionally been used to record electricity usage in homes and businesses. Smart energy metres, which are equipped with integrated electronics and wireless communication capabilities, offer instantaneous data on energy consumption, enabling consumers to monitor and improve their electricity usage [2].

The current billing systems face various challenges, including labour-intensive processes, human errors, inaccurate meter readings, delays in bill payments, lack of awareness regarding tariffs and power theft. These issues not only influence the efficiency of billing operations but also lead to incorrect pricing and billing, thereby affecting the overall economy. Small-scale workshops (such as those run by Jua Kali artisans in Kenya) play a significant role in society by generating revenue through machining services and the production and repair of farm equipment and tools. However, the minimal adoption of modern technology in these workshops has hindered their growth and efficiency.

The existing billing systems in most developing nations (for example, Kenya) may not work if implemented in small-scale workshops, considering that inefficiencies, including manual intervention and billing errors, plague them. These challenges not only influence businesses' cash flow but also hinder the adoption of modern technologies that could improve operational efficiency and customer satisfaction. Therefore, there is a pressing need to develop an automated billing system that leverages IoT technology to track machine usage, calculate accurate bills for each client, and facilitate seamless payment processes. These are components of Industry 4.0. Hence, it is necessary to incorporate the Fourth Industrial Revolution (4IR), sometimes referred to as Industry 4.0, into small-scale manufacturing industries [3].

The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) technologies has facilitated the development of cutting-edge solutions across multiple industries. In line with this trend, developing an IoT-based automated billing system for small-scale multipurpose machines presents an opportunity to streamline billing processes and enhance operational efficiency [2, 3]. Thus, it embraces the fourth industrial revolution even in small-scale workshops. This will contribute to the African Union Agenda 2063: Sustainable Development Goals (SDG) on Transformed economies [4, 5].

This study addresses the challenges faced by traditional billing systems in small workshops by proposing an independent client billing system that automates the invoicing process and provides clients with transparent billing information. Therefore, the main objective of this study is to develop and implement an IoT-based automated billing system for small-scale multipurpose machines that enables individual client billing without human intervention.

By integrating IoT technology into the billing process, the system aims to improve billing accuracy, enhance transparency for clients, and optimise revenue generation for small workshops. Additionally, the system will empower clients with personalised login credentials to operate the machine and access real-time billing information, thereby fostering a more efficient and customer-centric billing experience. Such a system does not exist-existing metering systems bill for utility power consumption. However, the proposed smart metering and automatic billing system under this study targets machines (small-scale workshops) and employs IoT. It is a personalised type of system that is able to serve a machine.

Billing technologies are essential in various sectors, such as energy and healthcare, affecting payment processing and service delivery. The advancement of billing systems, like smart meters in energy consumption and e-billing systems in tax payments, has revolutionised traditional billing methods into more efficient and user-friendly processes. These technologies streamline billing procedures, offer real-time monitoring, and provide personalised billing solutions [6]. Moreover, the implementation of innovative billing technologies, such as mobile financial reimbursement systems, has improved the accuracy and speed of billing information processing. For instance, prepaid metering systems have shown the potential to enhance service access, particularly among underserved populations [7]. Smart meters have played a crucial role in revolutionising billing systems, enabling real-time monitoring of energy consumption and facilitating efficient billing processes. Studies have shown that integrating smart meters into energy management systems enhances energy efficiency and enables effective monitoring of power quality within smart grids [1, 8]. Furthermore, the development of IoT-based smart metering systems has further improved energy management by providing scalable and responsive solutions for monitoring energy consumption in real-world environments [9].

Chooruang et al. [10] addressed the necessity for a cost-effective IoT energy monitoring system to encourage energy efficiency. By incorporating Message Queuing Telemetry Transport (MQTT) protocol for communication and integrating various sensors and microcontrollers, the system provides a practical solution for real-time energy monitoring. Nonetheless, there exists a clear challenge in the accessibility of such systems in developing countries due to cost implications, underscoring the significance of further research in developing affordable energy monitoring solutions. Karthick et al. [11] proposed various aspects related to energy management in smart grids, focusing on strategies like Demand Side Management (DSM), trans-active energy, and IoT devices. It explores the optimisation of residential microgrids through centralised and decentralised approaches, aiming to make decisions for optimal resource utilisation without compromising privacy. Additionally, it delves into pricing schemes and the introduction of smart energy meters based on IoT technologies for efficient billing and energy measurement processes.

Hasan et al. [12] proposed a novel approach to energy monitoring and control in households, leveraging IoT technology to provide real-time feedback on energy consumption. However, gaps in the study may include the need for further validation of the system's effectiveness in real-world settings and the scalability of the proposed solution to accommodate larger energy systems beyond household appliances. Additionally, addressing potential security and privacy concerns associated with IoT devices and data transmission could be crucial for the successful implementation of such systems in residential settings. Santhosh et al. [13] discussed the implementation of an IoT-based smart energy meter using Global System for Mobile (GSM) technology. The proposed system integrates smart meters with GSM modems to communicate energy consumption data over mobile networks wirelessly. This advanced metering technology allows for the remote reading, processing, and transmission of energy data to users. By incorporating smart grid technologies, the system aims to address the increasing power demand by providing an alternative method for measuring and billing energy consumption. The smart energy meter continuously monitors voltage and current readings, analyses the data, and displays the information on an LCD or LED screen. Unlike traditional billing methods that are prone to errors, the smart metering system ensures accurate readings and eliminates the need for manual data collection. Additionally, the system can send alerts, such as low-balance or zero-balance notifications, to users via SMS through the GSM modem. By leveraging GSM modems for communication, the smart metering system offers personalised and centralised energy monitoring and control capabilities, contributing to more efficient energy management.

1.1. Power Monitoring and Management

The integration of advanced billing technologies, particularly smart meters, has significantly enhanced billing processes in various sectors by offering real-time monitoring, personalised solutions, and streamlined procedures. These technologies have not only improved efficiency but also contributed to better energy management and secure billing transactions within smart grid environments. Smart metering in manufacturing, particularly when based on the Internet of Things (IoT), presents a promising avenue for enhancing energy management and operational efficiency.

Orlando et al. [14] emphasise the cost-effectiveness and scalability of implementing smart meters using off-the-shelf hardware, indicating a practical approach to deployment. This aligns with the need for efficient solutions in manufacturing settings. Additionally, [15] highlights the role of IoT in enabling real-time data collection for smart meters, underlining its significance in monitoring and securing energy consumption. Furthermore, [16] discusses the prevalence of standard-based protocols like the Device Language Message Specification (DLMS) protocol in the industry. This suggests a need for interoperability and standardisation in IoT-based smart metering systems. This interoperability is crucial in manufacturing environments where diverse equipment and systems are in operation.

Chen [17] introduced the concept of IoT-based smart grids, emphasising the integration of traditional industrial technologies with IoT advancements. This integration could offer manufacturing facilities a comprehensive approach to energy management and optimisation. Moreover, Hidayati Nashiruddin [18] conducted a study on Low Power Wide Area (LPWA). They stressed the importance of LPWA-based IoT technologies for real-time energy management, which could be particularly beneficial in manufacturing setups with dynamic energy demands. This aligns with the need for efficient energy usage in industrial processes. The existing literature underscores the potential of IoT-based smart metering in manufacturing to enhance energy efficiency and operational processes. However, gaps exist in areas such as standardisation, interoperability, and cost-effective deployment strategies, which warrant further research to optimise smart metering systems in manufacturing environments.

Moreover, exploring the implications of billing technologies on user behaviour, service quality, and financial management is vital for shaping future billing systems and ensuring seamless transactions in the digital era. Furthermore, the concept of automatic billing has never been discussed in small-scale manufacturing workshops (i.e. Jua Kali). Hence, the billing technology trends in literature can be used in manufacturing, particularly in the usage of multipurpose machines for small-scale workshops. The need arises to have a customer-centric automatic billing system that is user-friendly and more interoperable.

2. Materials and Methods

A smart metering system includes monitoring, control, and communication systems. To achieve this, Figure 1 below highlights the most important aspects of the work under study.

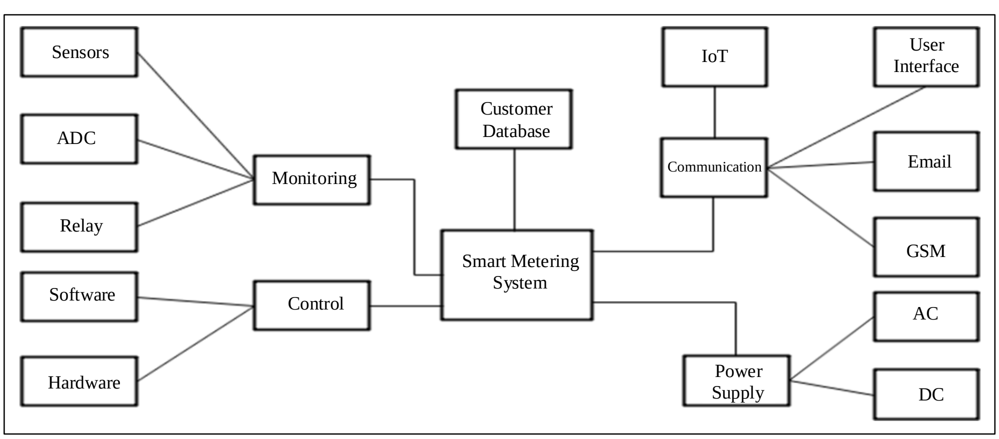


Fig. 1 Block diagram representation of a metering system

2.1. Sensors

2.1.1. Current and Voltage Sensors

In this study, the ACS712 current sensor Figure 2 and the ZMPT101B voltage sensor Figure 3 were used. These sensors operate from 5V. The current sensor outputs an analogue voltage proportional to the current measured on the sensing terminals. A Raspberry Pi, along with ADC, is used to read the values. ACS712 current sensor gives precise current measurements for both AC and DC (up to 5A) signals. The ZMPT101B, on the other hand, is an AC voltage sensor module that can measure AC voltages. Its output is analogue and varies as the input voltage changes. The module uses a resistive voltage divider circuit-based DC voltage-sensing device to generate an analogue output. These sensors are suitable for accurately quantifying and assessing the total power usage of a system [19, 20].

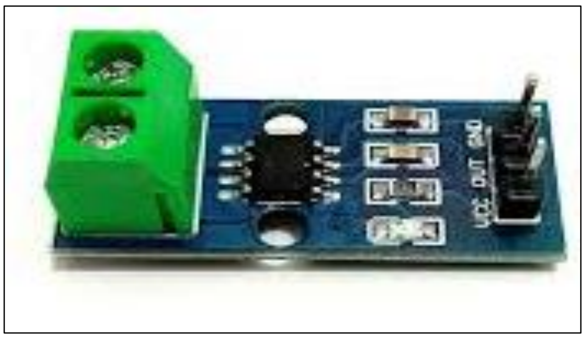


Fig. 2 Current sensor ACS712

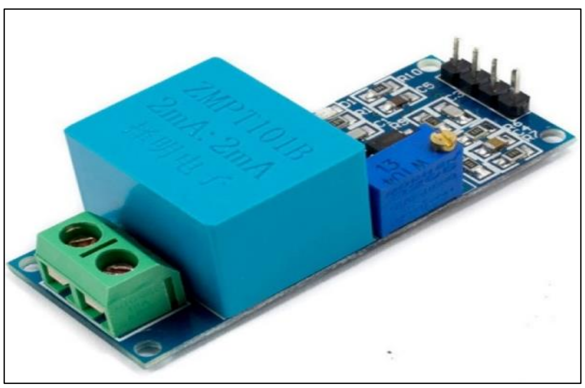


Fig. 3 Voltage sensor zmpt101b

2.1.2. ADC and GSM

The ADS1115 16-bit ADC module, as shown in Figure 5, is a valuable component in systems requiring high-resolution analogue-to-digital conversion, offering superior accuracy and precision in capturing and digitising analogue signals for various applications. Its capabilities make it a preferred choice in scenarios where exact signal conversion is essential, such as in research-grade instrumentation and measurement systems. In this study, it was used to convert the voltage and current analogue values into digital values so that the Raspberry Pi microcomputer could interpret them. On the other hand, the GSM SIM800L module Figure 4 can enable communication through SMS and calls, along with its compatibility with various microcontrollers and sensors, making it a valuable component in the development of efficient and reliable systems across different domains. It has been used here to send the bill in the form of SMS to clients after they have finished operating the multipurpose machine [20-22].

Fig. 4 GSM SIM800L module

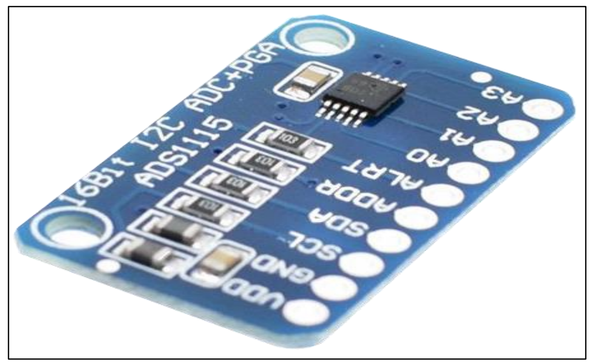


Fig. 5 ADC module

For this proposed billing system, a Raspberry Pi microcomputer was integrated, and it serves as the brain of the whole process. A continuous flow of data is transferred from the sensors to the Raspberry Pi via ADC and then to the cloud (Google Sheet), as illustrated in Figure 6. At the end of the machining process, the data is downloaded. Then, a final bill is computed based on the power consumption data and another miscellaneous amount for the sustainability and feasibility of the business. Figure 7 shows the Multipurpose Machine (MPM), whose IOT-based smart billing system was developed under this study.

Simultaneous execution of drilling, grinding, cutting and shaping/grooving operations is possible with this multipurpose machine Figure 7, which prioritises the use of coupling mechanisms to engage and disengage operations in order to deliver high power and improve performance, thereby reducing the time, energy, and labour required for operations. Coupling is utilised to achieve both engagement and disengagement. Depending on the need, the operator may execute any single operation, a combination of two operations or all four operations at once.

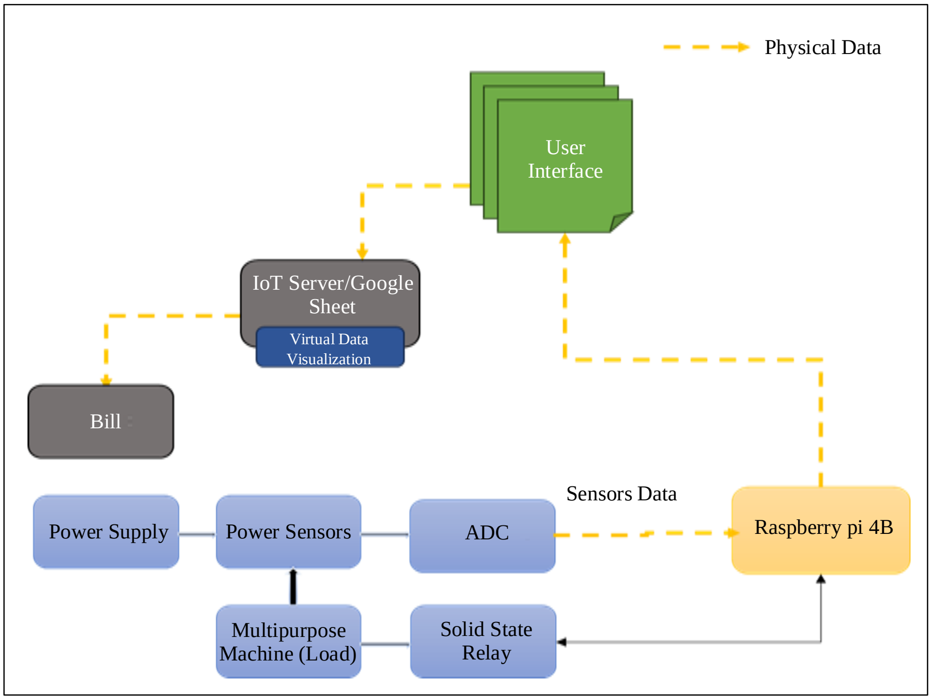


Fig. 6 Architecture of the automatic billing system

Fig. 7 Multipurpose machine at JKUAT

Key features of the machine are:

- Performs drilling operations
- Performs hacksaw cutting
- Cuts grooves and does shaping work
- Performs grinding
- Motion disengagement and engagement mechanism made up of a pinion and rack.
- Suitable for small-scale/farm workshops
- It is portable and consumes less power
- It uses single-phase AC voltage
- Requires less safety protocols from the operator

2.2. The Architecture of the Proposed Automatic Billing System

Figure 8 shows the system architecture, highlighting all the components of the proposed smart billing model using the Raspberry Pi 4b model.

Additionally, Figure 9 shows the block diagram of the IOT-based smart billing control system for power monitoring of a multipurpose machine. The energy consumption is monitored with a Raspberry Pi microprocessor, and the result is displayed on the user interface screen.

Upon completion of the machining process, the clients get an SMS (with the help of a GSM) and a mail notifying them about their total bill after using the MPM. Throughout the execution and simulation of this project, Python 3 was used with the help of Vscode software and a few libraries were installed. Below is the list of the few libraries used in this study:

- pip install adafruit-circuit python-ads1x15 (library for ADC)
- pip install secure-smtplib (library for sending email)
- pip install gspread (library for current and voltage sensor)
- pip install requests (library for Google sheet request)
- pip install pandas (library for data manipulation and analysis)
- pip install numpy (numerical computation)
- pip install scipy sci-kit-learn (library built on numpy and provides additional functionality for scientific and technical computing)
- pip install num2words (used for changing Python dictionaries to word)
- pip install pyserial
- sudo usermod -a -G dialout Paulo
- ls -l /dev/ttyS0
- twilio==9.0.0
- typing_extensions==4.9.0
- tzdata==2024.1
- urllib3==2.2.1
- yarl==1.9.4
- smbus==1.1.post2
- StrEnum==0.4.15

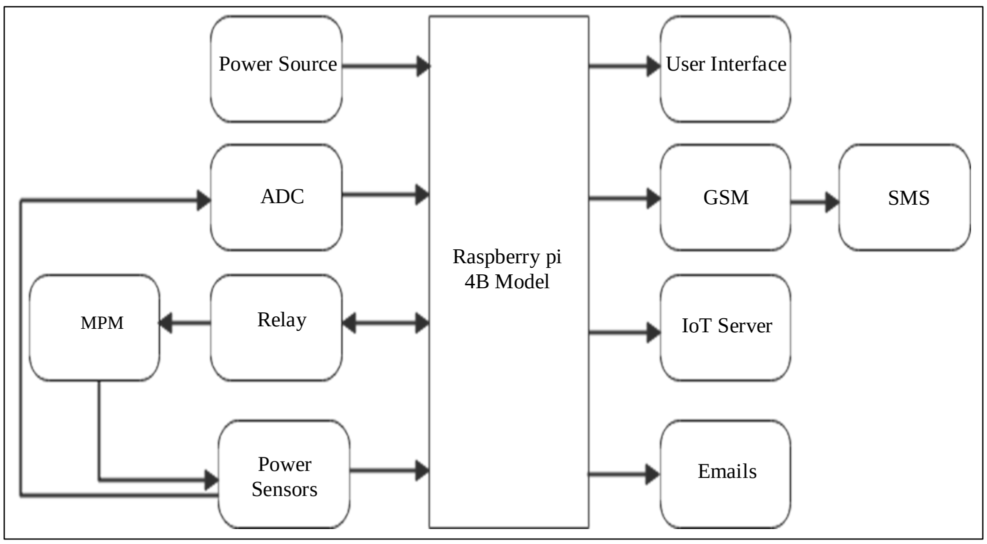


Fig. 8 Implementation of the billing system

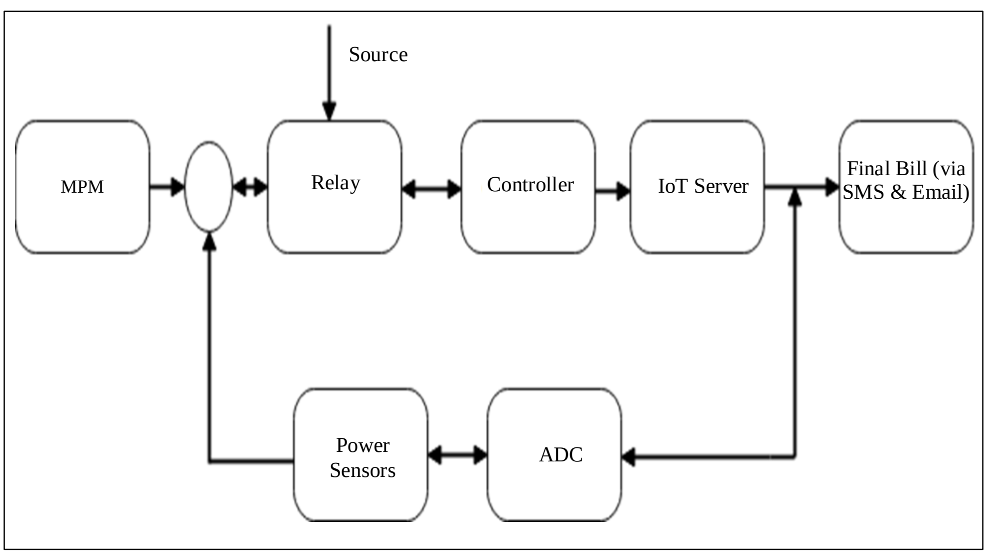


Fig. 9 Block diagram of the billing system

For real-time monitoring, the power consumption data (Voltage, current, power and energy data) was continuously sent to an online IoT platform, and the data was also displayed on a dashboard or client's interface.

A GSM SIM800L module and Twilio (which works on a subscription basis) were selected to send SMS to the client at the end of the machining process, highlighting their total bill. In addition, a Java script algorithm was used to also send emails to the customer with their final bill at the end of every machining process.

Clients cannot start the machining without first having to sign up if they do not have an account created yet. Once the account is created, the client can only perform the machining after successfully logging in using the login credentials generated during the signup process. Only after logging in successfully can the client start the machine. The start machine button turns on the relay (5V 1 Channel module SRD), which then turns on the MPM. At the end of the machining process, the client must hit the stop machine button and then log out. Figure 10 shows the flowchart for the execution of the proposed billing system.

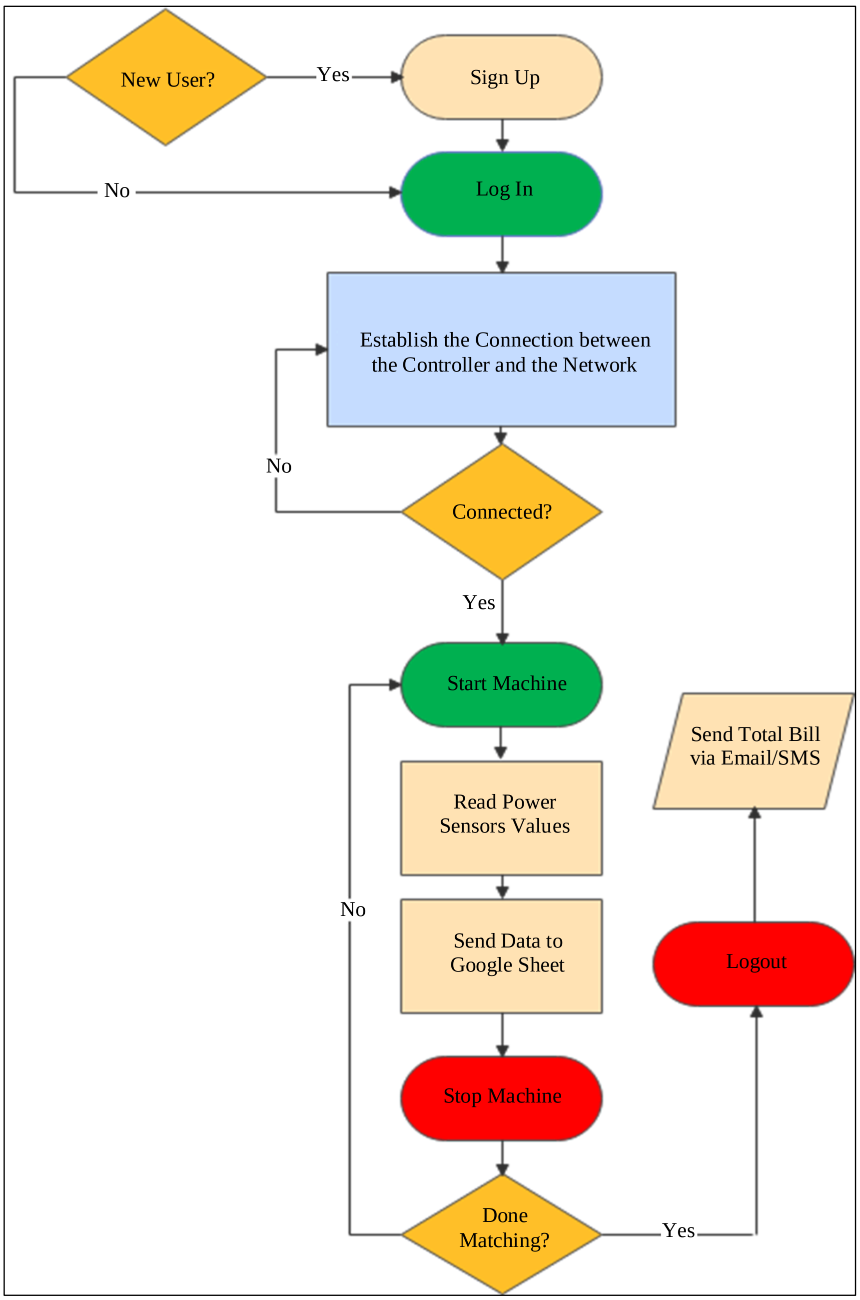


Fig. 10 Flowchart for the control of the billing system

3. Results and Discussion

Concerning the stated objective of this study, which is to design and implement an IoT-based automated billing system for small-scale multipurpose machines that enables individual client billing without human intervention, the automatic billing system was able to compute cost based on machine usage. There is also an independent client login and access system with a user-friendly interface for the machine users, as shown in Figure 11.

The client should be able to make payment in a post-payment manner at the end of every week or month or as agreed with the workshop owner. The client then receives a welcome to the machining centre email stating that the account has successfully been created. The system has been set to provide the client with the login details indicated by the clients themselves during sign-up, as shown in Figure 12. Therein, the client is eligible to use the machine with their unique login credentials. Failure to use these credentials will result in them not having access to the system. Therefore, the client must use these credentials. Once the client inputs the login credentials, the system will recognise them, as shown in Figure 13. Hence, the client can start the machine and do the machining work. Once the client clicks on the start machine button, the relay is active and thus turns on the multipurpose machine. The power consumption data is being monitored regularly.

Every 5 seconds, this power consumption data is displayed on the user interface and sent to the cloud (Google Sheets). Once the client stops the machine, all the data on the Google sheet is downloaded and used to calculate the client's final bill. The power consumption is not the only factor taken into consideration during the billing process. The system takes into account some fixed variables such as the rent of the place where the multipurpose machine will be located, maintenance of the machine (tool bits replacement), facility security, and the time usage of the multipurpose machine. A linear regression model was used to calculate the cost per unit values based on the Kenya power electricity tariff charges. This model works in the background of the code and can always be updated if the Kenya power tariff charges change.

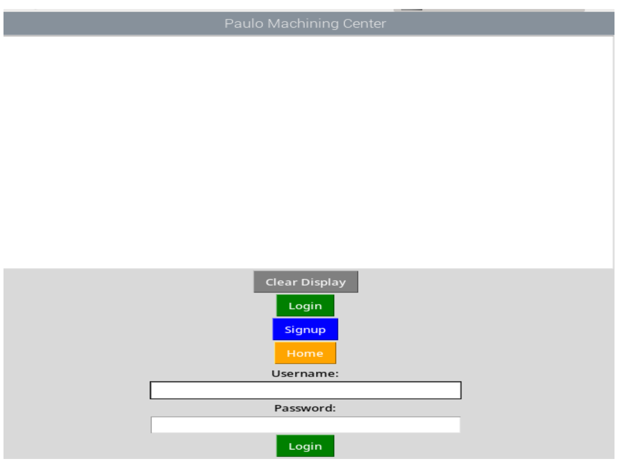


Fig. 11(a) First page of the interface of the billing system

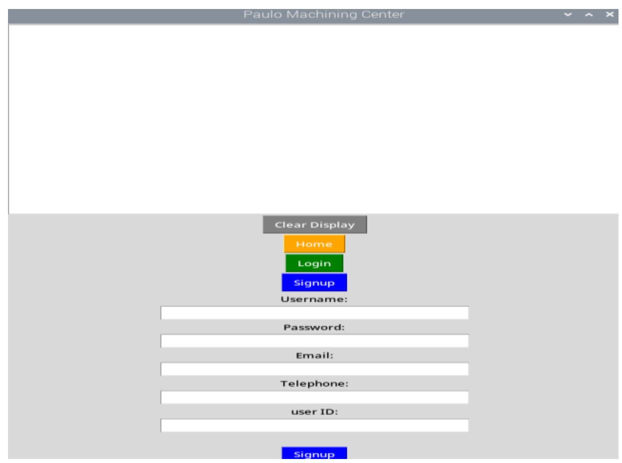


Fig. 11(b) Billing system client sign-up page

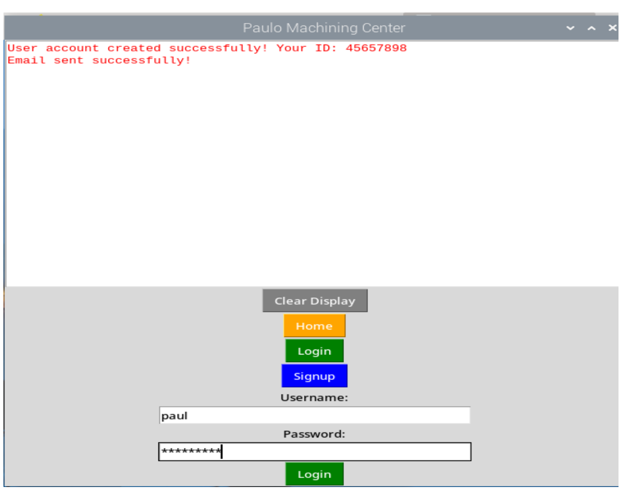


Fig. 11(c) Screenshot of a successfully created client account

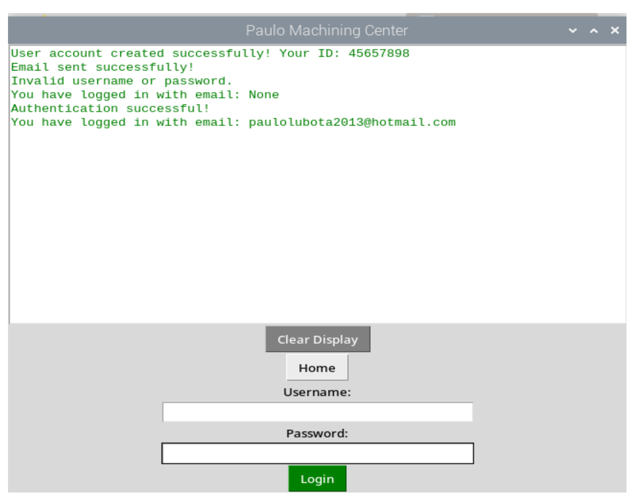
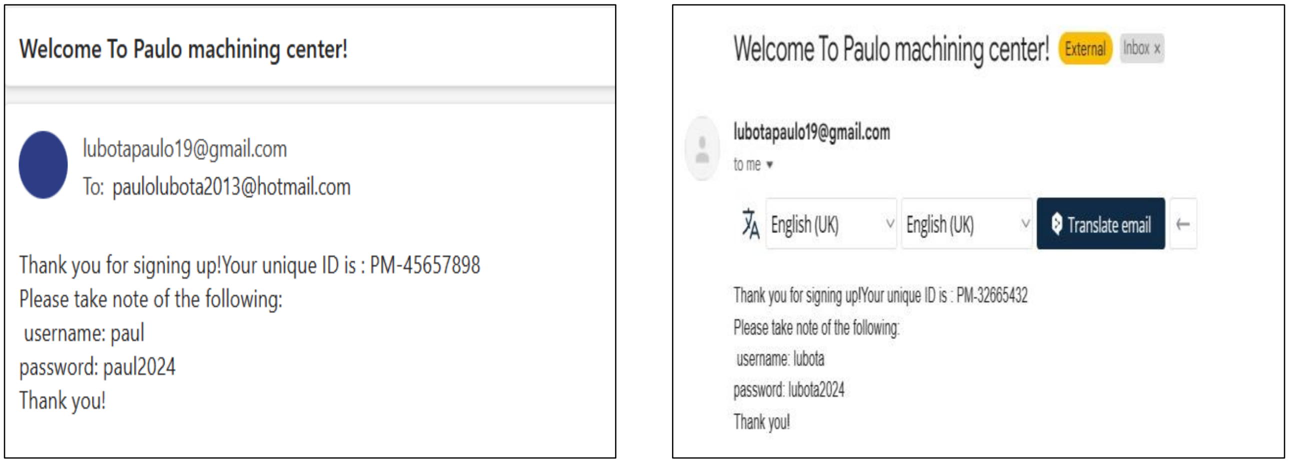


Fig. 11(d) Screenshot of client login page



(a) Client 1 **(b) Client 2**

Fig. 12 Client successfully signed up with their unique log in details

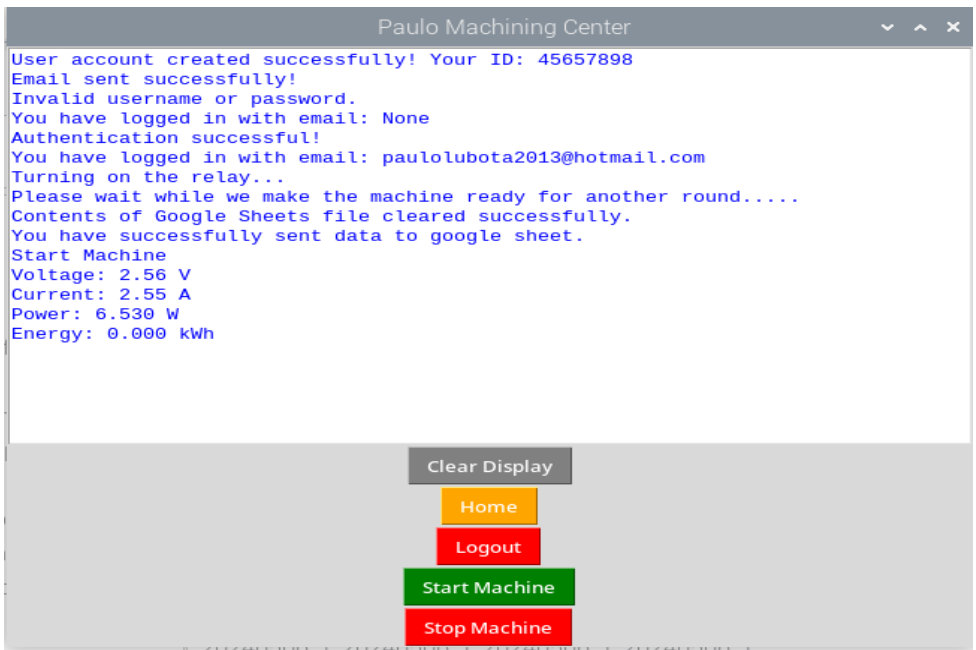


Fig. 13 The Client successfully logs in with their unique login details

3.1. Experimental Work Graphs and Analysis

As part of ongoing research, the client's final bill is calculated using the main equation below.

$$C_T = T_{Total}\left(\mathrm{S} + \mathrm{M} + \mathrm{R} + C_U P_t \exp\left(\int_t^T \left(\mathrm{A}(s) - \frac{B^2(s)}{2}\right) ds + \int_t^T \mathrm{B}(s) dW_s\right)\right) \quad (1)$$

But

$$\mathrm{A}(t) = \left\{\frac{\rho(V_t)[\mu(V_t) - V_t]}{V_t} + \frac{\rho(I_t)[\mu(I_t) - I_t]}{I_t}\right\} dt \quad (2)$$

$$\mathrm{B}(t) = \left[\frac{\sigma(I_t)\sqrt{2\rho(I_t)}}{I_t} + \frac{\sigma(V_t)\sqrt{2\rho(V_t)}}{V_t}\right] dW_t \quad (3)$$

Where:

C_T = Total cost.
P_t = Is the initial power consumption recorded.
T_{Total} = Multipurpose machine usage total time.
S = Facility security.
M = Maintenance (multipurpose machine tool bits maintenance).
R = Facility rent.
C_U = Cost per unit of usage of the multipurpose machine (material dependent) in KWH.
P_T = Total power consumed.
s = Simply a dummy variable because of the integration taking place.
ds = Quadrature integration.
dW_s = Brownian integration.

$\rho_{(V_t)}$ and $\rho_{(I_t)}$ = The speed of mean reversion. The speed at which the voltage and current values respectively return to the mean.

$\mu_{(V_t)}$ and $\mu_{(I_t)}$ = Is the mean or drift for voltage and current, respectively.

$\sigma_{(V_t)}$ and $\sigma_{(I_t)}$ = Is the diffusion or volatility in voltage and current, respectively.

As shown in Figure 13, the client's power consumption data is sent to the cloud via Google Sheets every 5 seconds. At the end of the machining operation, the sheet is automatically downloaded, and the billing takes place by using Equation 1. Other components added to the final bill include rent, maintenance, and security for the facility. An experiment took place using two clients' machining data, and the bill was completed. Client Paul did the machining for about five minutes, and the data was sent to a Google Sheet.

Figure 14 showcases client operator A power consumption trend. The client averaged 263W of power consumption within approximately 8 minutes, and that led to the bill, as shown in Figure 15, coupled with the other fixed variables that form part of the billing process. Therefore, the client's bill can be projected (e.g. for a week) based on this trend if the client works the workshop centre for 3 hours every day to an estimated amount of 2,619.54 Ksh (Kenya shillings). This bill is dependent on the time spent using the machine. The total bill is also affected by the machining operation being used by the client, whether they are using a single machining operation (e.g. drilling) or they are using a combination of two or all four operations at once. The machine motor produces much energy depending on how many operations are being used and the type of materials being machined. Hence, all these factors contribute to the client's total bill at the end of the machining work.

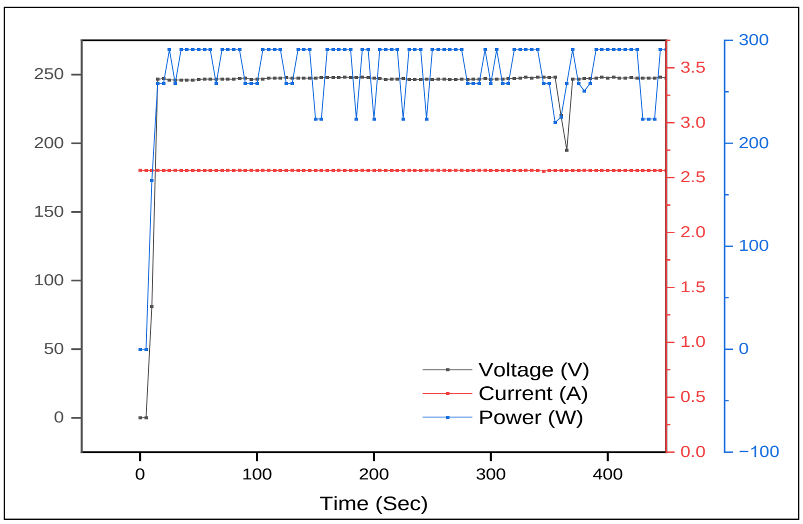


Fig. 14 Machining work sample power consumption of a client (operator A, ID 46358898)

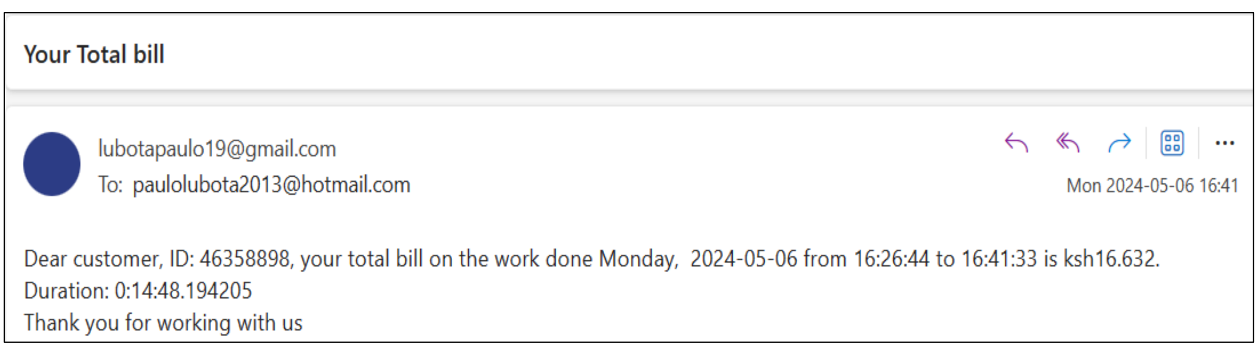


Fig. 15 Sample email notification for a bill to a client (operator A)

Operator B, on the other hand, did the machining for about 6 minutes, which is less time than that of operator A. Operator B averaged about 231W of power consumption, as shown by his power consumption trend in Figure 16. This data was sent to a Google Sheet and later computed to form part of his total bill Figure 17, sent via email. If he does machining work at the workshop centre for 3 hours every day, his total bill for the week based on his power consumption trend can be projected to an estimated amount of 2,328.48 Ksh. Again, this amount may vary depending on the machining time, the types of machining operations used, and the type of material to be machined.

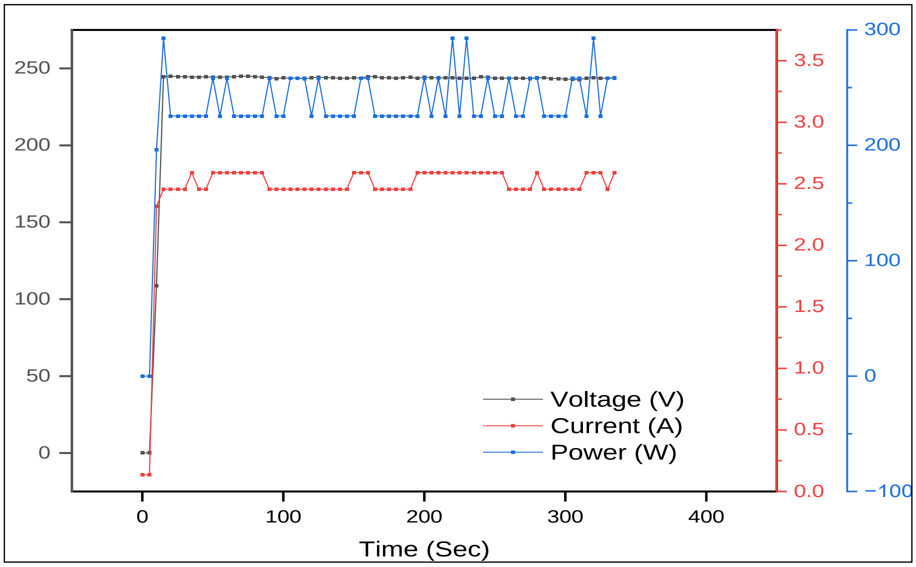


Fig. 16 Machining work sample power consumption of a client (operator B, ID: 31951322)

Fig. 17 Sample email notification for a bill to a client (operator B)

Some other rounds of machining were simulated, and the system successfully sent Operator C their total bill notification via email and SMS (with the help of the GSM module), as shown in Figure 19. He averaged about 8.3W of power consumption, as shown by his power consumption trend in Figure 18, in approximately 3 minutes. This data was sent to Google Sheets and later computed for the total bill shown in Figure 19.

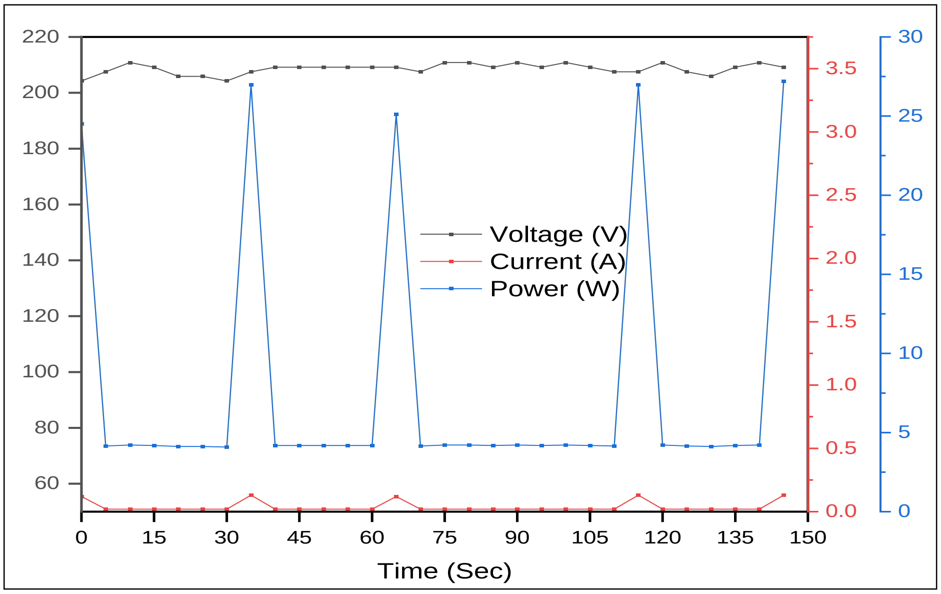
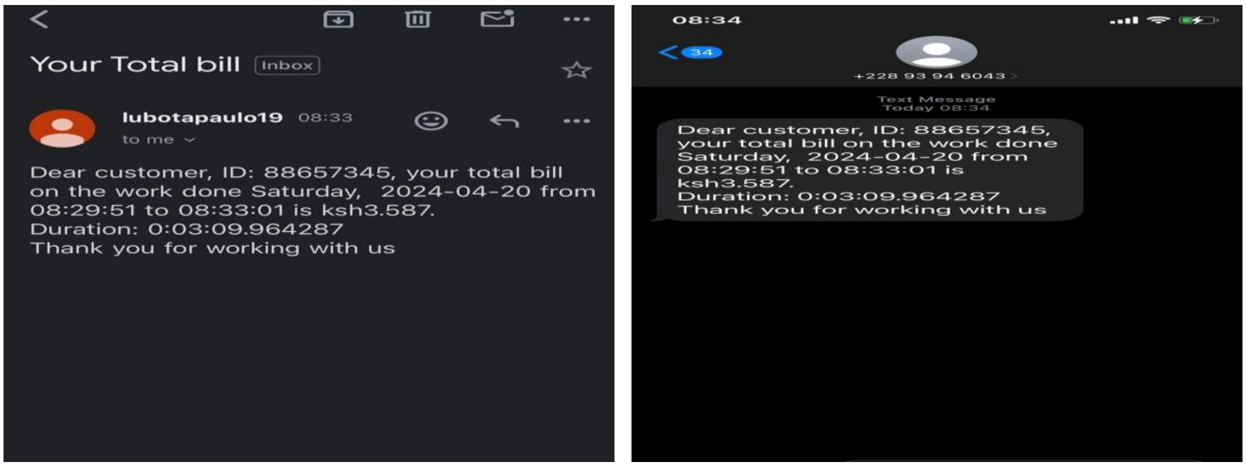


Fig. 18 Machining work sample power consumption of a client (Operator C, ID: 88657345)

If Operator C performs machining work at the workshop centre for 3 hours daily, the projected total bill for the week, based on their power consumption trend, is estimated to be 1,506.54 Ksh. The amount may vary based on factors such as machining time, types of machining operations, and the material being machined. Figure 20 showcases operator D's power consumption trend. The client averaged 744W of power consumption within approximately 3 minutes, which led to the bill, as shown in Figure 21, coupled with the other fixed variables that form part of the billing process. Therefore, the client's bill can be projected (e.g. for a week) based on this trend if the client works at the workshop centre for 3 hours every day to an estimated amount of 2,127.72 Ksh (Kenya shillings).



(a) Sample email notification for a bill to a client (operator C) **(b) Sample SMS notification for a bill to a client (operator C)**

Fig. 19 Sample bill notifications to a client

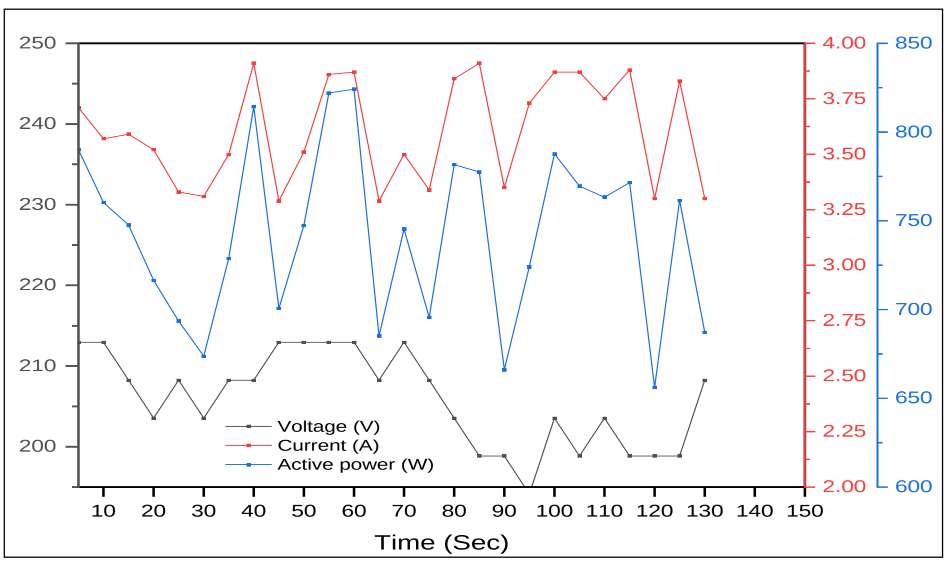


Fig. 20 Machining work sample power consumption of a client (operator D, ID: 46338823)

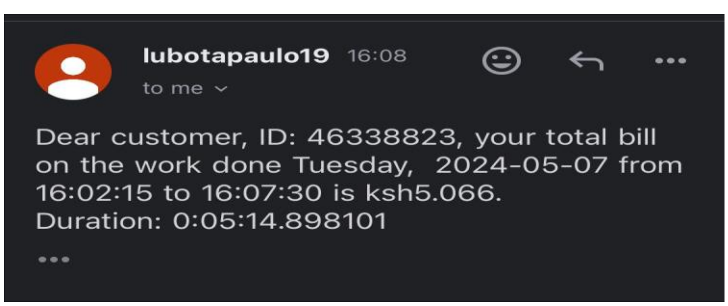


Fig. 21 Sample email notification for a bill to a client (operator D)

From all the experiments, it can be noted that both the power consumption, machining usage time, and machining processes (e.g. drilling, grinding, cutting and shaping) contribute significantly to the total bill amount that the client will have to pay. In fact, the power consumption is directly proportional to the machining process being used by the client because of the motor's loading. If the client is using two processes, the loading of the motor is higher than when using one machining process. Suppose the client uses all four MPM machining processes. In that case, the power consumption is going to be higher because the motor loading is way higher than using a single process or a combination of two.

4. Conclusion

The research offers an IOT-based automatic billing system for the multipurpose machine for small-scale workshops. The results of this research have shown that the machining total bill takes into account not just the power consumption but also other fixed variables that are part of the cost of the MPM. These other fixed costs are maintenance of the MPM, rent of the facility to keep the MPM and other related costs for the sustainability and feasibility of the MPM. When all these are considered, the total cost of running MPM is calculated. Hence, the approach taken in this study can form a basis for other billing mechanisms where several key aspects are known, especially in the small-scale manufacturing sector. It is also concluded that the more the machining time and power consumption, the higher the bill. An artificial intelligence algorithm can be implemented for customer payment via the GSM module for future work. An AI model can also be used to track the client's power consumption usage of the machine and advise them on their machine usage pattern.

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