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Innovating household efficiency: the internet of things intelligent drying rack system

Norhalida Othman[1], Zakiah Mohd Yusoff[1], Mohamad Fadzli Khamis @ Subari[2], Nur Amalina Muhamad[1], Noor Hafizah Khairul Anuar[1]
[1]Electrical Engineering Studies, Universiti Teknologi MARA (UiTM), Pasir Gudang Campus, Johor, Malaysia
[2]SMK Mutiara Rini, Johor, Malaysia

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ABSTRACT

The intelligent drying rack system (IIDRS) proposes an innovative approach to modernize clothes drying practices using internet of things (IoT) technology. Combining an Arduino Uno microcontroller, ESP8266 for data transmission, and an array of sensors including limit switches, light dependent resistors (LDRs), rain sensors, and temperature/humidity sensors, the IIDRS enables automated control of the drying rack and fan. Its remote accessibility via Blynk apps allows users to conveniently adjust settings and monitor drying progress. By autonomously adjusting drying cycles based on real-time environmental conditions, the IIDRS enhances efficiency and minimizes inconveniences such as wet clothes during rainfall. Moreover, it contributes to sustainable living by optimizing energy consumption through weather-based operation. With its intuitive interface and compatibility with modern lifestyles, the IIDRS represents a significant advancement in smart home solutions, showcasing the transformative potential of IoT technologies in everyday tasks.

Corresponding Author:

Norhalida Othman
Electrical Engineering Studies, Universiti Teknologi MARA (UiTM)
Pasir Gudang Campus, 81750 Masai, Johor, Malaysia
Email: halida8142@uitm.edu.my

1. INTRODUCTION

The internet of things (IoT) has revolutionized various domains of daily life, significantly advancing efficiency and convenience [1]–[4]. One notable application is in optimizing household chores like clothes drying, which traditionally suffers from inefficiencies and sustainability concerns [5]–[7]. Conventional drying methods are often manual and labor-intensive, leading to suboptimal results and increased energy consumption. This highlights the need for innovative solutions that streamline the drying process while aligning with eco-friendly practices. Recent research has explored IoT applications in home management, such as smart irrigation systems and energy-efficient appliances [8], [9]. Despite these advancements, specific challenges related to clothes drying remain inadequately addressed. Existing solutions often lack real-time adaptability and comprehensive user control, which limits their effectiveness in integrating with smart home ecosystems and adapting to changing weather conditions [10], [11]. Although some improvements have been made, they frequently fall short of providing the dynamic, real-time adjustments necessary for optimal clothes drying.

The IoT intelligent drying rack system (IIDRS) represents a significant advancement by incorporating IoT technology into a traditional household item. It features sensors for monitoring water, light, temperature, and humidity, all controlled by an Arduino Mega microcontroller, allowing for real-time monitoring and automatic adjustments based on environmental conditions and user preferences [12]–[14].

The IIDRS's wireless communication capabilities enhance user convenience by allowing remote monitoring and control of the drying process. Integration with mobile devices and smart home systems provides flexibility and seamless incorporation into daily routines, addressing the limitations of traditional and existing smart drying solutions. This level of interactivity and control offers a significant advantage over current methods, which often require manual adjustments and lack comprehensive user engagement [5], [15]. The connectivity of IIDRS to mobile devices and smart home systems enables users to remotely control and monitor the drying process. This level of interactivity and control enhances user convenience and flexibility, allowing for a seamless integration of drying tasks into daily routines.

The development of the IIDRS addresses critical gaps identified in previous research and existing systems, particularly in regions with unpredictable weather conditions. Conventional drying racks often rely on manual intervention and do not effectively adapt to environmental variables, leading to inefficiencies and increased energy usage [16]–[18]. By leveraging IoT technology, the IIDRS offers a novel approach to improving drying efficiency and user experience, making it a valuable contribution to sustainable home management.

This study aims to achieve two primary objectives: i) designing and implementing the IoT IIDRS using Arduino Mega, and ii) integrating wireless control and monitoring capabilities through a Wi-Fi module. The subsequent sections will detail the system's design, evaluate its performance, and demonstrate how the IIDRS surpasses existing solutions in efficiency, adaptability, and smart home integration, addressing the gaps and providing a sophisticated solution to the challenges of clothes drying.

2. RELATED WORK

The introduction of IoT IIDRS represents a pivotal advancement in the domain of household automation, offering a transformative solution to optimize the efficiency and convenience of clothes drying processes. Existing works on this domain delve into the development of a sophisticated smart clothes drying system rooted in IoT technology, elucidating its intricate integration of sensors and actuators to orchestrate drying sequences with precision while ensuring utmost energy efficiency and user satisfaction [17]–[20]. This underscores a critical paradigm shift towards autonomous and adaptive domestic appliances, mirroring the broader trend of IoT-driven smart homes.

Expanding on this narrative, some study presents a pioneering approach that marries IoT technology with image recognition algorithms to craft dynamic clothes drying system capable of discerning and responding to nuanced environmental cues in real-time. Their study underscores the fusion of cutting-edge technologies to create synergistic solutions that not only optimize drying efficiency but also mitigate environmental impact through judicious resource consumption [21], [22]. In a similar vein [23], [24] offer insights into the design and implementation intricacies of intelligent drying rack systems, highlighting their role in fostering sustainable living practices through meticulous environmental monitoring and adaptive control mechanisms. Their research not only advances the technical frontier but also underscores the broader implications of IoT-enabled solutions in fostering eco-conscious lifestyles.

Furthermore, IoT technology contribute to this discourse by unveiling comprehensive smart clothes drying rack system empowered by IoT, underlining its potential to transcend conventional drying methods by seamlessly integrating with users' daily routines while minimizing energy expenditure. Their work underscores the imperative for a holistic approach towards domestic automation, where technological innovation converges with user-centric design principles to redefine the contemporary household landscape [25]–[28]. The integration of IoT technologies in household appliances has garnered significant attention for its potential to enhance convenience and efficiency in daily tasks. Existing studies provide a comprehensive overview of IoT applications in smart homes, emphasizing their role in transforming traditional appliances into intelligent systems [15], [22], [29], [30]. Specific studies delve into the design and implementation of IoT-enabled home appliances, showcasing their capabilities in optimizing energy usage and improving user experience [31], [32]. Moreover, some works underscore the importance of IoT in promoting energy efficiency in residential settings. Understanding user perspectives and acceptance is crucial for the successful adoption of IoT-based solutions in homes. Additionally, assessing the environmental impact and sustainability implications of smart home technologies is essential for designing future-proof systems like the IIDRS. By synthesizing insights from these studies, we can appreciate the broader context of IoT-enabled home appliances and intelligent systems, laying a strong theoretical foundation for research on the IIDRS.

Collectively, these seminal studies underscore the burgeoning potential of IoT-enabled drying solutions to transcend traditional paradigms, ushering in a new era of efficiency, sustainability, and user-centricity in household chores. Such advancements not only redefine the boundaries of domestic automation but also hold profound implications for societal resilience and environmental stewardship in the face of evolving lifestyle demands.

3. METHOD

3.1. System diagram

This study focuses on developing the IoT IIDRS using the Arduino Uno microcontroller, aiming to optimize garment drying by protecting clothes from rain and ensuring ideal drying conditions. The Arduino Uno is selected for its strong performance, compatibility with various sensors, and its prevalent use in IoT applications. The system incorporates three key sensors: a rain sensor for detecting rainfall, a light dependent resistor (LDR) sensor for measuring ambient light, and a temperature and humidity sensor (DHT22) for monitoring environmental conditions. These sensors provide critical data that enables real-time, adaptive control of the drying process to enhance efficiency and safeguard garments.

The Arduino Uno processes the sensor data to manage system operations, with visual feedback provided through LEDs that indicate different stages of the drying process. An LCD Display shows detailed information about the drying process and environmental conditions, improving user awareness and control. The motor driver L298 controls the DC motor and DC fan, which are crucial for the drying rack's dynamic operation. The DC motor handles the extension and retraction of the drying rack, while the DC Fan improves air circulation for effective drying. This integration of advanced sensors, microcontroller technology, and user-friendly output mechanisms aims to revolutionize traditional drying methods, offering improved convenience, efficiency, and protection for garments against adverse weather conditions.

3.2. Block diagram and project flowchart

Figure 1 shows the complete methodology applied IIDRS system consists of the block diagram and flowchart of the system operation. The block diagram is depicted in Figure 1(a) provides a comprehensive overview of the components in this study. The system incorporates four distinct input devices and three output mechanisms. Input devices consist of a Raindrop sensor, an LDR sensor, a temperature and humidity sensor, and a limit switch. These sensors collectively gather environmental data essential for the system's operation and decision-making processes. Conversely, output mechanisms serve to convey pertinent information and enact control actions. The primary output is facilitated by a DC motor, which functions as the actuator responsible for moving the drying rack. Additionally, a 20×4 LCD display is utilized to present real-time data, including rainfall measurements and environmental temperature and humidity levels. Lastly, light emitting diode (LED) indicators are employed to provide visual feedback, signaling deviations from predefined thresholds set for sensor readings. By integrating these input and output components, the system effectively monitors environmental conditions, initiates appropriate actions, and communicates crucial information to users. This methodology underscores the systematic approach adopted in designing and implementing the IIDRS, ensuring robust performance and user-friendly operation in real-world scenarios.

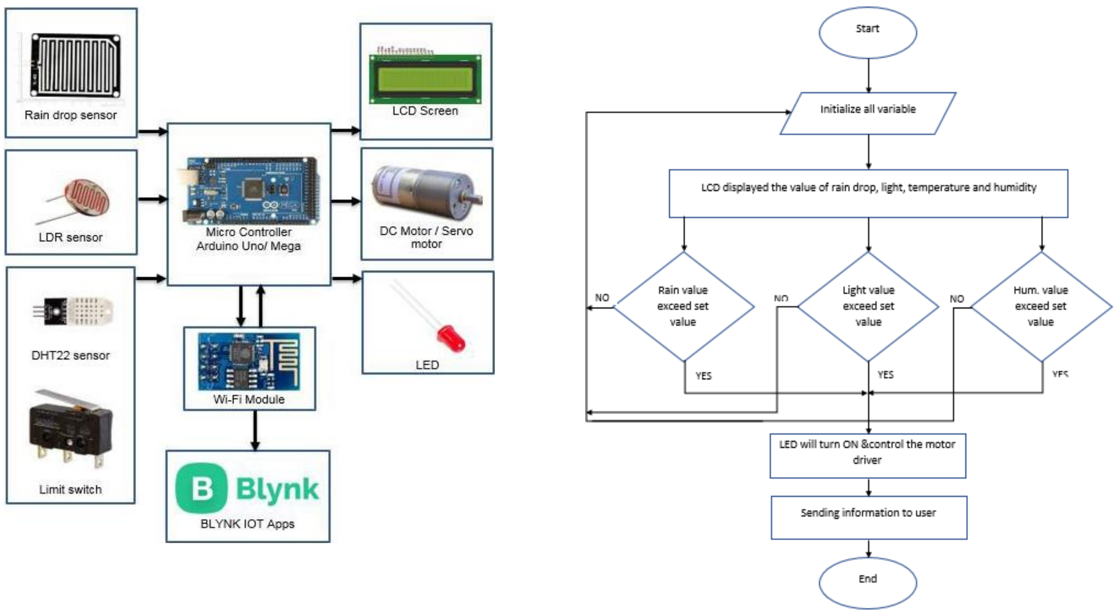
The flowchart detailing the operational workflow of the IIDRS project is depicted in Figure 1(b). The project commenced with a comprehensive analysis of key variables, encompassing the LCD display of raindrop measurements, ambient temperature values, and humidity levels in the surroundings. Additionally, the LDR sensor was employed to monitor sunlight availability. Subsequently, based on the gathered sensor data, the system autonomously activates the LED indicators and controls the operation of the drying fan motor. This automated process ensures efficient management of the drying process in response to prevailing environmental conditions.

Furthermore, to enhance user engagement and provide real-time notifications, the system integrates a Wi-Fi module that facilitates communication with the Blynk mobile application. Through this interface, users receive timely alerts and updates regarding the drying process, enabling remote monitoring and control from anywhere with internet connectivity. The IIDRS project aims to optimize clothes drying efficiency while enhancing user convenience and interaction. The integration of advanced sensor technologies, automated control mechanisms, and remote communication capabilities underscores the project's commitment to delivering a sophisticated and user-centric solution for modern household needs.

4. RESULTS AND DISCUSSIONS

The IoT IIDRS was developed to enhance the clothes drying process by adapting to varying environmental conditions, addressing limitations of traditional drying systems. Simulation results showcase how IIDRS adjusts to different scenarios such as changes in rain, light, and humidity. The system integrates several components: an Arduino Uno microcontroller, a rain drop sensor, a LDR sensor, a DHT22 sensor for temperature and humidity, a control switch, a 20×4 LCD display for data visualization, three LEDs for status indication, an L298 motor driver for motor control, a DC motor for rack movement, a DC Fan for airflow management, and a Wi-Fi module for wireless communication. The combination of sensors and microcontrollers allows IIDRS to monitor and control drying conditions in real-time, optimizing drying efficiency while reducing energy consumption. For instance, the system's ability to retract the drying rack when rain is detected helps prevent clothes from getting wet again, a common issue with traditional racks. Additionally, it manages humidity by activating the fan when needed, accelerating drying even in unfavorable weather. This simulation and testing reveal that IIDRS not only improves drying efficiency but also contributes to energy savings and garment preservation. The schematic diagram underscores the sophisticated integration of these components, highlighting the project's technical complexity and its potential for practical application in smart home environments.

Figure 2 illustrates Condition 1, where there is no rainfall, bright ambient lighting, and low humidity levels. In this scenario, all three LEDs red, orange, and yellow are turned off, indicating that the environmental conditions are optimal for drying. The DC motor is in the OUT position, which means the drying rack is retracted, and the DC fan is also inactive, reflecting the system’s energy-saving approach during favorable weather conditions. This setup highlights the system's ability to efficiently utilize resources by minimizing energy consumption when conditions are ideal. In contrast, Figure 3 depicts Condition 2, characterized by the absence of rainfall but with bright and high humidity. Here, the red and orange LEDs remain off, while the yellow LED lights up to signal elevated humidity levels. The DC motor continues to keep the drying rack in the OUT position, and the DC fan stays inactive to conserve energy. This visualization shows the system’s capability to adjust its operations based on environmental humidity, maintaining efficiency while conserving energy.



(a) (b)

Figure 1. Development of IIDRS: (a) block diagram and (b) flowchart

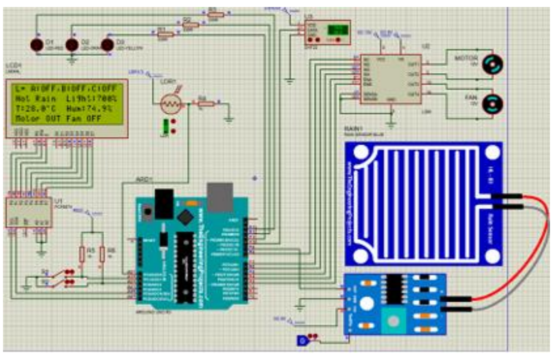


Figure 2. No rain, bright and not humid

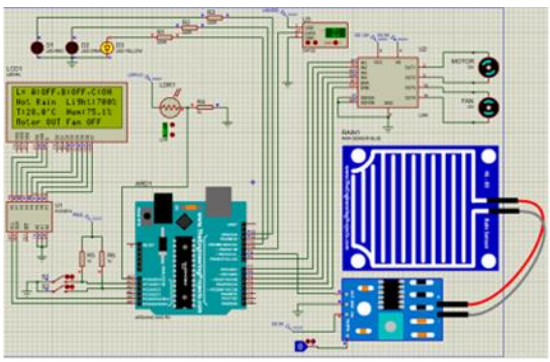


Figure 3. No rain, bright and humid

In Figures 4 and 5 both depict scenarios with no rainfall but differing ambient conditions. In Figure 4 (Condition 3), low brightness and low humidity are present, with the orange LED illuminated to indicate reduced sunlight, while the red and yellow LEDs are off. The DC motor keeps the drying rack retracted, and the DC fan remains inactive, reflecting the system's efficient energy conservation and drying optimization in these conditions. In contrast, Figure 5 (Condition 4) shows low brightness combined with high humidity, where the orange and yellow LEDs are lit to signal reduced sunlight and high humidity levels. Despite the DC motor still keeping the rack retracted and the DC fan inactive, the higher humidity in Figure 6 presents a more challenging drying environment compared to the low humidity scenario in Figure 7. Thus, while both conditions involve minimal operational changes, Figure 8 highlights the system's ability to handle more demanding drying conditions effectively.

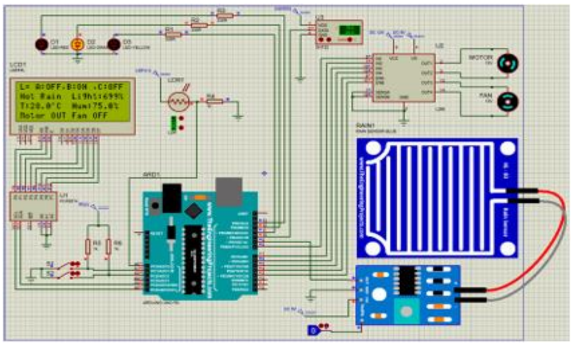


Figure 4. No rain, not bright, and not humid

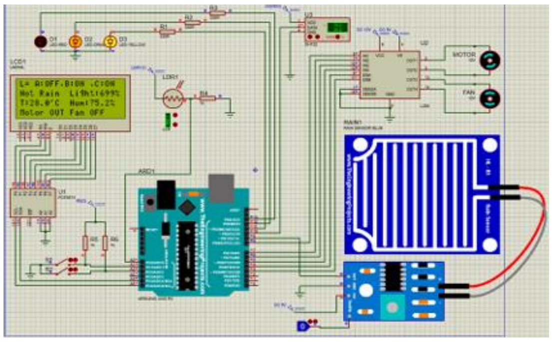


Figure 5. No rain, not bright and humid

Figures 6 and 7 both depict scenarios with rainfall but differ in terms of ambient humidity. Figure 6 (Condition 5) shows bright but non-humid conditions with rainfall, where the red LED is on to indicate rain, while the orange and yellow LEDs are off. The DC motor is in the IN position, meaning the drying rack is extended to protect clothes from getting wet, and the DC fan remains inactive as humidity is low. Conversely, Figure 7 (Condition 6) illustrates a scenario with both rainfall and high humidity. Here, the red and yellow LEDs are lit to signal rain and high humidity, respectively, while the orange LED is off. The DC motor is also in the IN position, indicating the extended drying rack, but the DC fan is activated to manage the increased humidity and enhance drying efficiency. The comparison highlights that while both conditions involve an extended rack to shield against rain, Figure 9 added humidity requires the DC Fan to assist with drying, demonstrating the system's adaptability to varying environmental challenges.

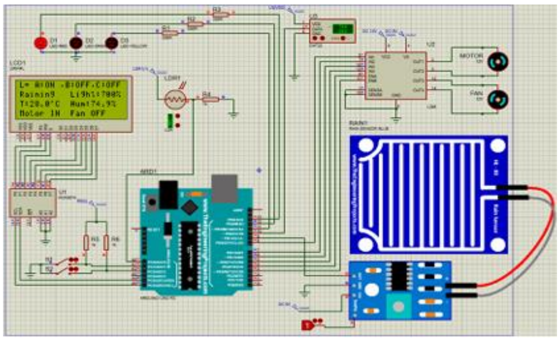


Figure 6. Rain, bright and not humid

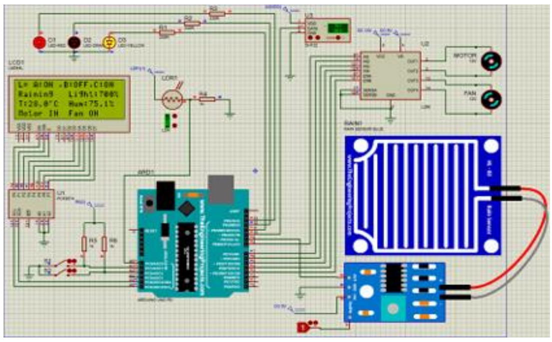


Figure 7. Rain, bright and humid

Figures 8 and 9 both depict scenarios with rainfall but vary in brightness and humidity levels. Figure 8 (Condition 7) shows rain with low sunlight and no humidity. Here, the red LED indicates rain, the orange LED signals reduced sunlight, and the yellow LED remains off. The DC motor is in the IN position, meaning the drying rack is extended to protect clothes from the rain, while the DC fan is inactive due to the absence of humidity. In contrast, Figure 9 (Condition 8) also shows rain but with low brightness and high humidity. All LEDs red, orange, and yellow are lit to indicate rain, low sunlight, and high humidity, respectively. The DC

Motor remains in the IN position to keep the rack extended, but the DC Fan is activated to manage the high humidity and aid in dying. This comparison illustrates that while both conditions require an extended rack to shield from rain, Figure 9's higher humidity necessitates the additional activation of the DC fan to ensure effective drying, highlighting the system's ability to adapt to more complex environmental variables.

The successful implementation and simulation of the IoT IIDRS have significant implications for smart home technology by demonstrating its ability to adapt to varying environmental conditions, making it ideal for regions with unpredictable weather patterns. By minimizing manual intervention and optimizing energy use, IIDRS promotes sustainable household management and exemplifies the potential of IoT technology to innovate home automation and smart living solutions. Its modular design, utilizing components like the Arduino Mega and Wi-Fi module, positions IIDRS as a prototype for future smart home appliances, offering scalability and adaptability for other household tasks. Future research could build on this by integrating additional sensors and machine learning algorithms to enhance predictive capabilities and efficiency, while data collected from IIDRS could provide insights into household energy consumption, contributing to more sustainable living practices.

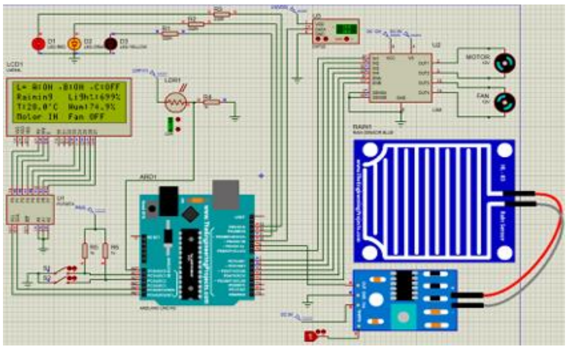


Figure 8. Rain, not bright and not humid

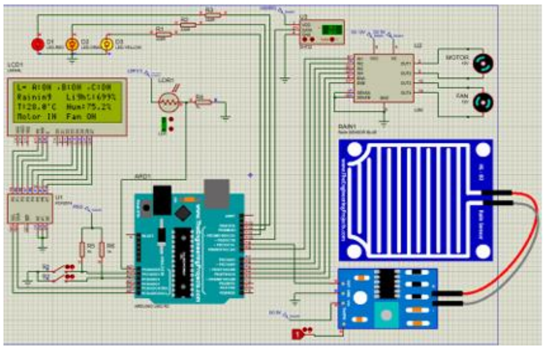


Figure 9. Rain, not bright and humid

5. CONCLUSION

The IoT IIDRS has been meticulously designed to gather and analyze environmental data from sensors such as temperature, humidity, light, and rain, enabling automated adjustments that optimize the drying process, reduce energy consumption, and protect garments from adverse weather conditions. Rigorous simulation and testing have demonstrated IIDRS's ability to control operations in real-time, ensuring efficient resource utilization and reducing operational costs. The system's integration with mobile applications and smart home systems enhances user convenience and promotes seamless daily routine integration. Additionally, the data collected allows for long-term analysis and trend forecasting, facilitating proactive maintenance and optimization, thereby preventing equipment failures and reducing downtime. IIDRS also significantly contributes to sustainability goals by minimizing energy consumption and waste, lowering the household carbon footprint. Our research underscores the importance of intelligent systems in improving efficiency and environmental stewardship. IIDRS exemplifies the transformative potential of IoT technology in household tasks, setting a new standard for intelligent home systems and paving the way for a fully automated, interconnected smart home environment. Future research could adapt IIDRS principles to other appliances, integrating advanced sensors and machine learning algorithms to enhance adaptability and performance, ultimately promoting a sustainable, efficient, and comfortable future.

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BIOGRAPHIES OF AUTHORS

Norhalida Othman is a senior lecturer currently affiliated with UiTM Pasir Gudang. She earned her master's degree in Engineering (Electrical-Power) from Universiti Teknologi Malaysia (UTM). With a specialized focus in the realm of Electrical Engineering, her research interests are notably centered around renewable energy and power system. She can be contacted at email: halida8142@uitm.edu.my.

Assoc. Prof. Ts. Dr. Zakiah Mohd Yusoff is an associate professor who is currently working at UiTM Pasir Gudang. She received the B. ENG in Electrical Engineering and Ph.D. in Electrical Engineering from UiTM Shah Alam, in 2009 and 2014, respectively. In May 2014, she joined UiTM Pasir Gudang as a teaching staff. Her major interests include process control, system identification, and essential oil extraction system. She can be contacted at email: zakiah9018@uitm.edu.my.

Mohamad Fadzli Khamis @ Subari is currently a lab assistant at SMK Mutiara Rini, Skudai, Johor. He received Diploma in Electrical Engineering (Power) at UiTM Cawangan Johor, Kampus Pasir Gudang in 2023. He can be contacted at email: fadzlikhamis@gmail.com.

Nur Amalina Muhamad is currently a senior lecturer under School of Electrical Engineering, College of Engineering, UiTM Pasir Gudang. She received the B. ENG in Electrical Engineering and Ph.D. in Electrical Engineering from UiTM Shah Alam, in 2010 and 2014, respectively. Her main research interests are nanotechnology, advanced materials, semiconductor devices and fabrication of thin films. She can be contacted at email: amalina@uitm.edu.my.

Noor Hafizah Khairul Anuar is a lecturer in UiTM Pasir Gudang since 2014. She earned a bachelor's degree in telecommunication engineering at Universiti Teknologi Malaysia (UTM) and a master's degree in computer and communications engineering at UiTM. Her research interest is in the field of sensor and system development. She is currently continuing her studies at Ph.D. level at Universiti Teknologi Malaysia in the field of system and instrumentation. She can be contacted at email: noorhafizah2575@uitm.edu.my.