The development of low-cost spin coater with wireless IoT control for thin film deposition

Ahmad Muhajer Abdul Aziz[1], Muhammad Idzdihar Idris[1,2], Zul Atfyi Fauzan Mohammed Napiah[1,2], Muhammad Noorazlan Shah Zainudin[1], Marzaini Rashid[3], Luke Bradley[4]
[1]Faculty of Electronic and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia
[2]Micro and Nano Electronic Research Group (MiNE), Faculty of Electronic and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia
[3]School of Physics, University Science Malaysia (USM), Penang, Malaysia
[4]Cyro-Electronics at School of Engineering, Newcastle University, Newcastle upon Tyne NE, United Kingdom

Article Info

Article history:

Received Jan 15, 2024
Revised Feb 21, 2024
Accepted Mar 16, 2024

Keywords:

ESP32
Spin coater
Thin film deposition
Visual basic
Wireless IoT

ABSTRACT

A low-cost spin coater with a wireless remote system that can deposit thin films of uniform thickness and quality at a significantly lower cost than traditional methods. The system consists of three main parts, a motorized spindle, a spin-coating head, and a control system connected to the network. The mechanical design on the mechanical part, spin coater system design with ESP32, and implementation of wireless control through visual basic. The network-enabled control system allows for real-time monitoring and adjustment of the deposition process, which can improve efficiency and reproducibility. This low-cost spin coating system represents a promising solution for organizations seeking to access thin film deposition technology at a fraction of the cost of traditional systems. By integrating wireless IoT control into low-cost spin coaters, the impact of this technology on coating uniformity will provide valuable insights for future advancements in this field.

Corresponding Author:

Muhammad Idzdihar Idris
Faculty of Electronic and Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka
Email: idzdihar@utem.edu.my

1. INTRODUCTION

A spin coater plays a crucial role in applying thin films to substrates. By rotating the substrate at various speeds, the coating material is uniformly spread, creating films of the desired thickness [1]. In 1958, Emsile *et. al.* developed the first spin-coating model, laying the foundation for subsequent advancements and becoming fundamental for developing spin coater with more specifications, features, and complicated models in the future [2]. This project focuses on the development of a cost-effective spin-coating machine utilizing affordable electronic components and open-source technology, with an emphasis on incorporating internet of things (IoT) capabilities [3].

The spin-coating machine integrates various sensors, such as lid closure and balancing along with IoT technology to record procedure histories, manage recipes on a cloud database, and provide real-time monitoring with cautionary alerts for user actions [4]. The hardware components include ESP, ESC 32, brushless motor, and read sensor, while software tools like Visual Basic Studio, Arduino IDE, and OneDrive cloud are employed in the project. The resultant spin coater offers a variable spin speed ranging from 300 to 5,000 rpm, controllable through a user-friendly touchscreen interface [5].

In addition to its critical role in semiconductor manufacturing, spin coating holds particular importance in the application of thin films, including cutting-edge materials like perovskites [6], [7]. Thin films, characterized by their nanoscale thickness, find widespread application in various fields, from electronics to optics. The ability of spin coaters to precisely deposit these thin films onto substrates makes them indispensable in the development of advanced technologies [8], [9]. It uses centrifugal force to spread coating material from the center to the edges.

The process involves four key steps. Figure 1 shows the process which is depositing the solution onto the substrate, accelerating the spin, allowing the solution to spread evenly, and drying it with generated airflow [10]. This straightforward batch process underscores the essential role of spin coating in achieving uniform thin film coatings on semiconductor substrates. Notably, in instances where the substrate's topography lacks uniformity, non-volatile solids undergo redistribution over topographical features through convection diffusion [11].

Perovskite materials, with their unique crystalline structure and remarkable optoelectronic properties, have gained prominence in recent years for applications in solar cells, light-emitting diodes (LEDs), and other emerging technologies [12]. The uniformity and precision achieved through spin coating play a pivotal role in the fabrication of perovskite thin films, ensuring optimal device performance. As shown in Figure 2, the simplicity of the spin coating process aligns well with the delicate nature of perovskite deposition, contributing to the reproducibility and efficiency of manufacturing processes [13], [14].

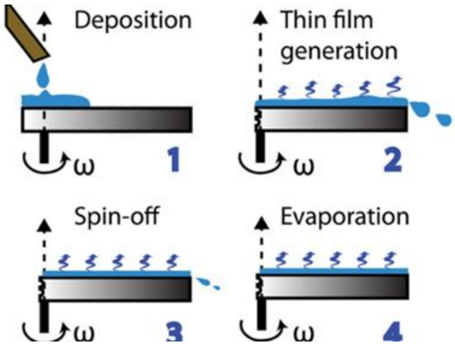

Figure 1. Procedure of spin coating process [10]

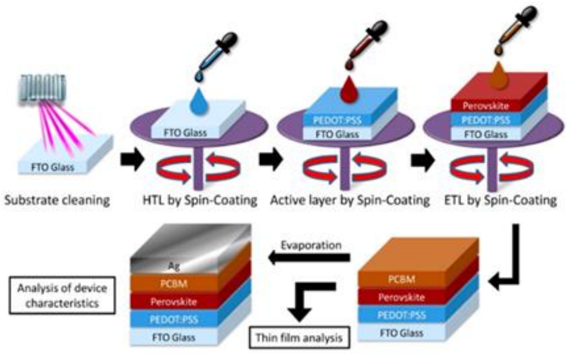

Figure 2. Process of perovskite deposition by using spin coating

This project develops an affordable spin-coating machine for precise thin film deposition. It caters to semiconductor manufacturing and addresses the need for versatile coating in advanced materials like perovskites. Using affordable electronics and open-source tech, the spin coater aims to democratize access to thin film innovation. The addition of IoT capabilities allows real-time monitoring, alerts, and data-driven optimization, especially beneficial for sensitive materials like perovskites. The cloud-based system ensures easy adaptation to evolving thin film requirements, including those specific to perovskite applications [15], [16].

2. METHOD

2.1. Mechanical design

The design of the spin coater system closely mirrors the standard spin coating system, with preliminary research conducted on the parameters and boundaries of a typical spin coating system to inform the conceptual design [17]. The criteria for a well-designed spin coating system include a robust structure, stability, water resistance, durability, and a marketable design. To realize the design, Autodesk Fusion 360, a commercial CAD software, was employed for modeling the 3D printed parts of the spin coater. Ultimaker Cura 4.0 Slicer was then used to generate the Gcode file from the STL file format. The build instruction details the print orientation, infill percentage, and layer height. All parts were 3D printed using a Creality Ender 3 v2 with a 0.2 mm nozzle, utilizing polylactic acid (PLA) filament with a 1.75 mm diameter at the manufacturer's recommended temperature. The model of the spin coater design is shown in Figure 3.

Our spin coater's design takes inspiration from the industry, particularly the vacuum-free Ossila Spin Coater, chosen for its convenience [18]. This design meets industry standards, aiming to improve thin film quality without the need for vacuum pumps. The 3D model design focuses on key components like the spill-resistant spin vase, protective casing, and substrate holder shown in Figure 4. The spin coater is designed to prevent spillage of the coating material during rotation, ensuring a clean and precise application process as shown in Figure 4(a). The protective casing in Figure 4(b) adds an extra layer of safety, shielding the user from any potential hazards. The substrate holder in Figure 4(c) is adjustable, allowing for different sizes and types of substrates to be securely held in place during the coating process. These features combine to create a reliable and efficient spin coater that can easily integrate into existing laboratory setups. The spin vase as shown in Figure 4(d) prevents spills during coating, accommodating a 15 mm wafer and allowing easy cleaning after 3D printing. The square-shaped casing (140 mm x 200 mm x 80 mm) shields electronic components, including the motor unit. The substrate holder, linked to the motor shaft, secures substrates using friction and centrifugal force, with three indentations for different substrate sizes.

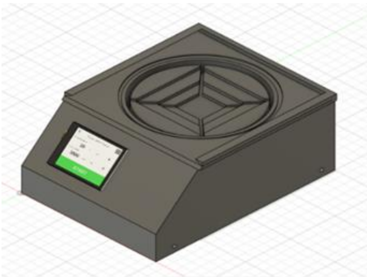

Figure 3. Spin coater designed in autodesk fusion 360

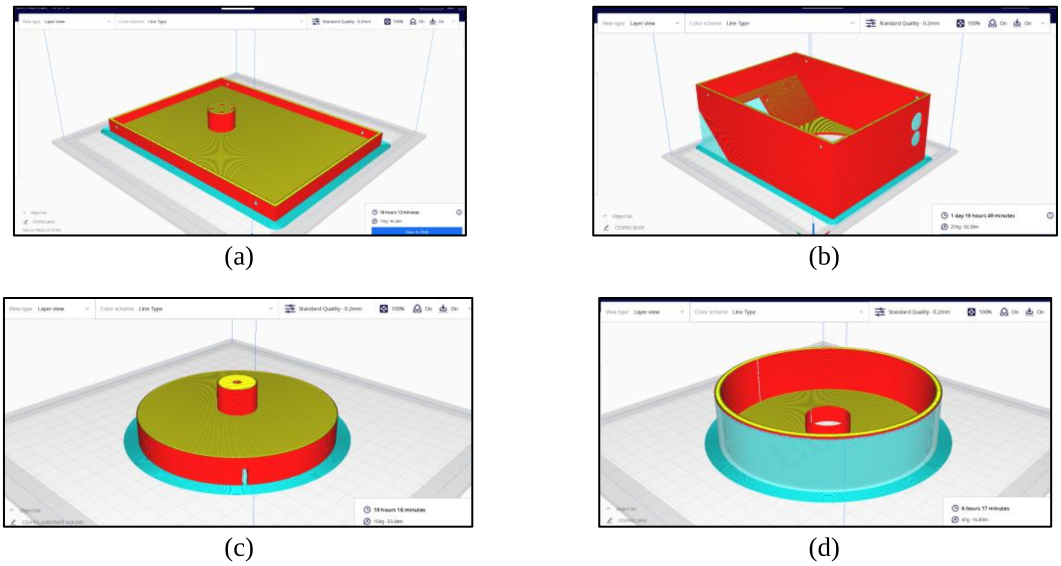

Figure 4. The 3D model design of the spin coater includes; (a) base holder, (b) protective casing, (c) substrate holder, and (d) spill-resistant spin vase

The 3D design process, conducted using Autodesk Fusion 360, involves sketching, extruding, and modifying to enhance functionality and aesthetics [19], [20]. Ultimaker Cura 4.0 Slicer is employed to convert the STL file into Gcode instructions for 3D printing. The 3D printing process, executed using the Creality Ender 3 V2 printer, includes calibration for accuracy and addresses common failure factors. Post-processing completes the 3D printing process by removing supports and refining the model's surface through specific coatings or polishing, resulting in a fully assembled and functional spin coater model. This seamless integration of 3D design and printing underscores the efficiency and precision achievable in the manufacturing process the model as shown in Figure 5.

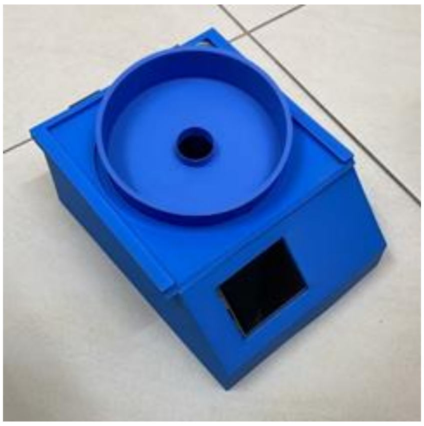

Figure 5. The complete 3D model

2.2. Spin coater system design

The development of a low-cost spin coater system commenced without the integration of IoT to ensure the individual functionality of each component [21]. The primary objective was to establish a robust system capable of maintaining the consistency of thin film outcomes in each coating process [22]. The designed spin coater system followed a well-defined flowchart, depicted in Figure 6. This initial design phase focused on optimizing the mechanical and operational aspects of the spin coater, laying the foundation for subsequent IoT implementation. The deliberate step-by-step approach aimed to guarantee the reliability and effectiveness of the spin coater system before introducing IoT elements to enhance functionality and connectivity. By ensuring the mechanical and operational aspects of the spin coater were optimized, potential issues and inconsistencies were minimized. This not only provided a solid base for the subsequent IoT implementation but also ensured the reliability and effectiveness of the spin coater system. The deliberate step-by-step approach allowed for thorough testing and fine-tuning, guaranteeing that the system was robust and capable of delivering consistent thin film outcomes. The introduction of IoT elements would further enhance the spin coater's functionality and connectivity, ultimately improving its overall performance.

The architecture of the spin coater system is depicted in Figure 7 through a block diagram and circuit representation. The block diagram illustrates the key components, such as the power supply, programmable logic controller (PLC), motor controller, and the spin coater itself, along with their interconnections [23]. The circuit diagram provides a more detailed view of the electrical connections, outlining inputs and outputs for each component. By incorporating IoT elements into the spin coater system, it can be connected to the internet and communicate with other devices and systems [24]. This connectivity enables remote monitoring and control of the spin coater, allowing operators to manage and adjust its settings from anywhere. Additionally, IoT integration can provide real-time data collection and analysis, facilitating predictive maintenance and optimizing the performance of the spin coater. Overall, the introduction of IoT elements not only enhances the spin coater's functionality but also opens up new possibilities for automation and process optimization in various industries.

Together, these visuals offer insight into the structured operation of the spin coater system, showcasing how different parts collaborate to achieve the desired spinning motion. Crucial components integrated into the system include a power regulator, touch-screen LCD, electronic speed controller (ESC), brushless motor, microcontroller, and various sensors. This thoughtful integration ensures a well-coordinated and efficient operation of the spin coater system, forming the basis for successful implementation and future enhancements, particularly with the incorporation of IoT technology [25]. For example, through visuals, one can observe how the power regulator controls the voltage supplied to the brushless motor, determining the spinning speed of the coater. The touch-screen LCD allows users to input specific parameters and monitor real-time data such as rotation speed and coating thickness. Additionally, sensors integrated into the system provide feedback on variables like temperature and viscosity, allowing for precise adjustments and optimization of the coating process. With IoT technology, these components could be connected to a network, enabling remote monitoring and control of the coating process. This would allow operators to manage and adjust the parameters from anywhere, increasing efficiency and reducing the need for constant physical presence. Furthermore, the connectivity provided by IoT technology would enable data collection and analysis, facilitating predictive maintenance and identifying potential issues before they lead to downtime.

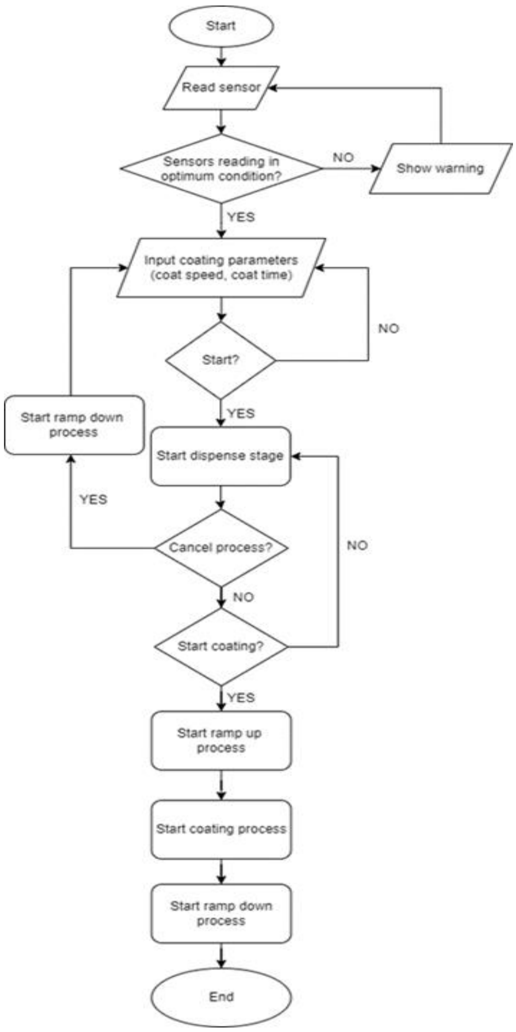

Figure 6. Flowchart of the operational system of a spin coater

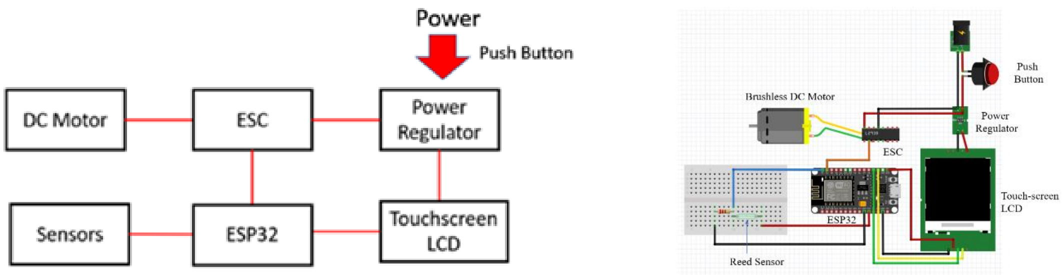

Figure 7. Spin coater system block diagram and circuit

The spin coating process relies on specific specifications and parameters to ensure a consistent and precise coating on a substrate [26], [27]. Table 1 outlines key factors such as rotation speed, acceleration, and spin cycle duration, which significantly influence coating thickness, uniformity, and overall quality. Adhering to these specifications is vital for optimal results in diverse applications, including microelectronics, thin film deposition, and photoresist coating. The rotation speed dictates the centrifugal force, ensuring even coating distribution. Acceleration controls the speed build up, minimizing the risk of uneven distribution. The spin cycle duration determines how long the coating material spreads and adheres, impacting coating thickness and quality. Following these specifications is critical in industries where precise and consistent coatings are essential for optimal performance and reliability. It ensures that the desired level of coating is achieved and maintained throughout the entire process.

Table 1. Spin coater specifications

Spin coater	Specifications
Coat speed	300 RPM - 5000 RPM
Coat time	1 sec – 80 sec
Power supply	12 V DC – 3A

The construction of the spin coater circuit was meticulously executed, referencing the block diagram depicted in Figure 7. The resulting circuit configuration is illustrated in Figure 8, showcasing a well -connected and integrated system. The spin coater has been controlled by the ESP32 microcontroller. ESP32 received multiple inputs including the reed sensor and input from the user interface. The ESP32 will produce a specific output according to the inputs received. The communication and instructions between input, output, and microcontroller have been programmed with Arduino IDE Power has been successfully supplied to the entire circuit, with each component receiving power, as indicated by the illumination of their respective onboard LEDs. Notably, the reed sensor's LEDs demonstrated dual illumination, one indicating the module's power-up and the other confirming the presence of a magnet. The brushless motor, crucial for the spin coater's operation, emitted a beep sound, serving as a clear indicator of its activation.

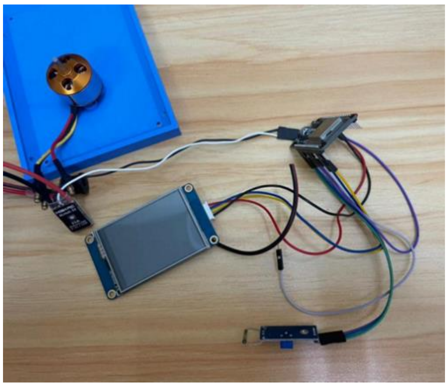

Figure 8. The complete circuit of the spin coater model

This systematic approach, including the verification of LED activations and sound signals, was implemented to ensure the individual functionality of each component. The microcontroller, an ESP32, received power from the ESC, solidifying the robust power supply across the entire circuit. This step-by-step validation process guarantees the reliability and effectiveness of the spin coater system, setting the stage for further testing and refinement.

2.3. Internet of things (IoT) implementation

The spin coater's flowchart, featuring remote control implementation was depicted in Figure 9. Notable enhancements to the system encompass remote control capabilities, database interaction for reading coating process recipes and storing coating history. The coating parameters, namely coat time and speed, form the recipe and history entries stored in the database. These additional features empower operators to remotely control the spin coater via the network, accessing the database for crucial coating parameters. This integrated approach enhances the versatility and accessibility of the spin coater system, providing operators with advanced control and data management capabilities [18].

The integration of the IoT into the spin coater system has been successfully realized through the use of visual basic (VB) as the communication platform [28]. VB, a programming language known for its graphical user interface (GUI), serves as the foundation for facilitating communication with the spin coater over the network. The VB programming interface, displayed in Figure 10, features a user-friendly GUI at the center window, providing an intuitive and interactive environment for seamless interaction with the spin coater system over the network. A GUI was programmed for the operator to control the spin coater over the Internet. Features provided by the GUI include connection to ESP32's IP address, display connection status, spin coater status, input coating parameter, input coating substrate, and load recipe.

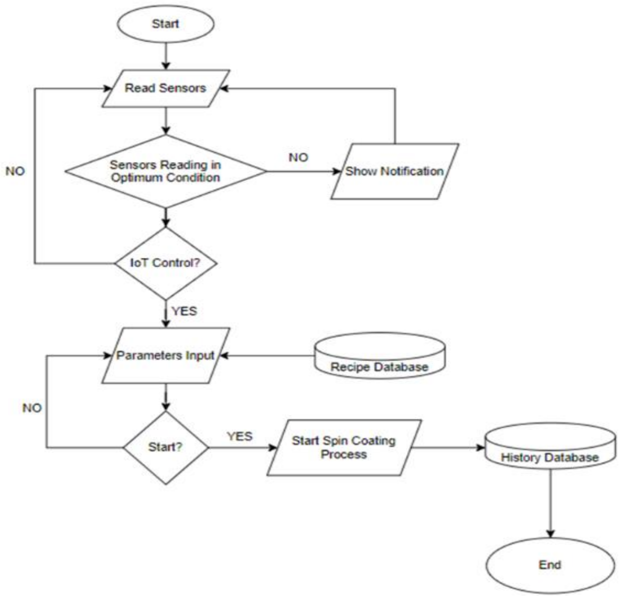

Figure 9. Flowchart for spin coater system with remote control

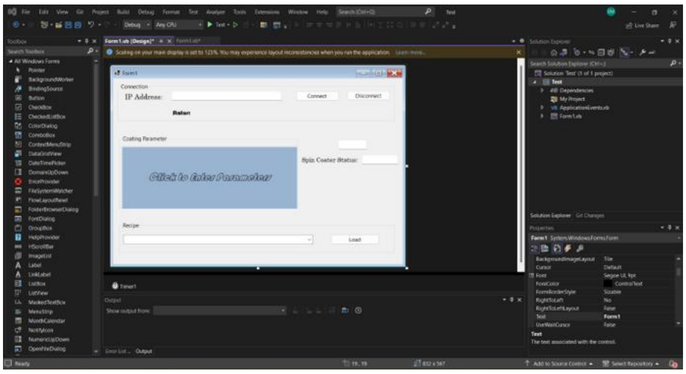

Figure 10. The interface of VB programming

3. RESULTS AND DISCUSSION

The spin coater system has been developed by referring to the block diagram and circuit, as shown in Figure 7. Two graphical GUIs are available for the spin coater. One is the touch-screen LCD attached to the spin coater, while VB GUI was the alternative option for IoT control. The minimum and maximum values of parameters have been configured at both GUI as shown in Figure 11. The minimum coat speed was 300 rpm with a minimum time of 1 second. Conversely, the maximum speed was 5000 rpm with a maximum coat time of 80 seconds. These parameters met the specifications set in Table 1.

More advanced coating parameters, such as ramp-up and ramp-down durations, can be set to the touch-screen interface. Figure 12 shows the more advanced parameter configuration for the touch-screen LCD interface. This configuration allows for more precise control over the coating process and ensures consistent results. Additionally, the touch-screen interface allows for easy adjustment and monitoring of the parameters during operation. With the advanced parameter configuration, operators can optimize the coating process for different materials and achieve superior quality and efficiency.

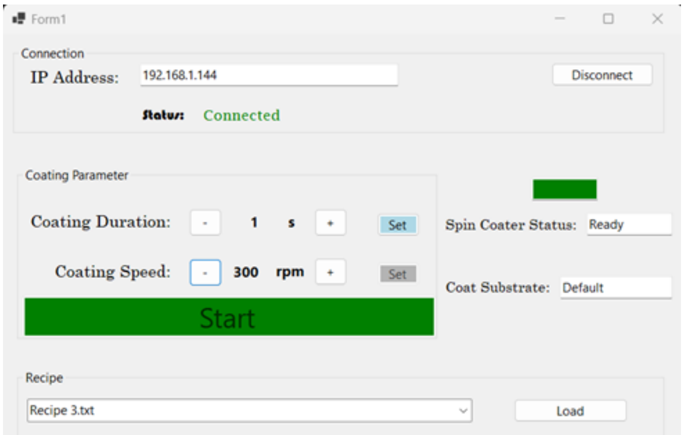

Figure 11. User interface with setup parameters

Figure 12. Advance parameter configuration

Furthermore, the touch-screen interface offers a user-friendly experience, making it effortless for operators to navigate through various settings and adjust as needed. This level of control is crucial in achieving optimal coating thickness, uniformity, and adhesion strength. The ability to fine-tune parameters during operation ensures that any deviations or variations in the coating process can be quickly addressed, resulting in consistent and reliable outcomes. Additionally, the touch-screen interface provides real-time monitoring of critical parameters such as temperature, pressure, and speed, allowing operators to promptly identify any anomalies and take corrective actions.

Two primary functionalities have been implemented for cloud storage: loading recipes and storing log files. Recipes, representing pre-set parameters like coat speed and coat time, are saved in a text file format following industrial standards. Figure 13 illustrates the VB GUI with "Recipe 3" loaded, where the loaded parameters (20 for coat time and 2,500 for coating speed) align with the stored recipe file. When the coating process initiates, a notification prompts the user to save the parameters to the cloud database. These coating parameters are then stored in a log file in text format, creating a comprehensive coating history. Figure 13 displays a list of coating history entries in the log file, capturing essential data such as coating speed, coating time, and coating substrate. This integration ensures efficient data tracking and retrieval, enhancing the spin coater system's overall functionality.

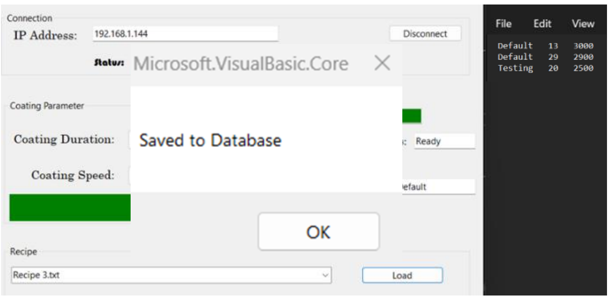

Figure 13. Notification for storing parameter to cloud

4. CONCLUSION

In conclusion, our project fulfilled objectives in terms of design, performance, and accessibility in addition to providing the essential demand for an affordable spin coater system. A robust mechanical framework that was 3D printed, an effective ESP32 microprocessor and an intuitive touch-screen interface were combined in a novel way to create a spin coater system that is highly precise and consistently functioning when applying thin layer deposition on a variety of substrates. The mechanical design that is produced by 3D printing is not only highly resilient but also cost-efficient, which makes it an appropriate match for a wide range of materials science applications. The overall reliability of the system was enhanced by the essential and precise control that the ESP32 microcontroller provided over spin duration and speed. A user-friendly touch-screen interface improves operability for researchers and technicians by enabling seamless adjustments to deposition parameters as needed. This device effectively meets the scientific community's need for an affordable and efficient spin coater. Furthermore, the brushless DC electric motor ensures outstanding coating while using minimal noise and power, satisfying performance criteria while prioritizing user comfort. Safety concerns are addressed by safety considerations such as the 3D-printed outer shell and emergency features, emphasizing the well-rounded nature of our design. Our spin coater system, featuring IoT capabilities, enables real-time monitoring and precise control, developing thin film deposition to a new level of sophistication. This spin coating technology, positioned as a low-cost option, shows tremendous promise in furthering research, stimulating innovation, and finding applications across diverse sectors in the dynamic field of thin film deposition. Our initiative demonstrates the ground-breaking potential of accessible technology in influencing the future of scientific research.

ACKNOWLEDGEMENTS

The study is funded by the Ministry of Higher Education (MOHE) of Malaysia through the Fundamental Research Grant Scheme (FRGS), Project No. INDUSTRI(IRMG)/MIHI/FKEKK/2022/I0072. The authors also would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for all the supports.

REFERENCES

[1] A. Kadhim, S. M. Swadi, and G. M. Ali, "Design and implementation of a feedback programmable spin coating system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 3, pp. 1516–1523, Mar. 2020, doi: 10.11591/ijeecs.v17.i3.pp1516-1523.

[2] M. Merenda, C. Porcaro, and D. Iero, "Edge machine learning for AI-enabled IoT devices: A review," *Sensors*, vol. 20, no. 9, Apr. 2020, doi: 10.3390/s20092533.

[3] R. F. Bianchi, M. F. Panssiera, J. P. H. Lima, L. Yagura, A. M. Andrade, and R. M. Faria, "Spin coater based on brushless dc motor of hard disk drivers," *Progress in Organic Coatings*, vol. 57, no. 1, pp. 33–36, Sep. 2006, doi: 10.1016/j.porgcoat.2006.05.004.

[4] R. G. Aguilar and J. O. López, "Low cost instrumentation for spin-coating deposition of thin films in an undergraduate laboratory," *Latin-American Journal of Physics Education*, vol. 5, no. 2, pp. 368–373, 2011.

[5] M. Fardousi, M. F. Hossain, M. S. Islam, and S. Rahat, "Cost-effective home-made spin coater for depositing thin films," *Journal of Modern Science and Technology*, vol. 1, no. 1, pp. 126–134, 2013.

[6] S. Muniandy *et al.*, "The effect of different precursor solutions on the structural, morphological, and optical properties of Nickel Oxide as an efficient hole transport layer for perovskite solar cells," *Pertanika Journal of Science and Technology*, vol. 31, no. 4, Jun. 2023, doi: 10.47836/pjst.31.4.26.

[7] A. M. A. Aziz *et al.*, "Investigation of the performance impact of active layer parameter variations on inverted perovskite solar cells using GPVDM," in *2023 IEEE Regional Symposium on Micro and Nanoelectronics (RSM)*, Aug. 2023, pp. 130–133. doi: 10.1109/RSM59033.2023.10326977.

[8] S. Muhammad, A. T. Nomaan, M. I. Idris, and M. Rashid, "Structural, optical and electrical investigation of low-temperature processed zinc oxide quantum dots based thin films using precipitation-spin coating on flexible substrates," *Physica B: Condensed Matter*, vol. 635, Jun. 2022, doi: 10.1016/j.physb.2022.413806.

[9] A. T. Nomaan, A. A. Ahmed, N. M. Ahmed, M. I. Idris, M. R. Hashim, and M. Rashid, "ZnO quantum dot based thin films as promising electron transport layer: Influence of surface-to-volume ratio on the photoelectric properties," *Ceramics International*, vol. 47, no. 9, pp. 12397–12409, May 2021, doi: 10.1016/j.ceramint.2021.01.094.

[10] R. P. Garcia, "Controlled deposition of fullerenes: Effects of topological nano-modifications of a surface on aggregation and growth phenomena," Thesis for: PhD Mathematik und Naturwissenschaftender Technischen Universität Berlinzur Erlangung des akademischen Grades, 2018.
[11] T. Gambaryan-Roisman, "Modulation of Marangoni convection in liquid films," *Advances in Colloid and Interface Science*, vol. 222, pp. 319–331, Aug. 2015, doi: 10.1016/j.cis.2015.02.003.
[12] N. Sahu, B. Parija, and S. Panigrahi, "Fundamental understanding and modeling of spin coating process: A review," *Indian Journal of Physics*, vol. 83, no. 4, pp. 493–502, Apr. 2009, doi: 10.1007/s12648-009-0009-z.
[13] M. I. Idris *et al.*, "Zinc oxide quantum dots as photoanode for dye-sensitized solar cell," in *2020 IEEE International Conference on Semiconductor Electronics (ICSE)*, Jul. 2020, pp. 57–60. doi: 10.1109/ICSE49846.2020.9166896.
[14] M. D. Tyona, "A theoritical study on spin coating technique," *Advances in materials Research*, vol. 2, no. 4, pp. 195–208, Dec. 2013, doi: 10.12989/amr.2013.2.4.195.
[15] N.-T. Nguyen, "Fabrication technologies," in *Micromixers*, Elsevier, 2012, pp. 113–161. doi: 10.1016/B978-1-4377-3520-8.00004-8.
[16] J. Wu *et al.*, "DMF as an additive in a two-step spin-coating method for 20% conversion efficiency in perovskite solar cells," *ACS Applied Materials & Interfaces*, vol. 9, no. 32, pp. 26937–26947, Aug. 2017, doi: 10.1021/acsami.7b08504.
[17] M. F. Hossain, S. Paul, Md. A. Raihan, and M. A. G. Khan, "Fabrication of digitalized spin coater for deposition of thin films," in *2014 International Conference on Electrical Engineering and Information & Communication Technology, IEEE*, Apr. 2014, pp. 1–5. doi: 10.1109/ICEEICT.2014.6919158.
[18] E. Pianca, "The embedded design process: CAD/CAM and prototyping," in *Foundations of Robotics*, Singapore: Springer Nature Singapore, 2022, pp. 333–373. doi: 10.1007/978-981-19-1983-1_12.
[19] B. V. Ossila, "Spin coater (L2001A3)." https://www.ossila.com/collections/pages/solar-cell-prototyping-platform (accessed Nov. 27, 2023).
[20] D. Carbonell Rubio, W. Weber, and E. Klotzsch, "Maasi: A 3D printed spin coater with touchscreen," *HardwareX*, vol. 11, Apr. 2022, doi: 10.1016/j.ohx.2022.e00316.
[21] M. M. Ferdaus, M. M. Rashid, and M. A. Rahman, "Design and fabrication of a simple ost effective spin oater for deposition of thin film," *Advances in Environmental Biology*, vol. 8, no. 3, pp. 729–733, 2014.
[22] D. Meyerhofer, "Characteristics of resist films produced by spinning," *Journal of Applied Physics*, vol. 49, no. 7, pp. 3993–3997, Jul. 1978, doi: 10.1063/1.325357.
[23] H. A. M. Mustafa and D. A. Jameel, "Modeling and the main stages of spin coating process: A review," *Journal of Applied Science and Technology Trends*, vol. 2, no. 02, pp. 119–123, Aug. 2021, doi: 10.38094/jastt203109.
[24] I. Sya'roni, A. Hartanto, N. R. Rahman, and I. Subiantoro, "Microcontroller base spin coating design and IoT data monitoring and storage," *Indonesian Physical Review*, vol. 6, no. 1, pp. 33–41, Dec. 2022, doi: 10.29303/ipr.v6i1.194.
[25] M. Abdelsamie, K. Cruse, N. Tamura, G. Ceder, and C. M. Sutter-Fella, "Impact of processing conditions on the film formation of lead-free halide double perovskite Cs 2 AgBiBr 6," *Journal of Materials Chemistry A*, vol. 10, no. 37, pp. 19868–19880, 2022, doi: 10.1039/D2TA00763K.
[26] L. E. Scriven, "Physics and applications of DIP coating and spin coating," *MRS Proceedings*, vol. 121, Feb. 1988, doi: 10.1557/PROC-121-717.
[27] "Spin coat theory," *Cost Effective Equipment*, 2023. https://www.costeffectiveequipment.com/service-support/technical-resources/spin-coating-theory (accessed Jan. 15, 2024).
[28] V. Kanade, "What is visual basic? Working, features, and applications," *spiceworks*, 2023. https://www.spiceworks.com/tech/devops/articles/what-is-visual-basic/ (accessed Jan. 15, 2024).

BIOGRAPHIES OF AUTHORS

Ahmad Muhajer Abdul Aziz is a graduate research assistant in the Faculty of Electronic and Computer Technology and Engineering at Universiti Teknikal Malaysia Melaka (UTeM) in Melaka, Malaysia. He holds a B.Eng degree in Electronic Engineering Technology (Computer System) from the same university and is currently pursuing an M.Sc in Electronic Engineering at UTeM. His research interests are semiconductors, thin film, solar cells, perovskite, renewable energy technology, internet of things (IoT) and artificial intelligence (AI). He can be contacted via email at: ahmadmuhajer96@gmail.com.

Muhammad Idzdihar Idris is a senior lecturer in Faculty of Electronic & Computer Technology and Engineering at Universiti Teknikal Malaysia Melaka (UTeM) in Melaka, Malaysia. He received his B.Eng degree in Electronic System Engineering from Hiroshima University, Japan, M.sc in Microelectronics from Universiti Kebangsaan Malaysia (UKM) and Ph.D. in Semiconductor Devices from Newcastle University, United Kingdom in 2010, 2012, and 2018, respectively. His research interests are fabrication and characterization of semiconductor devices: MOSFET, solar cell, and gas sensor. He can be contacted at email: idzdihar@utem.edu.my.

Zul Atfyi Fauzan Mohammed Napiah is a senior lecturer and serves as the Head of the Computer Engineering Department within the Faculty of Electronic and Computer Technology and Engineering at Universiti Teknikal Malaysia Melaka (UTeM) in Melaka, Malaysia. He earned his B. Eng degree in Electrical-Electronics from Universiti Teknologi Malaysia (UTM), a M.Eng in Microelectronics from the same institution, and a Ph.D. in Electronic Engineering from Kanazawa University, Japan. His research interests are semiconductor devices, optoelectronics, and solar cells. He can be contacted at email: zulatfyi@utem.edu.my.

Muhammad Noorazlan Shah Zainudin is a senior lecturer and serves as the Deputy Dean (Student Development) within the Faculty of Electronic and Computer Technology and Engineering at Universiti Teknikal Malaysia Melaka (UTeM) in Melaka, Malaysia. He earned his B. Eng degree in Computer Science from Universiti Teknologi Malaysia (UTM), a M.Eng in Computer Science from the same institution, and a Ph.D. in Intelligence System at UPM. His research interests are machine learning, artificial intelligence, and pattern recognition. He can be contacted at email: noorazlan@utem.edu.my.

Marzaini Rashid a lecturer at the School of Physics, Universiti Sains Malaysia (USM), Malaysia. He earned his B.Eng degree in Electrical/Electronic from Universiti Tenaga Malaysia (UNITEN), followed by an M.Sc in Physics from Universiti Sains Malaysia (USM) and a Ph.D. in Optoelectronics from the University of Newcastle Upon Tyne, United Kingdom. His research focuses on nanostructured semiconductors and optoelectronic devices. He can be contacted at email: marzaini@usm.my.

Luke Bradley a research associate at the University of Strathclyde within the Rolls Royce UTC group. He attained his Bachelor of Engineering in Electrical and Electronic Engineering from Newcastle University in 2015. Following this, he focused on Cryogenic Power Electronics during his professional tenure and completed his Ph.D at Newcastle University in 2020. His areas of expertise encompass power electronics and circuits operating at cryogenic temperatures, power device simulations, and the application of microcontroller data logging. He can be contacted at email: luke.bradley@strath.ac.uk.