PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 1 (2025) p. 771-779
https://publisher.uthm.edu.my/periodicals/index.php/peat

Design and Development of Used Cooking Oil (UCO) Container with IoT Approaches

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DOI: https://doi.org/10.30880/peat.2025.06.01.082

Article Info

Received: 20 January 2025
Accepted: 06 February 2025
Available online: 30 April 2025

Keywords

Smart UCO Containers, Sustainable Cooking Oil Management, IoT-enabled Recycling Systems, IoT-based Waste Management

Abstract

Improper disposal of used cooking oil (UCO) poses significant environmental risks, such as water pollution and blocked drainage systems, highlighting the need for effective waste management solutions. This study focuses on designing and developing an IoT-enabled smart container to optimize UCO collection and management. The container integrates an ultrasonic sensor to monitor oil levels and displays real-time data on an LCD screen, with wireless connectivity via NodeMCU to send alerts through the Blynk application when full. The system emphasizes user convenience, durability, and efficient data communication. The developed prototype enhances UCO collection efficiency, reduces environmental harm, and promotes sustainable waste management practices, demonstrating the potential of IoT technology for scalable and sustainable solutions.

1. Introduction

Cooking oil plays a vital role in kitchens globally, with different types preferred based on regional culinary traditions. In Western countries, oils like olive, canola, and sunflower are commonly used due to their adaptability and health benefits. In Asia, oils such as soybean, sesame, mustard, and palm oil are integral to diverse cuisines. Malaysia, known for its extensive use of palm oil, faces challenges in managing the disposal of used cooking oil (UCO), as improper disposal leads to environmental issues like blocked sewers and pollution. Efforts to recycle UCO into biodiesel and other products highlight the importance of sustainable waste management practices [1].

The improper disposal of UCO poses environmental and logistical challenges, including water contamination, sewer blockages, and harm to aquatic ecosystems. Current management systems often fail to address these issues effectively. Advanced technological solutions, such as Bluetooth and sonar-enabled systems like DarLinQ™, demonstrate the potential for precise monitoring and efficient management of UCO. To improve upon existing solutions, this study proposes the development of an IoT-enabled UCO container, offering real-time monitoring, remote management, and data analytics to optimise collection and recycling processes while promoting environmental sustainability [2].

This project focuses on designing a 20-litre IoT-enabled container specifically for the collection and monitoring of used cooking oil (UCO). The primary objectives include developing an innovative product concept that integrates IoT technologies, creating precise engineering drawings to facilitate prototype manufacturing, and testing the prototype to ensure functionality and reliability [3]. The container will feature ultrasonic sensors to measure oil levels, a NodeMCU V3 microcontroller for data processing, and an LCD display to provide real-time visual feedback on oil levels. Additionally, the system will be integrated with the Blynk app, enabling notifications to be sent when the container reaches its full capacity. By leveraging these technologies, the design aims to provide a user-friendly solution for efficient UCO collection and management.

The integration of IoT technologies in UCO containers offers significant advancements in operational efficiency and sustainability. Real-time monitoring of oil levels allows for prompt collection scheduling, minimizing waste and reducing logistical inefficiencies. Furthermore, by maintaining optimal storage conditions, the container helps preserve the quality of the collected oil, which is crucial for recycling processes, such as converting UCO into biodiesel. This streamlined approach to UCO recycling not only enhances waste management practices but also contributes to reducing the carbon footprint associated with improper oil disposal. By aligning with global sustainability goals, this project demonstrates the potential for IoT-enabled solutions to create more sustainable and environmentally friendly systems for managing waste resources.

2. Methodology

2.1 Design Process

The design process begins with defining the problem and establishing a structured methodology for developing a viable solution. This crucial step involves identifying the tools, strategies, and criteria required to guide the creation of an effective design, ensuring clarity and direction throughout the project. Setting a solid foundation includes determining the performance goals, constraints, and functional requirements that align the design with customer expectations, usability standards, and manufacturing limitations. These preliminary criteria act as a roadmap to ensure the end product is both practical and impactful.

The process progresses to Phase 1: Product Concept, where initial ideas and design concepts are generated. This involves brainstorming multiple approaches to address the identified problem while taking into account user needs, technical constraints, and functional objectives. Creativity and innovation take center stage during this phase, as designers explore diverse solutions to create a strong starting point. In Phase 2: Concept Generation, these preliminary ideas are further developed into detailed and refined solution concepts. Designers analyze materials, component placements, and operational strategies, focusing on technical feasibility, cost considerations, and the potential for innovation. This stage allows the team to evaluate multiple design paths and choose the most promising options for further development.

An essential phase follows, where the design is rigorously evaluated against the defined target specifications. This critical review ensures the design meets performance, usability, and feasibility criteria established at the outset. If any gaps are identified, an improvement loop is initiated. During this iterative phase, the design is systematically refined and optimized to resolve shortcomings, ensuring continuous improvement until all project requirements are met satisfactorily. This cyclical approach allows for flexibility and innovation while maintaining a sharp focus on achieving the design objectives.

Once the design successfully meets the target criteria, the process advances to Phase 3: Design for Manufacture. This phase ensures that the solution is optimized for efficient and cost-effective production. Prototypes are constructed to validate the design's functionality, manufacturability, and overall reliability. Testing and refinement occur during this phase to address any remaining issues and fine-tune the design for optimal performance. Rigorous testing ensures that the product not only meets the intended specifications but also delivers a high level of user satisfaction and dependability.

The process concludes with comprehensive documentation that captures all aspects of the design. This includes detailed design specifications, manufacturing instructions, test results, and any additional data that may support future production or system upgrades. By thoroughly documenting the project, the team creates a valuable resource for future reference, ensuring continuity and scalability for future needs. This structured and methodical design process ensures that the final product is not only innovative and functional but also fully optimized for real-world applications, setting the stage for long-term success and user satisfaction.

2.2 Functional Model

This section presents the functional model of the seat design. A functional model represents a product's functions as a structure of functional objects, which can be broken down into smaller components or combined to create a compound object [4]. This approach enables both top-down and bottom-up design. Functional design aims to link design functions (functional elements) with physical elements used to achieve them. Functional elements are the individual operations that contribute to the product's overall performance.

The functional model for a used cooking oil (UCO) container focuses on safely and effectively collecting, storing, and transporting spent oil for communal use in outdoor settings. Its main goal is to provide a leak-proof, spill-free solution that ensures safe disposal. The container should be durable, corrosion-resistant, and able to withstand harsh weather and temperature changes. It features ergonomic handles for easy transport and pouring, a large mouth for easy oil disposal, and clear labelling for user convenience. A filtering system may also be included to remove food particles and trash, ensuring clean storage for recycling or proper disposal. The functional model of the UCO container is based on the main structure of the seat with the function of the seat as a functional element as shown in Figure 2 and Figure 3.

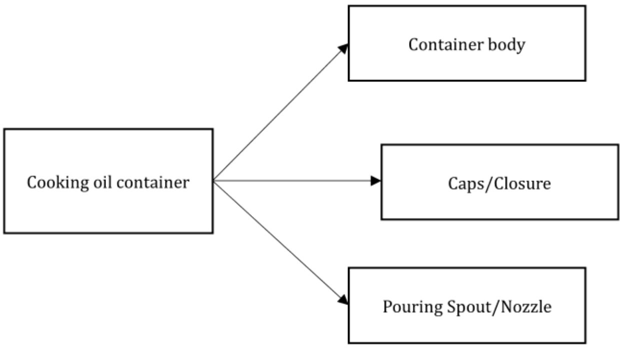

Fig. 1: Physical Element Chart

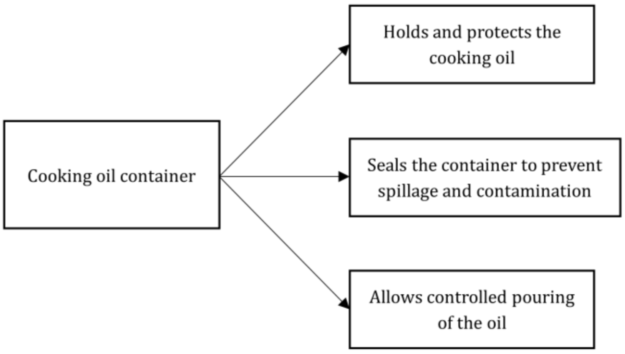

Fig. 2: Functional Element Chart

2.3 Morphological Analysis

Morphological analysis was used in this project to explore new design ideas for a used cooking oil (UCO) container [5]. This method helps identify all possible configurations of a problem by breaking it down into different variables, which can then be designed separately. The process starts by identifying the key variables and their range of conditions. In this project, the sub-systems of the UCO container, such as material, container body, extraction method, and lid type, were considered.

The type of morphological chart used is attribute listing, where an existing product is broken down into its components, reassembled, and new iterations are created [6]. The new UCO container design is based on references from previous designs but includes changes in the shape and dimensions of the sub-systems. SolidWorks software was used to further design and combine the sub-systems, resulting in a concept combination table for the new container design.

2.4 Design Selection

2.4.1 Screening concept

Concept screening, also known as Pugh concept selection, is a systematic decision-making technique developed by Stuart Pugh in the 1980s [7], designed to streamline the process of evaluating and selecting product ideas by narrowing down multiple design options to a few for further refinement. This method was employed in this project to assess 27 different design variants, each of which was compared against a predetermined reference concept using a simple yet effective rating system. The evaluation criteria were carefully selected based on the primary goals of the seat design and included factors such as simplicity, comfort, safety, shoulder fit, and ease of seat adjustment. Each design was scored using specific symbols, where a "+" indicated better performance, a "0" signified no difference, and a "-" represented a poorer outcome compared to the reference concept. By systematically assessing each concept against these criteria, the process provided a clear and structured comparison of the strengths and weaknesses of each design variant. Following this initial evaluation, a ranking system was applied to determine which designs demonstrated the most potential for further refinement and in-depth analysis, ultimately guiding the selection of the most promising concepts for further development.

2.4.2 Scoring Concept

The scoring concept for evaluating different designs of a used cooking oil container involves assessing criteria such as durability, ease of use, leak prevention, environmental impact, and cost-effectiveness [8]. Each design is rated on a scale from 1 to 5, with 1 being poor and 5 being excellent. Durability focuses on the material's ability to resist damage and weather. Ease of use considers features like ergonomic handles and easy pouring. Leak prevention evaluates the effectiveness of seals and lids. Environmental impact looks at material sustainability and recyclability. Cost-effectiveness compares the overall cost to the benefits. The total score for each design is the sum of the individual scores, helping identify the most balanced and effective container design. The scores for each criterion are shown in Table 1.

Table 1: Scale of Rating and Relative Performance

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

2.5 Types and Functions of Sensors Used

This design uses several sensors and components to accurately monitor the cooking oil level in the container and send alerts before it reaches full capacity. An ultrasonic sensor measures the distance to the oil surface, providing real-time data on the oil level [9]. The data is processed by a NodeMCU V3, which acts as the central microcontroller, ensuring smooth communication between components. The NodeMCU V3 is connected to the Blynk app, sending notifications to users when the oil level is nearly full [10]. Additionally, a 16x2 LCD display shows the current oil level on-site [11]. These components work together to effectively monitor the container and send alerts before it overflows.

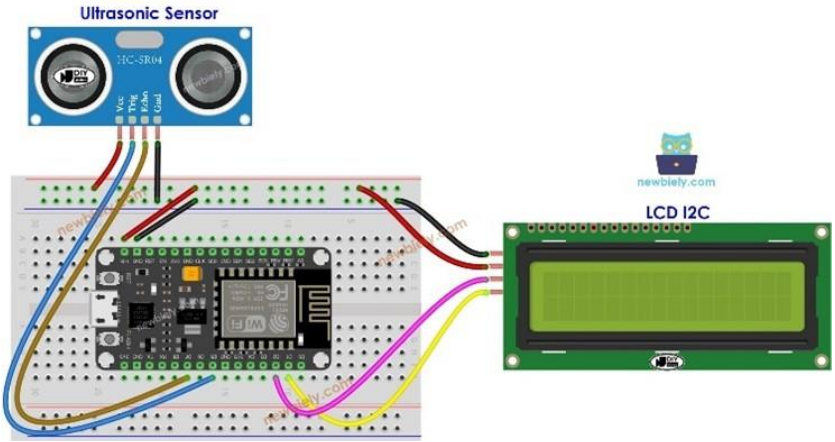

Fig. 3: Connecting of IoT devices [12]

If the connection between these three main sensors is not properly established, the entire system will not function as intended, which may result in significant errors, inaccurate readings, or even a complete system failure. This could lead to unreliable data collection and ineffective monitoring of the oil levels. Therefore, it is crucial to ensure that both the ultrasonic sensor and the LCD are correctly and securely connected to the NodeMCU, adhering strictly to the wiring configurations specified in Table 2 and Table 3. Proper wiring not only ensures accurate functionality but also enhances the overall stability and reliability of the system, preventing potential malfunctions that could affect its performance.

Table 2: Pinout for Ultrasonic Sensor [13]

Pin Label	NodeMCU Connection
VCC	Connect to the 3.3V pin (3V3) or VIN
GND	Connect to a GND pin
Trigger Pin (TRIG)	Connect to a GPIO pin (e.g., D1 or GPIO5)
Echo Pin (ECHO)	Connect to a GPIO pin (e.g., D2 or GPIO4)

Table 3: Pinout for LCD [14]

Pin Label	NodeMCU Connection
VCC	Connect to the 3.3V pin (3V3) or VIN
GND	Connect to a GND pin
SDA	Connect to the I2C data pin (e.g., D5 or GPIO4)
SCL	Connect to the I2C clock pin (e.g., D6 or GPIO5)

2.6 System Architecture

System architecture refers to the structure and organisation of the components involved in the design of a system. In this case, the system architecture includes an ultrasonic sensor to measure the oil level, a NodeMCU V3 microcontroller to process the data, and an LCD display to show the oil level on-site. The NodeMCU V3 is also connected to the Blynk app, allowing users to receive notifications on their mobile devices when the oil container is close to full [15]. These components work together in a cohesive manner, ensuring accurate monitoring, communication, and user alerts, forming an integrated and efficient system for managing the used cooking oil container.

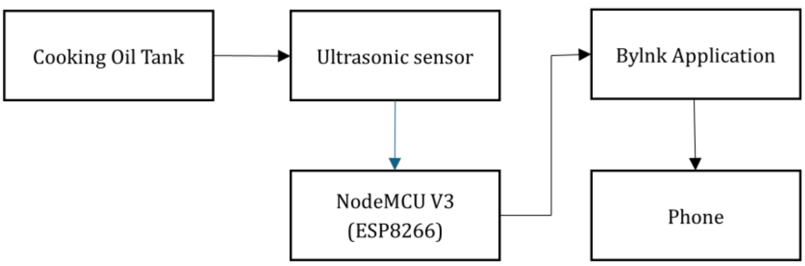

Fig. 4: *System Architecture*

In addition to these core components, the system incorporates a power supply to ensure uninterrupted operation, typically provided by a rechargeable battery connected via a voltage regulator to maintain consistent power levels. The ultrasonic sensor, mounted on the top of the container, continuously measures the oil level by emitting sound waves and calculating the distance based on the reflected signals [16]. The NodeMCU V3 acts as the central processing unit, collecting data from the sensor and interpreting it to determine the oil level in real time. This information is displayed on the LCD for on-site monitoring and simultaneously transmitted to the Blynk app via Wi-Fi, enabling remote notifications. The system's design emphasizes reliability and user-friendliness, with its compact arrangement ensuring easy installation and maintenance while promoting sustainability by encouraging proper disposal of used cooking oil.

2.7 System Flowchart

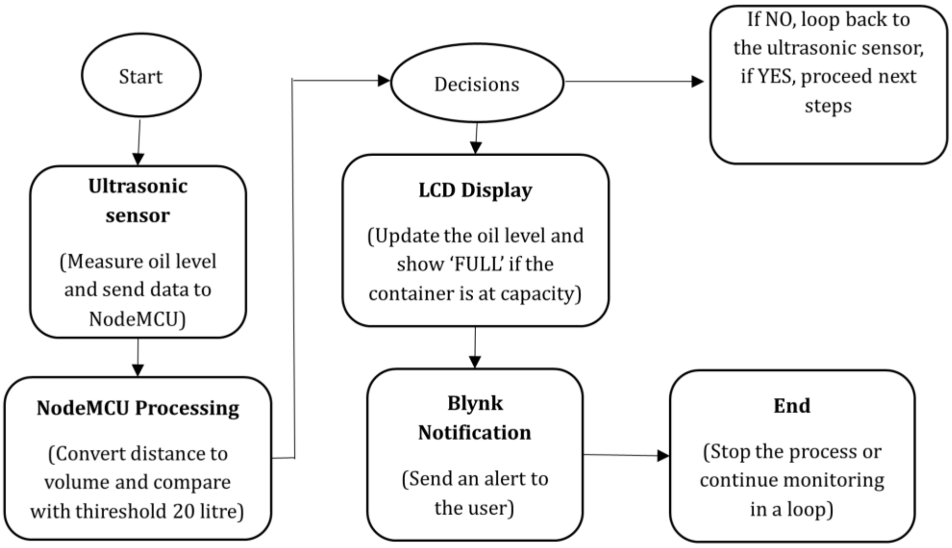

Fig. 5: System Flowchart

3. Result and Discussion

3.1 Final Design of the IoT-Enabled UCO Container

The final design offers an innovative solution for UCO management by incorporating IoT technology. The container, made of high-density polyethylene (HDPE), is chosen for its corrosion resistance and durability in oil storage. Its cylindrical shape ensures even pressure distribution and makes cleaning easy. The key components include an ultrasonic sensor (HC-SR04) for accurate oil level detection, a NodeMCU V3 microcontroller for processing sensor data and transmitting it to the Blynk app, and an LCD 16x2 display for on-site oil level feedback.

Fig. 6: The Fabricated Prototype

Additionally, the Blynk app integration alerts users remotely when the container is nearing capacity. The design also features ergonomic considerations such as a wide mouth for easy oil disposal and insulation to maintain oil quality under varying environmental conditions.

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3.2 Performance Testing

3.2.1 Sensor Accuracy and Calibration

After completing the fabrication of the prototype, functionality tests were conducted to ensure that the prototype functions perfectly and provides the desired data to complete the project. In this test, water is used as the primary source to replace cooking oil in order to reduce costs. After several tests, the desired and accurate data was obtained, as shown in Table 4.

Table 4: Result of Test

Distance From top (cm)	Measured Volume (L)	Actual Volume (L)	Error (%)
5.0	20	20	0
15.0	14.69	15	-0.89
25.0	9.80	10	-2.00
35.0	4.92	5.0	-1.60
45.0	2.45	2.5	-1.60
50.0	0.98	1.0	-2.00
65.0	0.24	0.25	-4.00

3.2.2 Notification System via Blynk App

3.3 Real-Time Monitoring and User Feedback

Combining the ultrasonic sensor, NodeMCU, and LCD enabled smooth real-time monitoring. The LCD displayed oil levels in litres (as shown in Figure 7), while the Blynk app provided remote updates. Users found the dual feedback approach (on-site and mobile) highly convenient. Real-time monitoring ensured the container remained operational, eliminating the need for manual checks.

Fig. 7: Example of real-time data displayed on the LCD

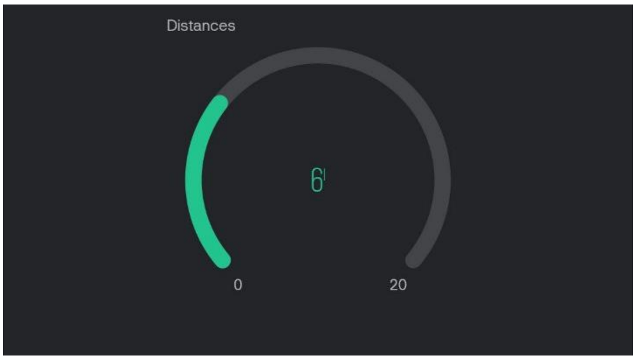

Fig. 8: Example of real-time data displayed on the Bylnk app

3.4 Comparative Analysis with Existing Solutions

After testing the prototype, it showed many advantages over traditional containers, which have several shortcomings in various aspects, as tabulated in Table 5.

Table 5: The differential between Proposed and Traditional Container

Feature	Proposed System	Traditional Containers
Real-time Monitoring	Yes	No
User Notification	Yes (Blynk app)	No
Material Durability	HDPE	Mixed material
Environmental Impact	Low	Moderate

The suggested system significantly outperforms previous methods by incorporating sophisticated monitoring capabilities, which allow for more precise and real-time data collection. This enhanced functionality helps in ensuring better accuracy and efficiency in tracking oil levels and quality. Additionally, the system is designed to minimize environmental concerns by promoting responsible waste management and reducing the risk of improper disposal. Furthermore, the inclusion of a user-friendly interface enhances accessibility, making it easier for users to interact with and manage the system without requiring extensive technical knowledge.

4. Conclusion

The project successfully achieved its goals by designing, fabricating, and testing an IoT-enabled used cooking oil (UCO) container. The system provides real-time monitoring, precise oil level tracking, and user notifications, addressing key challenges in waste oil management. The integration of components such as ultrasonic sensors, the NodeMCU microcontroller, an LCD display, and the Blynk app ensures accuracy and a smooth user experience. The system also eliminates the need for manual checks, offering convenience through dual feedback: on-site monitoring and mobile app updates.

The UCO container was designed with precision and user convenience in mind. Detailed engineering drawings and SolidWorks models were created to ensure the correct placement of components and an ergonomic design. Extensive testing confirmed the system's reliability in real-world applications, achieving its primary objectives of providing accurate oil level measurements and timely notifications. These results demonstrate the viability of IoT-based solutions for waste management.

For future development, several improvements could enhance the container's utility and scalability. Adding advanced sensors to monitor temperature and detect contamination would ensure the oil meets recycling standards. Incorporating offline data storage and expanding the system to larger commercial setups could increase its applicability. Exploring eco-friendly materials and integrating the container into smart waste management platforms could further improve its environmental impact and operational efficiency. Additionally, collaborations with biodiesel manufacturers could streamline the recycling process, turning waste oil into valuable products.

Acknowledgement

This research was supported by the Faculty of Engineering Technology and Universiti Tun Hussein Onn Malaysia.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of the paper.

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