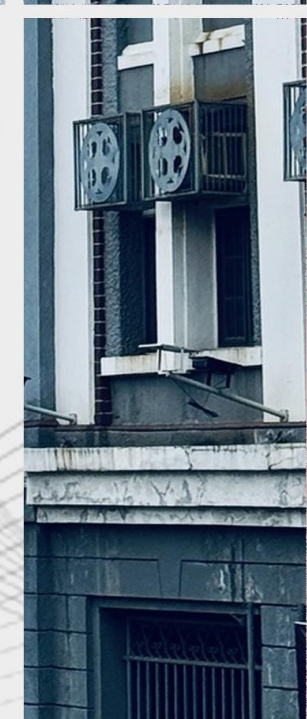
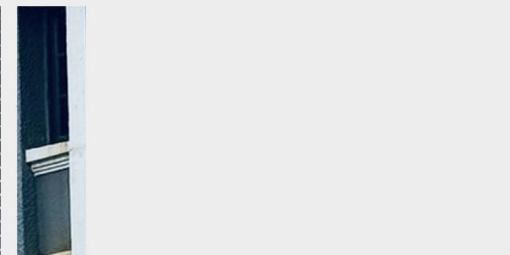




# THE HORIZON



**The Official Scholarly Journal of  
High School Students**



# THE HORIZON

The Horizon is the official academic journal of the high school students of Colegio de San Juan de Letran, Intramuros, Manila

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## GUIDED AUDIO-BASED ASSISTIVE YIELD (G.A.B.A.Y): SMART CANE WITH AUDIO NAVIGATION AND CAP SENSOR FOR VISUALLY IMPAIRED MOBILITY

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### ABSTRACT

This study aims to design and implement a smart cane with audio navigation and a cap sensor to enhance mobility and safety for visually impaired individuals. The system integrates ultrasonic sensors and a servo motor for obstacle detection, an ESP32 microcontroller for processing, and Bluetooth-enabled audio feedback through earbuds for real-time guidance. The cane handle is wrapped with organic banana fiber to improve grip and absorb sweat, promoting user comfort and sustainability. Performance evaluation focused on distance detection accuracy, direction command precision, and audio response time. Results showed that the smart cane reliably detected obstacles at 20 cm with an average audio response time of 1.48 s (SD = 0.420) across five trials. In comparison, the cap system detected upper hazards at 60 cm with an average response time of 0.106 s (SD = 0.00894). Overall, GABAY demonstrates an accessible and eco-friendly solution for the safe navigation of visually impaired users.

**Keywords:** smart cane, audio navigation, ultrasonic sensor, visually impaired, banana fiber

### INTRODUCTION

#### Background of the Study

Innovation is most powerful when it restores independence, especially for those whose vision limits their freedom of movement. For years, the traditional cane has been a trusted companion of the visually impaired, guiding each step with reliability. However, its limitations remain. Higher-level obstructions often go undetected, and even the firmest grip can falter when sweaty palms cause the cane to slip, turning safety into uncertainty.

This study takes on that challenge by introducing a dual-function navigation device that not only detects obstacles at ground level but also uses audio alerts to warn against elevated hazards. To further support accessibility, the handle is designed from organic banana fiber, providing natural grip, sweat absorption, and sustainability in one thoughtful material. By blending practicality, affordability, and eco-conscious design, this research aims to create more than just a tool; it offers freedom, security, and inclusion for those navigating the world without sight.

Millions of individuals are affected by blindness and visual impairment, which continue to be serious global public health issues that limit their ability to participate in social, professional, and educational activities fully. According to the World Health Organization (2023), at least 2.2 billion worldwide have a vision impairment or blindness, with a significant portion that could have been treated with proper interventions.

In the Philippines, the World Blind Union–Asia Pacific, citing supplementary reports from the Department of Health (DOH) and the Philippine Statistics Authority (PSA), stated that as of July 2023, there are 592,000 individuals who are blind—most of whom are poor and uneducated—and 2,179,733 individuals with low vision or other related visual impairments. These reports highlight the urgent need

for innovative, reasonably priced, and easily available assistive devices that can enhance the independence and quality of life of blind people.

In connection with this, Aganad et al. (2017), as cited in Gaspay et al. (2024), emphasized that the common challenges faced by blind and visually impaired individuals in their daily lives are not just about their disability but also come from limited accessibility and the lack of inclusive infrastructures that society has failed to address. This includes vehicles left parked that take up space for walking, narrow and crowded sidewalks caused by misuse of public spaces, uneven surfaces on the ground due to poor maintenance, and open manholes and pits.

As a technological response to such barriers, laser-sensing and vision-sensing smart canes have been developed to increase the independence of visually impaired people by offering better navigation support.

Advanced sensing systems in these canes help them sense obstacles and guide users more accurately than the traditional white cane.

However, most existing systems are still limited and need to be improved. Mai et al. (2023) pointed out that although laser and vision-sensing smart canes enhance mobility convenience, a majority of their capabilities are still lacking, especially in terms of precision and dependability. Similarly, Jin et al. (2024) compared conventional canes with secondary electronic mobility aids. They discovered that, even though such devices enhanced object detection and obstacle avoidance, they also led to slower processing times and hesitation on the part of users.

Beyond environmental barriers and technological limitations, another challenge arises from physiological conditions that affect from

physiological conditions that affect some users. Excessive hand sweating is a pathological disease known as primary palmar hyperhidrosis (PPH), which negatively affects a patient's social life, career, and mental health (Liu et al., 2022). To address this concern among individuals with excessive palm perspiration, banana fiber (abacá) is incorporated into the handle interface. As stated in Ali (2022), banana fiber possesses good absorbent properties, high breathability, quick-drying ability, and high tensile strength.

Even with the canes being used by people who are blind, they still face struggles due to their vulnerability to accidents. Obstacles that cannot be seen, detected, or anticipated pose a danger to the visually impaired. The existing cane integrates ultrasonic sensors, but these are often limited to detecting obstacles near the feet or knees. This leaves a critical gap as upper-body hazards such as low signboards, hanging branches, or protruding objects remain unaddressed, increasing the risk for users.

In addition to these detection limitations, another concern arises from sweaty palms, which can weaken the user's grip. This may cause the cane to slip or be dropped, creating further danger and leaving an important issue unresolved. Additionally, this research promotes sustainability since all materials to be used in the entire product are eco-friendly, making it not only safer and more functional but also durable, waste-reducing, and environmentally responsible.

### Objectives of the Study

This study aims to develop an innovative smart cane with audio navigation and a cap-based sensor system to enhance mobility and safety for visually impaired individuals. (1) To develop a smart cane and cap system with an ultrasonic sensor, obstacle detection, and integrated audio-buzzer alerts for real-time navigation support. (2) To evaluate the accuracy, response speed, distance, and reliability of the system to determine its overall effectiveness.

### Literature Review

#### Smart Cane Technologies for the Visually Impaired

The World Health Organization indicates that about 2.2 billion people across the globe experience vision loss that deeply impacts their daily lives. One of the most used devices among the visually challenged is the white cane, but it is only useful in detecting objects at ground level. It may result in collisions from the failure to see objects at higher levels. Ji et al. (2025) also recognized the drawback of existing intelligent canes regarding power management and power efficiency.

The traditional methods of recharging lead to low battery lives and ineffective functioning, and disrupt the independence of the users. Their DRL-based solution rectified the same, but with the setback of dependence on complex algorithms that might decrease accessibility in resource-poor locations for the users.

In order to help blind people, Kumar et al. (2025) suggested an Internet of Things (IoT) smart cane that uses machine learning and internet connectivity. However, the study's generalizability and reliability are limited by testing on a small number of blinded subjects.

The cane's efficacy in places with inadequate connectivity is further limited by its reliance on dependable internet. Furthermore, its capacity to identify intricate or shifting barriers may be hampered by the use of simple machine learning. Its durability and performance in the real world have not been confirmed because testing was conducted in controlled environments.

Both studies identified the shortcomings of existing intelligent canes. Ji et al. (2025) observed low power management and limited battery

life, and although their DRL-based approach optimized efficiency, it depended on advanced algorithms that limited accessibility. On the other hand, Kumar et al. (2025) found that an IoT-enabled intelligent cane had limited small-scale testing, stable internet dependence, and simple machine learning models that restricted reliability.

Both studies reveal that though intelligent cane technology is developing, it remains impractically unreliable in the field with respect to accessibility and adaptability.

According to Mai et al. (2023), the common cane is widely used as an auxiliary device for the visually impaired for daily travel due to its convenience to carry and use. However, the visually impaired face great travel challenges because of their limitations. By tapping around with the ordinary cane, the visually impaired can only feel the rough spaces, offering limited road information as they walk. Moreover, its detection range is restricted to about one meter, which greatly reduces its effectiveness in ensuring safety.

Additionally, dos Santos et al. (2020) emphasized that despite the help of a white cane for orientation and mobility for the users, its detection range is restricted, and it cannot sense overhead obstacles like hanging tree branches or elevated trash bins.

Both studies highlighted that the traditional white cane, though convenient and widely used, provides only limited spatial feedback within a short range and fails to detect overhead obstacles, leaving users vulnerable to safety risks and navigation challenges.

#### Dual Detection and Audio Navigation for Safety

According to Okolo et al. (2025), in their study published in the ScienceOpen Journal of Disability Research, the Smart Assistive Navigation System was developed to address these limitations. The system utilizes YOLOv8 object detection alongside ultrasonic sensors and a speaker module to identify both lower-body and upper-body obstacles.

With a reported 91.7% accuracy rate, the device provides real-time voice guidance and demonstrates effective performance in both indoor and outdoor environments. The authors emphasize that multi-sensor integration significantly improves mobility safety for visually impaired users.

Similarly, Simões et al. (2020), in their research featured in the MDPI Sensors Journal, introduced an audio guide system based on stereo vision and musical tones. Their device detects obstacles across a 120° field of view and translates spatial data into auditory cues, including spoken instructions and tonal signals. The use of Kalman filtering enhances indoor positioning accuracy, while the auditory feedback improves users' reaction time and confidence. Simões and colleagues highlight the importance of intuitive sound-based communication in promoting safe and independent navigation.

Both studies underscore the effectiveness of combining visual and ultrasonic detection with audio feedback to create safer mobility experiences. These findings align with the current project's innovation, which integrates a cane for lower-body detection and a cap-earbud system for upper-body hazard recognition and audio alerts. By merging tactile and auditory feedback, the device aims to reduce accidents and empower visually impaired individuals to navigate their environment with greater autonomy.

Besides these results, Ahmed (2023) shows a Smart Assistive Navigation Stick that is built with Arduino. It uses an SD card to keep WAV sound cues and gives voice alerts for different directions, like front, left, and right. Meanwhile, Zare et al. (2022) stress how important it is to have audio feedback in wearable navigation tools. So, adding a microSD card has real benefits—like quick, clear sound

autoplay; simple updates for new content without reflashing firmware; and robust offline performance that complements the sensor and audio strategies reported by Okolo et al. and Simões et al. and makes SD-backed audio well suited for the proposed cane + cap-earbud system.

Baldonado and Faelangca (2024), in Educational Administration Theory and Practice, developed an enhanced Audio-Based Smart Cane featuring object detection, distance measurement, and audio feedback. While generally accurate in obstacle detection, some inconsistencies in distance and audio output were noted. They recommended future upgrades like LiDAR, Bluetooth, and improved processing units.

Meanwhile, Panazan and Dulf (2024), in MDPI Technologies, introduced a smart cane with dual ultrasonic sensors for ground and chest-level obstacle detection. It provides vibration and audio alerts within a 2–400 cm range and connects to a mobile app via Bluetooth for tracking. Their study emphasized user-friendly design and improved safety.

Both studies highlight the value of multi-sensor detection and audio feedback. Baldonado and Faelangca focused on audio navigation, while Panazan and Dulf emphasized dual sensing and real-time alerts. These insights support the current project’s approach—using a cane for ground detection and a cap-earbud system for upper-body hazards and audio guidance—to enhance user confidence and mobility.

In addition to these, Salum et. al (2020) developed a helmet wiper using an SG90 servo motor and emphasized that it is generally used as actuators that require precise rotational positioning. It usually only moves in a certain angle, and for specific purposes, it can be modified to rotate continuously. Meanwhile, Ashari and Faruq (2019), as cited in Khamida et. al (2023), state that the SG90 servo motor provides high accuracy and takes up minimal space due to its tiny circuit. Therefore, both studies show that servo motors are suitable for precise control of position, angle, and movement.

**Ergonomic and Sustainable Design Features**

Ergonomics is linked to sustainability and eco-friendly design in addition to designing for user comfort and safety. The emerging field of ergoecology highlights how ergonomics supports eco-friendly design through eco-efficiency, eco-productivity, and systematic methods. According to Nacini (2020), sustainable products must be easy to use, and ergonomics provides a structured, user-centered approach that supports both human well-being and environmental responsibility. Integrating ergonomics with sustainability helps improve quality of life while protecting ecosystems in line with global goals like the MDGs and the 2030 Agenda.

Furthermore, Ivascu et al. (2021) explained that products created through manufacturing connect with workers, business owners, communities, and consumers both directly and indirectly at all stages of their life cycles. This is particularly evident during reverse logistics like recycling and reuse. Because of this, ergonomics plays a key role in checking these interactions to ensure products are useful, safe, and centered on user needs.

Ergonomics focuses on humans. It works alongside areas like engineering, design, production, transport management, and eco-friendliness to boost how well organizations work as they move towards sustainable development.

Therefore, when ergonomics and sustainability come together, they make sure that products are easy to use, safe, and good for the environment. By thinking about every stage of a product's life—from making it to reusing it—this method not only makes life better but also helps meet worldwide goals for sustainability.

As explained in the study of Kavya and Kavitha (2025), hypoallergenic banana sweat pads have been developed as a natural, gentle, and eco-friendly alternative in response to the issues caused by traditional sweat pads, which usually contain synthetic materials, chemicals, or adhesives that can lead to allergic reactions, discomfort, or environmental problems. Made from banana fibers, these eco-friendly pads offer absorbency and breathability while also being soft on the skin. Its hypoallergenic properties give a skin-friendly experience, free from harsh chemicals, which make them helpful to those with allergies and sensitivity, providing effective sweat absorption without causing irritation. At the same time, its biodegradable properties make it an environmentally responsible choice.

Moreover, based on the study of Islam et. al (2019), cited in Rajput and Khot (2022), banana fiber is a natural bast fiber that comes from the pseudo-stem of a banana plant. Research indicates that billions of tons of banana plant stems are wasted every year. After harvesting the fruit, farmers typically throw this waste into rivers, lakes, or burn it, which can be highly harmful to the environment if not managed properly.

According to Ebisike et. al (2013), cited in Rajput and Khot (2022), the banana tree must be disposed of after yielding the fruit since it cannot produce fruit again. With the growing population, the demand for bananas will rise, which leads to an increase in banana tree plantations. Moreover, this consequently produces more waste each year. Therefore, efforts should be made to turn this waste into a valuable resource.

Therefore, this concludes that hypoallergenic banana fiber can not only benefit the user by being an effective, natural, and eco-friendly sweat absorbent pad that is gentle, chemical-free, and highly absorbent. It can also benefit the earth by providing a sustainable way to turn banana waste into something useful that lessens the potential harm to the environment.

**Theoretical Framework**

Feedback systems, originally developed for industrial regulation, have evolved into adaptive models that underpin many intelligent technologies. According to Mayr (1975), cited in Lipnevich and Panadero (2021), these systems operate by monitoring input, comparing it against predefined thresholds, and adjusting output accordingly. This principle is embedded in the device’s decision-making loop. Ultrasonic sensors detect obstacles, and specific audio cues are triggered based on the user's environment. This continuous feedback mechanism ensures safe and efficient navigation by dynamically responding to real-time changes, aligning with the core tenets of adaptive system design.

According to Epstein et al. (2017), the brain builds a visual representation of the environment’s space, also called a ‘cognitive map’, supporting the memory and providing guidance. For four decades, studies on rodents have shown that special neurons in the hippocampus and surrounding regions, known as place, grid, border, and head direction cells, are the physical basis for the brain's internal "cognitive maps".

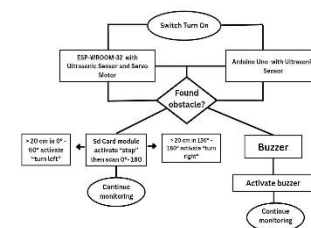


Figure 1. Conceptual Framework of the study

## Scope and Limitations

This study focuses on designing, developing, and evaluating a smart cane with audio navigation and a cap sensor system powered by an ESP32 with built-in Wi-Fi and Bluetooth. Ultrasonic sensors are used to detect low and high obstacles, while Bluetooth earbuds deliver real-time audio guidance. The cane also features an organic banana-fiber handle to improve grip, absorb sweat, and support sustainability. The scope includes testing the accuracy of distance detection and direction commands to ensure safe and reliable navigation for visually impaired users.

However, the study does not cover external factors such as weather conditions, battery lifespan, or durability when dropped or struck. The cane detects obstacles at around 20 cm, while the cap detects up to about 60 cm because the cane is held diagonally, placing its sensor farther forward. The system is also unsuitable for users who are both blind and deaf, as it relies solely on audio feedback, and alerts may be less noticeable in noisy environments. The banana-fiber handle may weaken after 4–6 months due to natural decomposition (Mehta et al., 2020).

Other limitations include the fixed detection range of the cap, which reduces effectiveness in wider or dynamic environments. The study does not cover long-term maintenance such as sensor cleaning, recalibration, or component replacement, nor integration with GPS or mobile navigation apps. Performance under extreme lighting conditions is also excluded from the scope.

## METHODOLOGY

### Research Design

This study employs a non-iterative developmental design. According to Wynn and Maier (2022), this approach follows a linear, step-by-step process that minimizes revisions, costs, and uncertainties, making it suitable for projects with stable requirements and limited resources (Bianchi & Suganthan, 2020).

This design is appropriate due to the study's defined scope and time constraints. The objective is to develop a single, functional prototype of the G.A.B.A.Y smart cane rather than undergo multiple redesign cycles, which are not feasible within the given timeframe. Although the project involves a user-centered assistive device, risks are minimized by using established technologies such as ESP32, ultrasonic sensors, and Bluetooth audio feedback with predictable performance. Therefore, a non-iterative approach enables efficient development and evaluation of the prototype while still addressing the essential needs of the intended users.

### Materials and Equipment

The smart cane materials include an ultrasonic sensor, ESP32 WROOM32, Bluetooth earbuds, SG90 servo motor, 4AA battery, SD card module, bamboo stick, battery holder, and Y dupont wire. The cap materials consist of an Arduino Uno, ultrasonic sensor, active buzzer, 9V battery, wires, and a cap insert safety helmet for storing and protecting the components. The banana fiber handle materials include resin, sandpaper, cane body, fresh water, and fresh banana pseudostem. The equipment used in the study includes a soldering iron, soldering wire, wire stripper, cutter, and glue gun.

### Procedure for making the GABAY smart cane for lower hazards

The cane's handle is wrapped with banana fibers to enhance grip, sweat absorption, and user comfort. An ultrasonic sensor is mounted on an SG90 servo motor and secured using adhesive to allow controlled tilting for scanning purposes. The assembled unit is then attached to the upper section of the cane.

Audio commands (“left,” “right,” and “stop”) are stored in an SD

card and integrated through an SD card module to enable feedback. The ESP32 microcontroller is configured to read the stored data and establish a connection with Bluetooth earbuds for audio output.

The system operates in two modes. In the first mode, the servo is maintained within a limited range of 70° to 110° to detect obstacles at a distance of up to 20 cm. In the second mode, the servo rotates from 0° to 180° to scan and determine the clearest path.

All components, including the sensor, servo, and SD card module, are connected to the ESP32 using a common ground and powered by an external battery. The circuitry is enclosed within the cane and secured with protective materials. The device is then tested in different environments to evaluate its reliability and performance.

### Procedure for Making the Cap with Buzzer for Upper Hazards

The process of making the cap with a buzzer for detecting upper hazards begins by gathering all the necessary materials, including an Arduino Nano, an ultrasonic sensor, an active buzzer, a 9V battery, connecting wires, and a cap with a safety helmet insert. Next, the ultrasonic sensor is attached to the cap at an upward angle so it can effectively detect upper-level obstacles such as signboards or branches. After securing the sensor, it is connected to the Arduino Nano and programmed to activate the active buzzer whenever an obstacle is detected within a distance of 50 centimeters. Finally, the Arduino Nano, active buzzer, and 9V battery are placed securely inside the cap's safety helmet insert to ensure that the system remains discreet, lightweight, and comfortable for the user.

### Process on making Organic Banana Fiber as sweat absorbent

The process for making the GABAY cane and cap-based audio navigation system, focusing on the organic banana fiber handle, begins with collecting raw banana (abacá) stalks. Mature banana or abacá plants with thick stalks are selected to ensure stronger fibers. The outer layers of the stalk are then stripped using a sharp knife or stripping tool to expose the inner fiber bundles. These fibers are extracted by pulling or scraping along the length of the stalk, separating long strands of natural banana fiber. The extracted fibers are thoroughly washed in clean water to remove plant sap, dirt, and impurities that may cause odor or stickiness. After washing, the fibers are boiled in water mixed with a small amount of natural soap or sodium bicarbonate to soften them, remove excess gum, and improve absorbency. The fibers are then dried under direct sunlight for several hours until they become completely dry, lightweight, and flexible.

Once dried, the fibers are combed or brushed to straighten them and remove coarse particles, resulting in a smoother texture suitable for wrapping. The prepared fibers are then twisted or woven into thin ropes or flat strips, depending on the handle design, to improve strength and grip. These fiber strips are tightly wrapped around the cane handle, overlapping slightly to ensure even coverage, and secured with eco-friendly adhesive at the start and end points. Finally, the absorbency of the fiber-wrapped handle is tested by lightly wetting it; the banana fiber should quickly absorb moisture, preventing slippage when held with sweaty hands.

### Procedure for testing the dual detection system: distance accuracy, command response, and real-time audio navigation

The dual detection system was evaluated by first powering on the smart cane and verifying that the ESP32 system, ultrasonic sensors, servo motor, and Bluetooth earbuds were functioning properly. The servo's default sweep range of 70°–110° and its ability to transition to a full sweep of 0°–180° upon obstacle detection were also confirmed. A participant was then instructed to hold the cane naturally while walking within a marked indoor testing area, with Bluetooth earbuds connected to receive real-time audio feedback.

Obstacles were positioned at predetermined distances in 20 cm

increments, including placements directly in front, to the left, to the right, and across multiple angles. Both upper-level hazards, such as branches or signboards, and lower-level hazards, such as stairs or potholes, were incorporated to simulate real-world conditions. During each trial, an obstacle was introduced within the detection range while the participant was in motion. Response time was measured from the moment the obstacle entered the sensor's range until the correct audio feedback was delivered.

System performance was assessed by comparing the detected distance with the actual obstacle distance, as well as verifying the accuracy of navigation commands such as "turn left," "turn right," "stop," or hazard alerts. The responsiveness of the servo in shifting between default and full sweep modes was also observed. Each testing scenario was repeated multiple times, with slight variations in obstacle angles, to ensure consistency and robustness of detection and response.

All relevant data, including actual distance, system response, and measured response time, were recorded for each trial. Any delays, missed detections, or inconsistencies in audio feedback were documented. The collected data were then summarized through the calculation of average response times, accuracy rates, and command correctness to evaluate the overall reliability and effectiveness of the dual detection system.

**Procedure for testing the cap with buzzer for upper hazards**

The cap system was powered on, and the functionality of the Arduino Uno, ultrasonic sensor, and buzzer was verified prior to testing. The participant was instructed to wear the cap naturally while ensuring proper sensor orientation. System performance was first evaluated by placing an obstacle at a fixed distance of 60 cm.

A timer was started once the obstacle entered the detection range and stopped upon activation of the buzzer. This procedure was repeated five times, and the average, minimum, and maximum response times were recorded.

To assess height-based detection performance, obstacles were introduced at varying elevations ranging from 10 cm to 60 cm to simulate upper hazards.

The system was expected to trigger the buzzer at or within 60 cm and remain inactive beyond this threshold. Each distance condition was tested at least five times to determine the maximum reliable detection range, defined as the farthest distance at which successful detection occurred in at least two out of three trials.

Controlled directional scenarios were then conducted, including obstacles positioned directly overhead, slightly to the left, and slightly to the right of the participant. During each scenario, the participant walked naturally while obstacles were introduced into the detection field. Buzzer responses were observed to ensure correct activation within the 60 cm range and the absence of false activations beyond it.

Each scenario was repeated five times to evaluate consistency. All observations, including correct activations, missed detections, and false activations, were recorded.

The collected data were summarized by computing average response times, accuracy rates across different distances, and overall system reliability to assess the effectiveness of the cap-based upper hazard detection system.

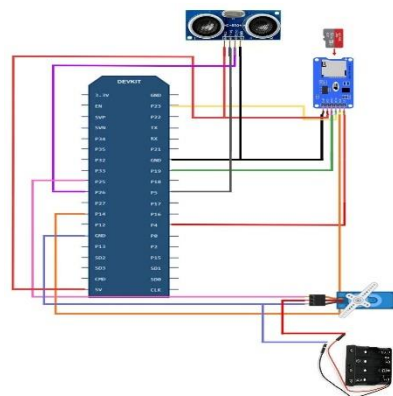


Figure 2. Physical connection of the G.A.B.A.Y. cane

Figure 2 shows the wiring of the GABAY cane prototype. The ESP32 WROOM32 microcontroller collects data from the ultrasonic sensor, which detects the distance of obstacles. The SD card module provides the audio files to the ESP32, determining which audio should play. Meanwhile, the servo motor controls the angle, helping the system indicate the correct direction, either left or right.

**Research Instrument**

For this study, the researchers used a researcher-made observation sheet as the main instrument. The sheet was designed to record the Smart Cane's distance accuracy, direction command accuracy, and audio response accuracy, as well as the cap's detection accuracy. It includes spaces for actual and measured values, system outputs, classifications, accuracy rates, detection or precision rates, and response delays across multiple trials.

**Statistical Treatment**

The study used descriptive statistical treatments to analyze the data gathered through the researcher-made observation sheet. Descriptive statistics refers to a collection of techniques used to organize, summarize, and present data in a clear, systematic way, often through tables, charts, and numerical measures (Bhandari, 2020; VisionLearning, n.d.). Key measures include the mean, which is the arithmetic average of the data points, and the standard deviation, which quantifies how spread out the values are from that mean (VisionLearning, n.d.; UW Quantitative Analysis, n.d.).

The mean measurement was computed to determine the average speed recorded by the system's sensor across all trials. This provided the researchers with a general estimate of the system's typical output at each set distance, allowing for a clearer assessment of its overall reading behavior.

Standard deviation was used to determine the consistency of the system's performance. A low SD indicated stable results, while a high SD signaled variability across trials.

**Ethical Considerations**

In this study, safety is prioritized by conducting all tests of the smart cane and cap system in controlled, low-risk environments. Before every trial, the researchers inspected all components—including sensors, buzzer, wiring, and power supply—to ensure proper function and prevent risks such as overheating or loose connections. Testing was stopped immediately if any irregularities were observed, keeping the process safe throughout.

No external participants were involved in the testing; only the researchers operated and evaluated the device, eliminating any risk to

human subjects.

Integrity and transparency were also upheld. All results, observations, and limitations were recorded accurately based on actual device performance, without modification or exaggeration. Only data necessary for evaluating the system's functionality were collected, ensuring responsible and ethical use of technology. Through these practices, the study maintained fairness, honesty, and safety in the development and evaluation of the prototype.

## RESULTS AND DISCUSSION

This chapter presents the results of the Smart Cane System and demonstrates that the device performed successfully across all conducted trials. Throughout the tests, the cane consistently detected obstacles and generated the correct direction commands without failure. The audio feedback was activated each time promptly, showing stable responsiveness across repeated trials. These outcomes indicate that the system is not only functioning as intended—it is also dependable and consistent under real-use conditions, proving its reliability as an assistive navigation tool.

**Table 1. Smart Cane System Trial**

Trial No.	Direction Command Accuracy (Yes/No)	Audio Response Speed (in seconds)
1	Yes	1.4
2	Yes	1.5
3	Yes	0.91
4	Yes	1.5
5	Yes	2.09
<b>Mean</b>		1.48
<b>SD</b>		0.420

Across all five trials, the smart cane consistently detected the obstacle at 20 cm and correctly recognized the direction command every time. The audio response times ranged from 0.91 to 2.09 seconds, showing generally prompt feedback with small variations. Overall, the results demonstrate stable detection accuracy and reliable system responsiveness throughout the test.

The obtained response times are consistent with findings from related studies, such as Sustainability: Evaluation of Bluetooth Detectors in Travel Time Estimation, which emphasizes that assistive navigation devices relying on wireless communication often experience slight delays due to signal transmission and processing (Krit Jedwanna & Saroch Boonsiripant, 2022). In comparison, Bluetooth-based systems typically operate within approximately 0.7 to 0.95 seconds, while the developed system showed a slightly higher range of 0.91 to 2.09 seconds. This indicates that although the system performs reliably, further optimization in communication and processing could reduce latency and improve real-time responsiveness in practical navigation scenarios.

**Table 2. Cap System Trial**

Trial No.	Buzzer Accuracy (Pass/Fail)	Audio Response Speed (in seconds)
1	Pass	0.10
2	Pass	0.11
3	Pass	0.10
4	Pass	0.12
5	Pass	0.10
<b>Mean</b>		0.106
<b>SD</b>		0.00894

The data shows that the sensor consistently detects the obstacle within 60 cm across all five trials and uses the buzzer as a response. In every test, the buzzer's detection time remained constant at 0.10 seconds for all trials. This indicates that the cap system functions with high accuracy and fast response time regardless of repeated testing.

The cap system consistently detected obstacles at 60 cm with an average response time of 0.106 seconds. These results align with benchmarks reported by Joseph, Kian, & Begg (2023), who note that wearable obstacle detection systems are effective when detection occurs within 50–60 cm and response times are below 0.2 seconds. Thus, our system demonstrates high accuracy and faster responsiveness than the minimum standards established in current literature.

## CONCLUSION

This research focused on creating a Smart Cane with audio navigation and a cap sensor system designed to improve mobility and environmental awareness for visually impaired individuals. After conducting systematic testing and performance assessment, the following conclusions were established.

The smart cane and cap sensor system was successfully developed, with all major components such as the ultrasonic sensors, components such as the ultrasonic sensors, servo motor, SD card module, ESP32 for the cane, buzzer, Arduino Uno, and the cap-mounted ultrasonic sensor properly integrated. Minor wiring adjustments were needed to stabilize the connections. However, the system ultimately worked as intended, providing real-time obstacle detection, clear audio feedback, and improved comfort through the banana-fiber-wrapped handle.

The cane consistently detected obstacles at the 20 cm threshold in every trial, demonstrating reliable range measurement. Directional audio commands were accurately delivered, and with response times ranging from 0.91 to 2.09 seconds, the system provided prompt and effective guidance for real-time navigation.

The cap also showed consistent and precise performance across all tests. Obstacle detection remained accurate at 60 cm, and the buzzer responded reliably within the designated range. With a response speed of 0.10 to 0.12 seconds, the system reacted quickly and effectively to detected obstacles.

The banana-fiber-wrapped handle fulfilled its intended purpose, improving grip stability and natural moisture absorption. Under simulated sweaty-hand conditions, the material demonstrated enhanced comfort and secure handling during extended use.

## Recommendation

Based on the study's results showing reliable obstacle detection, fast response times, and stable performance of the smart cane and cap system, the following improvements are recommended: (1) Adjust and evaluate multiple detection distances for the front, left, and right sensors to establish optimal range settings for diverse walking environments. (2) Integrate lighter and more durable materials to improve structural longevity and reduce user fatigue during extended use. (3) Test and select more stable and compatible earbuds or audio devices to ensure consistent and uninterrupted auditory guidance. (4) Expand the cap's sensing system by incorporating additional sensor modalities or head-tracking technology to enable detection of a wider

range of obstacles.

Future studies are recommended to adopt an iterative developmental approach to improve the G.A.B.A.Y smart cane. This would allow continuous user testing and refinement, which is essential for assistive technologies. With fewer time constraints, multiple design cycles can enhance usability, performance, and overall effectiveness.

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## THE PERCEIVED INFLUENCE OF WAITING TIME ON CUSTOMER SATISFACTION AND SERVICE QUALITY AT MCDONALD'S INTRAMUROS AMONG COLLEGE STUDENTS OF LETRAN MANILA

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### ABSTRACT

This study investigated the perceived impact of waiting time on customer satisfaction and service quality at McDonald's Intramuros, focusing on Letran's college students as the participants. The results show that waiting time has a significant negative perceived effect on customer satisfaction. Respondents consistently showed in the results that the longer the waiting times, the lower the satisfaction level, with delays in service as one of the biggest disadvantages to their dining experience. Satisfaction falls sharply as waiting time increases. Results further indicate that existing waiting times often exceed students' tolerance, leading to a strong sense of poor service quality. Speed of service is a basic determinant of quality in fast-food service; failure to provide timely service will directly undermine customer satisfaction and brand reliability. However, these findings have to be viewed with caution, considering their limitations.

**Keywords:** smart cane, audio navigation, ultrasonic sensor, visually impaired, banana fiber

### INTRODUCTION

#### Background of the Study

Long waiting times in restaurants significantly undermine customer satisfaction, often leading to negative experiences that drive away repeat business and harm revenue. This issue is particularly acute in the competitive food service industry, where poor service timing contributes to lost loyalty and reputational damage, making it essential for operators to address waiting times to sustain profitability. Fast food restaurants are known to be quick and convenient—commonly called Quick Service Restaurants (QSR). This implies that when a QSR delays, it may influence a customer's perception and may lead to lower satisfaction.

Several studies have explored strategies to mitigate waiting time's negative effects on restaurant customer satisfaction. Baek et al. (2025) employed big data analytics on online reviews, using topic modeling and regression, revealing waiting as the strongest negative predictor of ratings and highlighting its disproportionate impact. Jo (2025) investigated psychological mechanisms via surveys in physical and virtual queues, finding waiting equity perceptions drive intentions to wait and consume, advancing equity-based management. Studies like Baek et al. (2025) and Jo (2025) focused on big data from unspecified or advanced markets, overlooking Southeast Asian urban dynamics that amplify wait sensitivities in high-density areas.

According to Khan et al. (2021), customer satisfaction remains one of the most important outcomes of organizations in various service sectors such as retail, banking, hospitality, and health. One of the most important determinants of satisfaction is service quality, often conceptualized through the SERVQUAL model comprising tangibles, reliability, responsiveness, assurance, and empathy. Aside from service quality, waiting time is the most important factor shaping consumers' perceptions of service and their general satisfaction. The

longer customers wait, the more likely they are to experience negative emotions, like frustration or impatience, which decrease satisfaction even in cases where service quality is objectively high. On the other hand, brief waiting times or better-organized waiting times increase satisfaction and positively affect ratings of service quality accordingly (Khan et al., 2021).

Quality of service is one of the most important factors that define the success of the hospitality industry, which boasts a very high degree of interaction between service providers and guests (Ali et al., 2021). The assessment of service quality has undergone changes over time to tailor itself to the needs of various demographic segments and industry types (Pratik Ghosh et al., 2023). It was through their study that it was established that QSR service quality has a direct effect on the satisfaction and thus the behavioral intentions of Gen Z consumers. To be more specific, it has been suggested that satisfaction mediates the relationship between service quality and consumer behavior.

Previous studies focused on fast-food restaurants globally and have investigated the impact of waiting time on customer satisfaction and service quality. However, there are limited studies about how perceived waiting time affects overall customer satisfaction and service quality locally—specifically, McDonald's Intramuros. Gaining deeper insights about the relationship of the given variables may improve customer experience in local quick-service restaurants. Therefore, there is a need to examine how perceived waiting time affects customer satisfaction and service quality.

#### Objectives of the Study

The purpose of this study is to determine the perceived influence of waiting time on customer satisfaction at McDonald's in Intramuros,

Manila. To specify, the study aims to: (1). Examine the perceived effect of customers' waiting time on their overall satisfaction. (2). Identify how perceived waiting time for the customer influences customer perceptions of service quality.

**Research Framework**

**Conceptual framework**

The conceptual framework in this research centers on making sense of waiting time and its impact on satisfaction and service quality perceptions. Waiting time can be defined as the time elapsed prior to the commencement of services.

The impact of waiting time would, therefore, influence the perceptions of service quality, apart from affecting satisfaction levels. Customer satisfaction implies the degree to which an individual's expectation was fulfilled, while service quality perceptions refer to an individual's assessment of the service delivery with respect to dependability, responsiveness, and general service excellence.

This conceptual framework precisely captures the aims of this research, addressing both aims in one: first, to explore the relationship between waiting time and satisfaction, while the secondary aim seeks to explore the relationship between waiting time and perceptions of service quality.

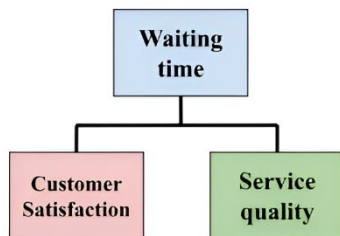


Figure 1. Conceptual framework of the study

**Scope and Limitations**

This study mainly aims to explore the relationship between perceived waiting time, customer satisfaction, and service quality among college students of Colegio de San Juan de Letran, Manila, from the Academic Year 2025–2026.

College students were questioned through a 5-point Likert scale survey to determine their satisfaction and perception of service quality depending on the perceived waiting time of their orders in a fast food restaurant.

This study focused exclusively on dine-in experiences of Letran Manila college students, excluding delivery and online orders due to differences in waiting procedures. The selected fast food restaurant for this research is the McDonald's branch located in Intramuros, Manila, as it is the closest to Letran, Manila. The purpose of this study is to investigate how waiting time influences customer satisfaction and perceptions of service quality. However, the findings of this study may not be entirely reliable, as they are based solely on the perceptions of the respondents.

**METHODOLOGY**

**Research Design**

This study employs a descriptive quantitative study to investigate the perceived relationship between waiting time and consumer satisfaction, along with the perceptions of service quality among the college students of Colegio de San Juan de Letran, Manila. The researchers collected the data using a survey based on the SERVQUAL model (tangibles, reliability, responsiveness, assurance,

and empathy), and the participants of this study are college students from Colegio de San Juan de Letran who have experience dining or ordering at the McDonald's branch in Intramuros during the Academic Year 2025–2026.

**Procedures**

In this part of the study, the researchers first had their instruments validated by the research department to ensure that each question is appropriate for this study, ensuring each question is relevant in order to answer the goals of this study. They also added the aspect of SERVQUAL dimensions of customer satisfaction, waiting time, and service quality. In order to get data from the survey, a 5-point Likert scale was used from strongly disagree= 1 to strongly agree = 5.

The participants were chosen through purposive sampling—the students must be from Colegio de San Juan de Letran, Manila, who are enrolled during the Academic Year 2025–2026 and have experienced ordering at McDonald's in Intramuros. Creswell & Poth (2018) stated that purposive sampling is appropriate in cases where a study requires direct experience or knowledge of participants. They were provided with a consent form to ensure that participants give their full permission before proceeding to the survey—they are required to answer based on their latest visit to McDonald's in Intramuros and must give an honest answer regarding their experience based on what they recall. Their responses will be based on their perceptions as this study uses a descriptive method.

Lastly, the collected data was encoded, analyzed, and represented in tables via suitable software such as Google Sheets and statistical analysis tools to provide results regarding waiting time, customer satisfaction, and service quality perceived.

**Research Instrument**

This study utilized a researcher-made structured survey questionnaire as the primary instrument to gather data from college students of Letran, Manila. The questionnaire is designed to measure participants' perceptions of waiting time, customer satisfaction, and service quality in McDonald's Intramuros.

The instrument aims to assess how perceived waiting time influences overall customer satisfaction and shapes customers' perceptions of service quality in a quick-service restaurant setting. Cronbach's Alpha was used to determine the reliability and accuracy of the instrument. Items for waiting time and service quality were separated to ensure a clean and clear questionnaire. Waiting time focused on the speed of service; on the other hand, service quality focuses on service performance and efficiency.

Table 1. Customer satisfaction

Cronbach's alpha (α)	Interpretation
α ≥ 0.90	Excellent
α ≥ 0.80	Good
α ≥ 0.70	Acceptable
α ≥ 0.60	Questionable
α ≥ 0.50	Poor
α < 0.50	Unacceptable

According to Taber, K. (2018), Cronbach's alpha is used to measure the consistency and reliability of a questionnaire. It shows how correlated each set is. An alpha value of 0.70 is commonly accepted, while a higher value is considered significant and accepted.

Table 2. Reliability Statistics for Customer Satisfaction and service Quality Scale

Scale	Cronbach's alpha (α)	Interpretation
Customer Satisfaction	0.71	Acceptable
Service Quality	0.78	Acceptable

Table 2 presents the reliability statistics for the customer satisfaction and service quality scales. The customer satisfaction scale obtained a

Cronbach's alpha of 0.71, while the service quality scale obtained a Cronbach's alpha of 0.78. Both values meet the acceptable threshold of 0.70, indicating that the items for perceived waiting time and service quality are consistent and reliable.

The slightly higher value for service quality suggests greater internal consistency among items measuring service performance and efficiency. This reliability test was conducted during the pilot testing phase prior to the main study. With a sample size of 20 participants, the results confirm that the instrument is suitable for use in the full-scale data collection.

**Participants**

The participants in this study are college students aged 18 and above who are currently enrolled for the academic year 2025-2026 in Colegio de San Juan de Letran, Manila. The researchers ensured that each participant had given their full consent before distributing the survey. According to Kuncel and Huber in 2016, college students are more capable of mature, reflective, and critical thinking than pre-college students, making college students appropriate participants for this study.

A total of 50 participants were selected to complete the survey for this study. Due to time constraints, the sample size was limited to 50 participants, but this number is still adequate to yield meaningful results. According to Mursa et al. (2025), 50 participants is considered acceptable for a descriptive quantitative study since there are no fixed rules in settling for a sample size. Creswell, J. W., & Creswell, J. D. (2018) also stated that a descriptive study may employ small sample sizes if the objective is to describe rather than the general population. The researchers employed a purposive sampling technique, which facilitated the recruitment of participants who had recent dining experiences at McDonald's in Intramuros. This approach ensured that the data collected was relevant to the study's objectives.

**Statistical Treatment**

Validated results from the survey questionnaires were collated, coded, and interpreted with the aid of Google Sheets. All the forms were validated for correctness before the results could be processed further. Perception regarding waiting time, customer satisfaction, and service quality based on the five dimensions of the SERVQUAL model (tangibles, reliability, responsiveness, assurance, and empathy) was also measured with the use of the five-point rating scale (1 = Strongly Disagree, 5 = Strongly Agree).

To determine the influence of the variables, the mean and standard deviation analyses were used to establish the influence of waiting time, customer satisfaction, and service quality perceptions.

**RESULTS AND DISCUSSION**

**Table 3. Influence of waiting time in customer satisfaction**

Statement	Mean	SD	Interpretation
1.The waiting time at McDonald's Intramuros affects my overall satisfaction as a customer.	4.22	0.91	Strongly Agree
2.Short waiting times at McDonald's Intramuros increase my satisfaction.	4.40	1.14	Strongly Agree
3. I feel frustrated when I experience long waiting times for my order at McDonald's Intramuros.	4.28	0.83	Strongly Agree
4.The waiting time for my order influences my overall dining experience at McDonald's Intramuros	4.00	1.05	Agree
<b>Overall</b>	<b>4.23</b>	<b>0.98</b>	<b>Strongly Agree</b>

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

Table 3 presents the participants' level of agreement regarding the

perceived influence of waiting time on customer satisfaction at McDonald's Intramuros. The overall mean score is 4.23 with a standard deviation of 0.98, which is interpreted as Strongly Agree based on the given scale. This indicates that, generally, participants perceive that waiting time influences their overall satisfaction.

Among the individual statements, the highest mean was recorded for statement 2, with a mean value of 4.40 and a standard deviation of 1.14—it was interpreted as strongly agree. This suggests that minimal waiting time may positively contribute to their satisfaction. This is followed by statement 4 with a mean of 4.28 and a standard deviation of 0.83, interpreted as strongly agree, which highlights that long waits can affect their mood.

Statement 1 also obtained a high mean value of 4.22 and a standard deviation of 0.91, also interpreted as strongly agree, showing that waiting time influences customers' satisfaction. Meanwhile, waiting time influenced the overall dining experience, with an average value of 4.00 and a standard deviation of 1.05, both interpreted as agree, suggesting that although participants recognize the impact of waiting time, the effect may vary depending on individual experiences.

Statements 2 showed the highest value of standard deviation, followed by statement 4 suggesting that, regardless of the fact that both statements have a high mean value, the answers of the participants are scattered. Meaning, there are still some that vary in individual perceptions if short waiting times decrease their satisfaction, as well as if waiting time influences their overall satisfaction.

Additionally, the mean scores across all statements range from 4.00 to 4.40, indicating agreement among respondents on the listed statements related to waiting time. However, the standard deviation of 0.98 indicates that the responses from participants are somewhat spread out from the average, reflecting some differences in personal views, yet the overall answers remain quite uniform.

**Table 4. Influence of waiting time in service quality**

Statement	Mean	SD	Interpretation
1.Employees at McDonald's Intramuros provide prompt service with minimal waiting time.	3.50	0.79	Agree
2.Orders at McDonald's Intramuros provide prompt service with minimal waiting time.	3.38	1.01	Neutral
3. During busy hours, employees at McDonald's Intramuros handle orders efficiently.	3.30	0.95	Neutral
4.The speed of service at McDonald's Intramuros meets my expectations.	3.20	1.03	Neutral
5.McDonald's Intramuros consistently delivers orders without unnecessary delays.	3.18	1.12	Neutral
<b>Overall</b>	<b>3.31</b>	<b>0.98</b>	<b>Neutral</b>

Note: Legend: 1.00 - 1.79 Strongly Disagree; 1.80 - 2.59 Disagree; 2.60 - 3.39 Neutral; 3.40 - 4.19 Agree; 4.20 - 5.00 Strongly Agree

The table shows The overall mean value of table 4 is 3.31 with a standard deviation of 0.98, which interprets as neutral based on the scale and shows that McDonald's Intramuros service quality depends on customer waiting time and the aggregate score indicates a neutral assessment in which the customers neither agree nor agree that perceived waiting time influences their insights of service quality reflecting a mixed experience between participants.

Based on the results, the perceived service quality indicates that there are inconsistencies in service speed, especially during busy hours. Some may have received service with a reasonable waiting time, while others have experienced longer queues, affecting their perceptions of service quality in McDonald's Intramuros.

Statement 1 acquired the highest mean of 3.50 with a standard deviation of 0.79, suggesting that certain participants acknowledge that employees provide fast service. Meanwhile, Statements 2, 3, 4, and 5 received neutral assessments, with standard deviations ranging from 0.95 to 1.12, indicating that respondents observed various service speeds during their experience at McDonald's Intramuros.

Results show that statement 5 had the highest standard deviation, showing a value of 1.12. It suggests how inconsistent the service from McDonald's Intramuros is—there's a difference in the quality of service in each participant, which makes the value very scattered.

The neutral analysis shows that while employees at McDonald's Intramuros provide prompt service, there is room for improvement when it comes to consistency.

Based on the results for customer satisfaction and service quality, it shows that perceived waiting time influences customer satisfaction more than service quality. While both results show that opinions may vary, customer satisfaction is interpreted as strongly agree with a mean value of 4.23 and standard deviation of 0.98, while service quality is neutral with an average of 3.31 and standard deviation of 0.98—showing that longer waiting time influences their satisfaction.

## CONCLUSION

The primary objective of this study was to examine the perceived influence of waiting time on customer satisfaction and service quality at McDonald's Intramuros. The data reveal that waiting time exerts a significant negative perceived influence on customer satisfaction. The results indicate that Letran students perceive delays as a major detriment to their dining experience; as waiting time increases, satisfaction levels decline sharply. The study found that current waiting times frequently exceed the students' patience limit, leading to a distinct perception of poor service quality. These findings highlight a critical gap in service efficiency at McDonald's Intramuros. The reported low satisfaction implies that the branch is currently failing to meet the speed expectations of its core market. This is significant because, in the fast-food industry, a failure to deliver on the promise of "speed" directly equates to a failure in service quality. If left unaddressed, this dissatisfaction could lead to a decrease in student patronage or a shift toward competitors with faster service turnover. Readers should exercise caution when interpreting these results, as the study relies entirely on self-reported opinions rather than objective metrics. As a consequence of this methodological limitation, the findings are not sufficiently reliable to serve as a baseline for factual conclusions.

## Recommendations

It is recommended that the management of McDonald's Intramuros invest in additional self-ordering kiosks to significantly reduce customer waiting times. Intramuros should adapt a facility layout that would facilitate a more efficient and orderly customer flow to reduce congestion, minimize customer confusion, and speed up customer service to ensure a higher level of service quality during busy periods of service. The management of McDonald's Intramuros should improve the queuing experience to minimize the perceived burden of waiting. Future researchers are encouraged to investigate strategies to reduce waiting time in Intramuros, Manila. Conduct an inferential analysis to examine the relationship between waiting time, customer satisfaction, and service quality.

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## FROM CLICK TO CARTS CORRELATION OF SOCIAL MEDIA CLICKBAIT CONTENT ON FACEBOOK IN THE CONSUMER BEHAVIOR OF GENERATION X

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### ABSTRACT

In the Philippines, Facebook is a widely used app, including older age groups. This creates an opportunity for marketers to promote their products through social media, attracting attention using Clickbait. This study aims to analyze the influence of Clickbait Content on Facebook on the Consumer Behavior of Generation X, particularly in terms of Consumer Engagement and Purchase Intention. Additionally, the study aims to determine the level of exposure to Clickbait content on Facebook. The study utilized a predictive correlational design. The data was collected with a structured survey from 40 Generation X respondents, ranging from the ages of 45 to 60. With the collected data, a Simple Regression Analysis was utilized to examine the influence of Clickbait Content on Consumer Behavior. The findings show that Clickbait Content has a significant influence on Consumer Behavior. Additionally, results showed that Clickbait can predict whether a consumer chooses to engage and purchase.

**Keywords:** *Clickbait Content, Consumer Behavior, Generation X, Consumer Engagement, Purchase Intention*

### INTRODUCTION

#### Background of the Study

Scrolling through Facebook has become part of the daily routine of many consumers. However, colorful and interesting posts can become an unexpected trap. One moment, they are drawn in by extravagant product photos and convincing captions, and the next, they find themselves holding an item that looks nothing like what was promised. Experiences such as being given the wrong product or no product at all, show how clickbait can quickly turn curiosity into regretful purchases.

Clickbait content is not easily detected by much older generations, such as Generation X. This generation witnessed the shift to traditional approaches to a world dependent on technology. For a generation that grew up with newspapers and television, it was a completely different world. Detecting false information from accurate information may not be as easy. Mass postings can be seen everywhere, even with exaggerated headlines.

Clickbait is defined as short teaser messages that make use of cognitive biases to engage users to click on said content. (Jung et al., 2022). On Facebook, clickbait is mostly seen, and this can affect user engagement. Though the content on the platform can be appealing, it is often seen as misleading, as users are left disappointed with the outcome. They found that unbelievable and exaggerated headlines on posts increased engagement. On the other hand, boring headlines and common clickbait phrases made it less reactive. Sometimes, clickbait text inside the post has different results. This shows that clickbait is not always working the same way depending on where it comes out.

A study called "Decoding Clickbait" shows that highly visual headlines are effective in quickly grabbing the attention of users (Wang et al., 2024). It is also noted that exaggerated ones are also

great in boosting clicks and virality. This, however, lowers trust when misled. Clickbait works by using exaggerated and saturated posts to grab the attention span of consumers. An additional study by Rachmad (2025) supports this idea regarding headlines that trigger feelings of surprise and amusement tend to gain more attention from users with an already short attention span. Though, because of the false or saturated advertising, it makes consumers less willing to engage with said product.

Though there are several studies tackling clickbait content and consumer behavior, there are only limited studies when it comes to the specific relationship between the two variables. The studies centering on clickbait often show how its effects and delays information to the users (Scott, 2021). With these existing studies, this research is able to correlate this information in a consumer's lens, identifying how they engage and their purchase intention with clickbait content.

The effects of social media clickbait on social media users are studied in a wider range. Despite this, the wide range of studies is mostly centered around the generations of Millennials and Generation Z, as they make up most of the population who use social media and are considered more tech-savvy in comparison with other generations. By making the respondents of this research Generation X, a group of people born between 1965 and 1980, the study can delve into how they respond to obvious social media clickbait, evaluating their consumer habits and behaviors.

#### Objectives of the Study

(1) To determine the respondent's level of exposure to Social Media Clickbait Content. (2) To measure the extent of Engagement and Purchase Intention of consumers in Social Media. (3) To examine and analyze the influence of Social Media Clickbait content on Consumer Behavior of Generation X.

### Statement of the problem

This study aimed to determine the influence of clickbait content on Facebook on the consumer behavior of Generation X. Specifically, it sought to describe the respondents' demographic profile in terms of age, location, and Facebook social media usage. It also assessed the respondents' level of exposure to social media clickbait content, as well as their level of consumer behavior in terms of engagement and purchase intention. Furthermore, the study examined whether clickbait content had a significant influence on consumer behavior, particularly in relation to consumer engagement and purchase intention.

In line with this, the study tested the following hypotheses: the null hypothesis ( $H_0$ ) stated that clickbait content did not have a significant influence on consumer behavior in terms of consumer engagement and purchase intention, while the alternative hypothesis ( $H_a$ ) stated that clickbait content had a significant influence on consumer behavior in terms of consumer engagement and purchase intention.

### Review of Related Literature

#### Clickbait in Social Media

Indurthi et al. (2020) studied how clickbait can be detected using computers and digital apps. They created computer models that can analyze patterns and outperform all existing methods. They found that literary techniques made detection more accurate. The study explained that clickbait headlines often use exaggeration cliffhangers to get people's attention. To contrast the idea, Jung et al. (2022) focus on Facebook posts to see how clickbait affects engagement. It showed that illogical and exaggerated headlines get more engagement and virality, while simple or common clickbait phrases receive less. The gap of this research is that it only focuses on user reactions and does not measure whether they review the article for how authentic it is.

In addition, Bazaco, A. et al. (2020) have findings on how headlines are the main factor in influencing readers. The research showed that a lot of clickbait headlines use emotive words to grab attention. Though it could increase consumer interest, trust may be lessened because of the disappointment that follows when the content is potentially false. The study pointed out that it weakens credibility and affects the perspective of the audience in the media.

Jácobo-Morales & Marino-Jiménez (2024) revive this idea; they explained the "news gap" of media, audiences, and networks. They also added that clickbait strategies are effective for grabbing attention. This connection helped them present how headlines in posts not only affect credibility but also create a contradiction in digital platforms.

Additionally, according to a study by Shrestha et al. (2024), clickbait has become a growing risk in security concerns with the recent boom in social media. It proves to be effective as users and consumers lack knowledge regarding the content. Social Media users are found to have been unable to determine and comprehend clickbait and its dangers.

Both studies of Indurthi (2020) and Jung et al. (2022) state the idea that clickbait generally works on exaggeration rather than fact. It is through these strategies that posts can gather the attention of users that leads to engagement and virality. However, Bazaco, A. et al. (2019) add more to the idea. Jácobo-Morales & Marino-Jiménez (2024) explain that clickbait produces gaps in information. To further deepen this idea, clickbait becomes effective as users lack the knowledge about its dangers on social media security. All studies give insights into clickbait and how it works. It provides the idea that clickbait is good for grabbing attention, but not necessarily for giving out information.

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### Social Media as Marketing Platform

Throughout the years, Social media has dominated the world. From entertainment to shopping for goods, it has it all. According to Evans & McKee (2021), many perceive social media to be vital in a business nowadays. It not only serves as a tool for marketing, but also as a tool for direct communication with customers. Many organizations utilize it as a way for engagement and exposure to their product, defining it as a way to seek "virality". Social media marketing is effective if done properly. Consumers tend to take note of different factors of social media marketing, such as posts, influencer advertising, and engagement overall. Brands know that users use social media not only for entertainment, but to check out new products from time to time. This is why digital marketing has become easier for marketers to reach out to consumers through apps like Instagram, Facebook, and YouTube (Verma, 2025).

A study by Khanom (2023) compares traditional marketing with online marketing. According to the study, traditional marketing uses print ads like billboards and commercials to reach local and offline customers. With this marketing strategy, it can become expensive fast. With digital marketing, some of these costs are cut, and it could reach more consumers with the widespread use of social media. This is why it is important to understand how social media marketing works. Marketers must take note of the availability of resources and decide on marketing strategies of competitors to join trends. This joining of trends tends to ask the question of its effectiveness in the market. With all the repetitive trends, it becomes difficult to stand out as a brand. This leads them to innovate towards other strategies for consumers to engage with their product.

Rani (2025) reinstates the idea that social media has become vital in today's marketing. The study utilized a survey and was able to analyze strategies of social media marketing, content creation, and how these factors shape and strengthen brand recognition. However, the study highlights concerns of data privacy within social media. Another highlight is how social media marketing, like advertisements, saturates content as a way for consumers to engage with brands without being totally truthful about the authenticity of their product.

To support this idea, a study by Shin et al. (2025) categorizes clickbait into two, information bait and rage bait. Both categories are used in social media to market products to users. However, conservative media mostly uses rage bait as it taps into the emotion of the reader and the consumer, gathering more engagement in the said content. Social media clickbait targets emotion-driven content to appeal and intrigue consumers as a way of social media marketing.

These studies talk about how social media has become vital in today's world, especially in marketing. Evans & McKee (2021) reiterate that social media has become dominant in our world. It is not only a means of entertainment but has also become an indispensable tool in businesses. Khanom (2023) compares digital marketing with traditional marketing, highlighting the customer reach of both strategies. The study highlights the importance of consumer engagement and the ways brands innovate and think about new ideas. To complement this idea, Verma (2025) states that digital marketing is effective when done right. Brands strategically use social media apps to encourage product discovery. However, it notes that consumers may not assess their purchases, which may lead to questions about its authenticity. This is proven by Shin Shin et al. (2025) by reinforcing the idea that social media content is catered to intrigue consumers through bait, specifically Clickbait. Marketers strategically make content that taps into the emotions of the user, deeming it more effective.

### Generation X's Social Media Behavior

According to the study conducted by Sirait and Purnama (2022), the

psychological factors mediated by consumption behavior are the main influence for Generation X to conduct digital transactions. Consumption behavior factors regarding shopping experiences, desire to buy, shopping habits, promotions, and other factors drive Generation X consumers to mediate digital transactions. Generation X's consumer behavior is based not just on the person's mindset and psychological makeup, but is also based on the convenience and accessibility of using technology. Technology provides the platform and the tools that make their desired shopping experiences possible.

Anoop Gurunathan, A. K. S. Lakshmi (2025) observed what factors affect Generation X's shopping habits on social media. Income was one of the factors of social media behavioral patterns. Additionally, decisions concerning preferred social media by users, as well as the influences for them to use social media has been noted. This suggests that marketers tend to tailor and center their strategies to the relevant socio-economic groups with their promotions. Age was also revealed to be a big factor which influences engagement with social media platforms. The study's findings suggest that consumers belonging to different age groups, specifically younger and older individuals, display completely different patterns of behavior. This reiterates that the implementation of marketing strategies tailored to the specific age group is important in order to effectively engage and appeal to the different age groups.

Another study by Lakshmi and Gurunathan (2023) explores the generational similarities and differences of Generation X, Millennials, and Generation Z towards social media and digital marketing. Traditional approaches tend to be more influential on Generation X than a digital one. The generational differences and similarities in perceptions are identified while promoting the products and services. Though extensive studies have been conducted on the perceptions of generations towards social media and digital marketing, there is a gap and a need to explore further the differences and preferences in social media marketing among Gen X, Y, and Z.

As noted by the previous studies, Generation X's approach to consuming and transacting digitally stems from a unique blend of psychological drivers, the convenience of technology, and demographic factors. As stated, while younger generations may have a natural affinity for technology, the impact of social media marketing for products on Generation X is rather limited. This study indicates that social media marketing for this generation is less effective than authentic testimonials and reviews, which play a greater role in influencing their purchasing behavior and participation in online shopping. This study indicates that Gen X still responds more to traditional than web-based media. It also raises doubts about the uniformity of generations, pointing out that even within the same generation, there can be different preferences for online platforms. The research suggests that one size may not fit all for generations in the use of a single website.

## Research Framework

### Theoretical Framework

The Theory of Planned Behavior introduces and explains the idea of the underlying influences on a person's intention and behavior. According to Ajzen (1991, as cited in Rozenkowska, 2023), three factors influence an individual's behavior. First, there is the attitude that reflects the evaluation of the action, whether negative or positive. Second, subjective norms, which reflect an individual's perception of the social pressure to behave in a certain way or the perceived importance of an action. The last factor is the perceived control, which captures an individual's ability to act. Under this factor could include digital ability and trust ability, which are vital to know in consumer behavior. All these factors combined form a person's intention to execute the behavior towards a certain thing.

In the case of consumer behaviors, the Theory of Planned Behavior suggests consumer engagement towards clickbait content is not an impulsive response but rather a planned action. Numerous factors may influence their behavior, such as their personal evaluations and perceived control as consumers. Thus, it is hypothesized that consumer behavior towards clickbait content is a response shaped by psychological and social determinants.

## Conceptual Framework

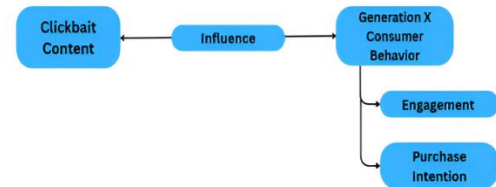


Figure 1. Conceptual Framework

The framework shows the relationship between the two variables of clickbait content and consumer behavior. It describes the variable's correlation while also identifying the influence of both. Under the Consumer Behavior variable are also the components that will be delved into in the research. These said components are Engagement and Purchase intention. It aligns with the study's objective to learn and identify relevant behaviors of consumers, whether they will engage or even purchase a product coming from clickbait content.

## Scope and Limitations

This study is centered around Clickbait content, specifically on Facebook posts. However, other digital platforms posted on Facebook as clickbait content are considered. Under these digital platforms are applications like Temu, Shopee, and Lazada, as these are applications still seen utilizing clickbait promotional posts in the app. The study delved into consumer behavior regarding clickbait content, specifically how they engage with the content and their purchase intention. The research respondents are focused on Generation X, who are active Facebook users who spend at least 3-5 hours on social media.

The research specifically focuses on Facebook and does not extend to any other social media platforms. It does not address consumer behaviors such as brand loyalty, brand trust, or purchasing behaviors. Additionally, the respondents in this study are exclusively from Generation X; other generations, such as Generation Y or Z, were not considered relevant and were therefore excluded from the research.

## METHODOLOGY

### Research Design

This research study utilized a predictive correlational research design. This design was defined to investigate and determine the specific commonality and relationship between the given variables (Thomas & Zubkov, 2023). Therefore, the research design was essential and suitable for the situation where the research study established the correlation of social media clickbait content on the consumer behavior of Generation X. To study the given variables in a natural setting, the said design proved effective for the research to determine the relevant relationships between clickbait content and its effect on consumer behavior without having to manipulate either variable.

### Procedure

The researchers began by creating a survey using Google Forms and

distributing it to Facebook users belonging to Generation X. The survey utilized Likert scale questions to gather relevant data. Once the responses were collected, the data were transferred to Google Sheets for organization and review.

The variables of the study were then identified. The dependent variable was consumer behavior, which included purchase intention, adding items to a cart, and actual purchasing after clicking. The independent variables were the features of Facebook clickbait, such as eye-catching headlines, frequency of exposure, and perceived believability.

Furthermore, the study tested the following hypotheses: the null hypothesis ( $H_0$ ) stated that there was no significant relationship between clickbait content and consumer behavior, while the alternative hypothesis ( $H_a$ ) stated that there was a significant relationship between the two variables.

### Research Instrument

The research utilized a survey as a research instrument. The survey included Likert-scale questions that aimed to determine the frequency of the research variables. These are Clickbait Content in Facebook and Consumer Behavior of Generation X. This instrument allowed a more effective way of gathering information needed for the study.

To ensure the effectiveness and reliability of the research instrument, it underwent a validation process with an expert from the Letran Research Publication Department. This step was conducted to evaluate whether the questions were appropriate, clear, and aligned with the objectives of the study. The content was carefully reviewed and revised in order to be more specific and concise to be well-catered to the Generation X participants. By ensuring the instrument is specific and concise, it allows participants to be able to respond with utmost authenticity and honesty.

### Sampling Method

This study used purposive sampling as it is the most suitable method for selecting respondents who can provide relevant insights about the study. The focus of the study centered around the correlation or relationship between Clickbait content and Consumer behavior. Thus, purposive sampling allows individuals to be chosen according to their encounter with or exposure to clickbait content on Facebook. Bisht (2024) defines purposive sampling, sometimes referred to as expert sampling, as the selection of individuals intentionally to fit and align with the research questions. The sampling technique is deemed most suitable for the study as it has a clear respondent group and objectives.

The respondents of this study are people born between 1960 and 1980, or are generally called Generation X. These individuals were purposely chosen for their experiences and perceptions about digital media, as a Generation raised on a traditional approach. Additionally, these certain groups were chosen to gain their relevant insights towards Clickbait content and their Consumer Behaviors.

40 respondents were taken. Having this number of participants in the study sample group is done to ensure there is a reasonable prediction towards the results of the study or the behavior of the population (Budiu & Moran, 2021). This sampling approach ensures that the collected data are rich, relevant, and aligned with the research objectives.

### Statistical Treatment

The data collected was analyzed with a Simple Linear Regression

statistical analysis. This is fit to be utilized as the statistical treatment, as it helps in better understanding the influence of the research variables. A simple regression analysis allows the study to show and understand the influence of Clickbait Content and Consumer Behaviors.

The mean was calculated to determine the average responses of the participants regarding the variables, Clickbait Content and Consumer Behavior. This was used to find out the general response and assessment of the responses. It helped to identify the central tendency and typical patterns of the respondents to the variables. This was calculated using the formula:

The standard deviation was calculated along with the mean. This is to identify and measure the responses and how they vary and spread out from the mean. The value of the standard deviation was the indicator of whether the responses were closer to the mean or not. The standard deviation was calculated using the formula:

Lastly, the percentage frequency of the demographic variables was also calculated. This is to help describe the characteristics of the respondents in terms of their age, location, and social media usage. This showed how many of the respondents belong to each category and how the data proportionally represents them in the total population of the study.

These descriptive statistics and variables, the mean, standard deviation, and percentage of frequency, are crucial to be used as a way to summarize and describe the respondents' answers for each variable of the study.

### Ethical Considerations

The research ensured strict compliance with the Data Privacy Act of 2012 (RA 10173). Respondents were informed beforehand about the intended purpose of the study and how the collected data would be used, ensuring transparency and voluntary participation of the respondents. Informed consent was obtained before any data collection took place. All personal information gathered was treated with strict confidentiality and used solely for academic purposes. Data were stored securely and were accessible only to the researcher, ensuring that no unauthorized individuals could view, use, or share the information. Participants were also assured of their right to withdraw from the study at any time without penalty. The researcher ensured that no physical, emotional, or psychological harm would result from participation, and all findings were reported honestly and responsibly.

## RESULTS AND DISCUSSION

**Table 1. Demographic Profile of the Respondents**

Profile	Frequency	Percentage
Age	45-49 years old	10
	50-59 years old	25
	60 years old	5
Location	Within Manila	24
	Outside Manila	16
Social media hours		17
		11
		2
<b>TOTAL</b>	<b>40</b>	<b>100%</b>

As a way to describe the Generation X population, a demographic profile is collected. This was then calculated using the percentage formula and allows a better understanding of the category of Generation X. As formerly stated, Generation X spans between the range of 1965-1980. Hence, the ages fall between the ages of 45 and 60.

The largest group of fall between the ages of 50-59 years old, showing a percentage of 63%. This is followed by the group of 45-49 years old (25%). A smaller portion of the size falls in the age of 60 years old (12%). Most reside within Manila City, showing a result of 60%. Meanwhile, the remaining 40% are located outside Manila.

### Generation X’s Social Media Usage

**Table 2. Respondent’s level on social media usage.**

Clickbait Content	Mean	SD	Interpretation
1. Use Facebook often when using social media	3.98	0.62	Agree
2. Use E-commerce apps like Shopee, Lazada, and Temu directed by Facebook post.	4.53	0.61	Strongly Agree
<b>WEIGHTED MEAN</b>	<b>4.25</b>	<b>0.61</b>	<b>Strongly Agree</b>

Note: 4.21-5.00 : Strongly Agree, 3.41-4.20 : Agree, 2.61-3.40 : Neutral, 1.81-2.00 : Disagree, 1.00-1.80: Strongly Disagree

In line with the demographic profile, Generation X’s Social Media Usage was also collected and calculated, deriving the mean and standard deviation. This is to determine better how Generation X is exposed through Social Media Clickbait content by first understanding their Social Media Usage.

Having calculated the mean and standard deviation, it shows that Generation X often uses Facebook when using social media. In the process, Generation X is well-equipped with E-commerce apps like Shopee, Lazada, and Temu when directed by Facebook posts. The said apps are where they could purchase products online and could be linked to Facebook. The results show that Generation X “Agree” that they often use Facebook when engaging with social media (Mean = 3.98), indicating that Facebook is a commonly accessed platform among them. Meanwhile, the group “Strongly Agree” that they frequently use e-commerce applications such as Shopee, Lazada, and Temu (Mean = 4.53), suggesting a very high level of exposure to online shopping environments where clickbait content is commonly encountered.

The overall mean ( $\bar{x}$ = 4.25), where it shows a result of “Strongly Agree”, indicates that Generation X uses social media often — reflecting the high level of social media usage. Additionally, it shows a high usage of apps that are known for having a heavy clickbait presence, particularly Facebook. Meanwhile, the relatively low standard deviation of the results ( $\sigma$ = 0.61) implies that responses show consistency, having only slight variations in Generation X’s usage.

### Generation X’s Exposure to Clickbait Content

**Table 3. Respondent’s level of exposure to Social Media Clickbait Content**

Clickbait Content	Mean	SD	Interpretation
1. Encourage content where product is exaggeratedly promoted on Facebook.	2	0.62	Rarely
2. Encounter content where headline is misleading and inauthentic.	2	0	Rarely
3. Encounter too good to be true products promoted on Facebook.	2.15	1.1	Rarely
4. Encounter exaggerated headlines recommended on Facebook.	2.03	0.86	Rarely
5. Encounter Clickbait content under comments in a post.	2.43	1.28	Rarely
<b>WEIGHTED MEAN</b>	<b>2.12</b>	<b>1</b>	<b>Rarely</b>

Note: 4.21-5.00 : Very Often, 3.41-4.20 : Often, 2.61-3.40 : Neutral, 1.81-2.00 : Rarely, 1.00-1.80: Never

From the results, it is implied that Generation X encounters Clickbait content under comments in a post with the highest mean score. However, it is shown that Generation X rarely encounters it, having a mean score of 2.15. This result states that though they may encounter Clickbait content under Social Media posts, it is not frequent enough to be part of the online experience or usage. Additionally, Generation X may also encounter too-good-to-be-true products promoted on

Facebook ( $\bar{x}$ = 2.15). It may be encountered occasionally; however, posts like these rarely show up in users' browsing experience on the app.

The calculated results show a weighted average of 2.12. This implies that Clickbait Content is quite uncommon in being exposed to Generation X social media users. Although Clickbait posts still roam online, particularly in social media apps like Facebook, results generally show that Generation X doesn’t frequently encounter posts with the said exaggerated content. The standard deviation score ( $\sigma$ = 1.00) shows moderate variability in the results. This means that some Gen X users may encounter clickbait slightly more or less than others, but overall exposure remains limited.

**Table 4. Respondent’s level of consumer behavior in terms of consumer engagement**

Consumer engagement	Mean	SD	Interpretation
1. Click on post with intriguing and sensational headlines.	2.4	1.03	Rarely
2. React on posts that are intriguing.	2.4	1.13	Rarely
3. Share content on Facebook that are interesting.	2.64	1.41	Neutral
4. Discuss interesting posts with friends.	2.53	1.15	Rarely
5. Follow the Facebook page that promotes too-good-to-be-true products.	2.6	1.19	Rarely
<b>WEIGHTED MEAN</b>	<b>2.51</b>	<b>1.18</b>	<b>Rarely</b>

Note: 4.21-5.00: Very Often, 3.41-4.20: Often, 2.61-3.40: Neutral, 1.81-2.00: Rarely, 1.00-1.80: Never

The results shown in Table 4 show that respondents rarely engage or interact with Clickbait posts seen on Facebook. The weighted mean of 2.51 indicates a low frequency of engagement overall. It suggests that Generation X doesn’t normally interact and engage with posts with exaggerated headlines and content. However, the standard deviation score of 1.18 shows a moderate variation in the responses, which may imply that some may be more likely to often engage than others.

Though results may show that Generation X may occasionally share the posts on Facebook with interesting content, garnering the highest mean score of 2.63, it is rare that it happens. However, most are inclined to share the posts as a form of their online public engagement. In contrast to online public engagement, Generation X may still occasionally discuss the said interesting and sensational content with their friends privately as a form of engagement ( $\bar{x}$ = 2.53), although it is still interpreted to be done rarely.

### Generation X’s Consumer Behavior in terms of Purchase Intention

**Table 5. Respondent’s level of consumer behavior in terms of purchase intentions**

Consumer engagement	Mean	SD	Interpretation
1. Intention to purchase product seen on Facebook.	2.63	1	Neutral
2. Intention to purchase when post is viral.	2.63	1	Neutral
3. Add to cart products seen on Facebook posts.	2.75	1.03	Neutral
4. Inquire to sellers about products posted online.	2.75	1.03	Neutral
5. Purchase and avail intriguing products on Facebook	3.03	1.14	Neutral
<b>WEIGHTED MEAN</b>	<b>2.76</b>	<b>1.04</b>	<b>Neutral</b>

Note: 4.21-5.00: Very Often, 3.41-4.20: Often, 2.61-3.40: Neutral, 1.81-2.00: Rarely, 1.00-1.80: Never

The overall results of Generation X’s purchase intention show a neutral stance, with a mean score of 2.76. Their responses indicate neither strong enthusiasm nor reservation when it comes to the intention to purchase products online from Clickbait posts. Results show that Generation X is not impulsive online shoppers, but

cautious and selective.

Generation X is more likely to purchase online when the products that are promoted on Facebook seem intriguing enough, having the highest mean score of 3.03. Intriguing products tend to catch more attention. However, it does not directly result in a purchase, showing a neutral stance. Additionally, Generation X users may also have the option to first “add to cart” products they may encounter in Facebook posts and inquire about the product to the seller. Though results show a mean of 2.75 and a neutral interpretation, it can be concluded that Generation X is not inclined towards spontaneous purchases.

### The Influence of Clickbait Content on Facebook in Generation X’s Consumer Engagement

**Table 6. Influence of clickbait content towards consumer engagement**

Variables		t-value	p-value	Decision	Conclusion
Clickbait content	Consumer engagement	4.33	<.001	Reject Ho	Significant

The table presents the analysis of the influence of Clickbait Content on the Consumer Engagement of Generation X. The results of the analysis show that Clickbait does have a significant influence. It shows the predictor variables of the t-value have a value of 4.33 and a p-value of <.001, which is well below the accepted significance level of 0.05. Thus, with these results, the null hypothesis is rejected, which states that Clickbait content does not have a significant influence on Consumer Engagement.

Though the weighted mean of the level of consumer engagement shows it may rarely happen, the results suggest that Clickbait content is a predictor of whether Generation X consumers engage with the said content. This implies that the more Clickbait content is exposed, the more likely Generation X is to interact. It has a significant influence on whether they choose to share, comment, react, or even discuss the content online.

### The Influence of Clickbait Content on Facebook on Generation X’s Purchase Intention

**Table 7. Influence of clickbait content towards Purchase intentions**

Variables		t-value	p-value	Decision	Conclusion
Clickbait content	Purchase intentions	2.7	0.01	Reject Ho	Significant

With the second sub-variable of Consumer Behavior, results show that Clickbait content also has a significant influence on Generation X’s Purchase Intention. The predictor variables show values that allow the rejection of the null hypothesis. The t-value shows a value of 2.70, and the p-value has the value of 0.010, which falls under the accepted significance level.

Just like the case with consumer engagement, the results imply that with higher levels of Clickbait content, the higher chance of purchase intention. Clickbait content is a predictor of whether a consumer intends to purchase a product through online apps. Clickbait content functions as an incitement not only to capture the consumer’s attention, but also as a way to nudge customers towards a purchase.

The relationship between Clickbait and purchase intention shows that consumers may rely on quick and attention-grabbing cues in social media. Within the sea of countless online products, clickbait content serves as a shortcut that simplifies decision-making, as it offers products that are interesting and even offer special offerings to consumers. Generation X consumers may be more inclined to

purchase products that feed on their curiosity with exaggerated content and product visuals, further suggesting that the strategic use of clickbait by sellers can lead to increased likelihood of not only consumer engagement, but also purchase intention.

## CONCLUSIONS

Generation X demonstrates a high frequency of social media usage, particularly on platforms like Facebook, and is also actively engaged with e-commerce applications such as Shopee, Lazada, and Temu. This challenges the common perception that this age group is digitally illiterate. In fact, Generation X has witnessed the evolution of technology firsthand, which provides them with a unique advantage in adapting to and navigating digital platforms (Media Culture, 2023). Their familiarity with technological developments enables them to explore and utilize both social media and online shopping platforms effectively.

In terms of exposure, results indicate that Generation X is only rarely exposed to clickbait content on Facebook. This suggests that their social media feeds are not heavily saturated with such content and are instead influenced by their browsing behaviors and preferences. Older users tend to engage more with purposeful and relevant content, which may reduce the likelihood of encountering clickbait posts (Xing et al., 2020).

When it comes to engagement, Generation X appears to be cautious in interacting with clickbait content. While they may occasionally find such posts interesting, their overall level of engagement remains low. This aligns with existing research indicating that older social media users are generally more skeptical of viral or sensationalized content and are less likely to engage in impulsive online interactions (Su et al., 2024). Although they may still be influenced by social factors, their decisions are typically more deliberate rather than impulsive.

Similarly, Generation X exhibits a neutral stance in terms of purchase intentions when exposed to clickbait posts. Rather than making immediate purchases, they tend to evaluate products more carefully, often by adding items to their cart or seeking additional information before making a decision. This behavior reflects established consumer research, which shows that older consumers prioritize practicality, reliability, and security in their purchasing decisions (Olumekor et al., 2025). Even highly appealing or viral content does not strongly drive them toward impulsive buying.

Despite their low exposure and cautious engagement, clickbait content still exerts a measurable influence on Generation X’s consumer behavior. The findings suggest that even minimal interaction with clickbait can shape how they perceive online content and evaluate products. This supports recent digital marketing studies indicating that clickbait remains an effective strategy, as it subtly captures attention and influences decision-making processes—even among more cautious and mature audiences (Wang et al., 2024).

### Recommendations

For Generation X as consumers, developing strong media literacy is essential to navigating social media safely and meaningfully. Older users are encouraged to become more aware of clickbait content, particularly the psychological tactics—such as exaggeration and information withholding—used to capture attention. By engaging with free and credible educational toolkits available online, Generation X can improve their ability to identify misleading content

and reduce their vulnerability to scams. In addition, media literacy should be complemented by the habit of regularly cross-checking information. Verifying claims through multiple credible sources and utilizing fact-checking platforms allows users to assess the legitimacy of products and online promotions more effectively, ultimately leading to more informed and secure digital consumption.

For online sellers, the findings highlight the importance of prioritizing factual, transparent, and credible content over traditional clickbait strategies. Given Generation X's cautious and selective engagement behavior, brands must focus on delivering clear and accurate information that aligns with consumer expectations. Building trust is crucial; this can be achieved by presenting content that is supported by evidence, endorsed by recognized experts, or associated with reputable brands. Since Generation X consumers are not purely impulsive in their decision-making, content should emphasize tangible benefits, practical value, and reliability. Moreover, straightforward and honest promotional strategies are more effective than exaggerated or overly saturated messaging. Business content creators are encouraged to highlight measurable benefits and problem-solving features to capture attention and foster long-term trust.

For future researchers, there is an opportunity to further expand the scope of study by incorporating additional variables related to consumer behavior, such as consumer trust and brand loyalty. Exploring how these factors interact with exposure to clickbait content can provide a deeper and more comprehensive understanding of its influence. By broadening the analytical framework, future studies can contribute to more nuanced insights into digital consumer behavior and the evolving effectiveness of online marketing strategies.

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## G.A.R.D. (GAS ALERT AND REAL-TIME DETECTION): DEVELOPMENT OF AN IOT-ENABLED GAS (LPG) LEAKAGE DETECTION WITH MOBILE APP INTEGRATION

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### ABSTRACT

This study developed an IoT-enabled LPG gas leakage detection system with real-time alerts to reduce fire and explosion risks. Using an MQ-6 gas sensor and DHT22 temperature sensor, data is processed by an ESP32 microcontroller, triggering a five-LED indicator and buzzer for local alerts. Simultaneously, a LoRa module sends data to a secondary ESP32 and the G.A.R.D. mobile app for remote monitoring. Tests showed reliable detection and notifications within 10–30 m (mean times 10.69–13.28 s, SD < 1). G.A.R.D. maintains reliable performance between 40m and 60m; however, signal failure occurs beyond 70m due to environmental and signal interference. The system provides a portable, IoT-integrated solution that combines local and remote alerts.

**Keywords:** *IoT-enabled, LPG leak, detection system, real-time alert, bluetooth*

### INTRODUCTION

#### Background of the Study

The presence of gas leaks poses severe risks to both human health and property, requiring immediate and accurate detection. When detected early, individuals can take timely action to prevent harm. However, many accidents still occur because leaks are discovered too late, and conventional detectors often underperform due to delayed response, leaving homes at risk of fire and explosions.

The introduction of G.A.R.D. aims to significantly enhance home safety by detecting gas leaks and delivering real-time alerts through a custom built mobile application. Furthermore, the device offers portability through Star network enabling offline functionality. This integration guarantees reliable performance even in low-connectivity environments, offering continuous protection without requiring an internet connection.

In the Philippines, gas leaks and related incidents remain a persistent public safety concern. Residential and commercial establishments rely heavily on liquefied petroleum gas (LPG) for cooking and heating; however, leaks caused by faulty appliances, damaged tanks, or improper handling have repeatedly led to accidents. For instance, on July 5, 2023, two individuals were injured after an LPG tank exploded in a pizza and pasta restaurant in Quezon Province (Estacio, 2023).

Similarly, on February 1, 2024, three persons sustained second-degree burns following a gas tank explosion in Makati City (Bautista, 2024). More recently, in February 2025, six restaurant workers in Davao City were hospitalized after an LPG tank leak ignited near an electric fryer, causing a severe explosion (Esteban, 2025). These recurring incidents underscore the vulnerability of Filipino households and communities to undetected gas leaks and highlight the urgent need for reliable, technology-based safety systems that can reduce risks and safeguard lives.

A gas detector serves as a safety mechanism that prevents accidents by providing early warning signals when hazardous substances are detected. Devices that monitor gases such as LPG, methane, and

carbon monoxide allow users to detect leaks before they escalate. The presence of detectors enables prompt evacuation, emergency response, and corrective action, reducing the likelihood of fire and explosions. Beyond saving lives, gas detectors also protect property and promote a culture of safety within homes and workplaces.

Existing gas detection systems minimize the risk of combustible and toxic gas exposure to prevent incidents. These devices are typically stand-alone detectors equipped with sensors such as metal-oxide-semiconductor (MOS), catalytic-bead (pellistor), or electrochemical sensors that trigger alarms when gas concentrations exceed safe limits. These detectors are commonly wall-mounted near gas appliances or leak-prone areas and rely on alarms or indicator lights to alert owners. While these systems have proven useful, their main limitation is delayed response.

Recent technological advancements have given rise to smart and IoT-based gas detection systems, which integrate sensors with microcontrollers and communication modules (Luca, 2025). Unlike conventional detectors, these systems provide real-time monitoring and are capable of sending alerts through various channels, such as text messages, mobile applications, or internet-based notifications.

An Arduino Uno microcontroller with an MQ-series gas sensor and a GSM module (SIM900A) can detect gas leaks and automatically send warning notifications to the owner via SMS, sound an alarm, or even activate a DC fan to disperse gas (Arduino Documentation, 2025). To ensure that users are informed even in the absence of an internet connection, another prototype combines the NodeMCU ESP8266 microcontroller with the MQ-6 sensor to transmit alerts via SMS and the Blynk mobile app.

This connectivity ensures that users are informed of gas leaks even when they are away from their homes, allowing for faster emergency responses. Studies have shown that IoT-enabled detectors significantly improve safety by extending awareness beyond physical

alarms (Luca, 2025). However, these systems remain relatively costly and less accessible for widespread adoption in average Filipino households, signaling the need for more affordable and practical implementations.

Existing gas detectors commonly utilize conventional alert systems such as buzzers and indicator lights to signal the presence of gas leaks. While effective for immediate, localized alerts, these systems offer limited functionality in terms of remote accessibility and user engagement. This research addresses the opportunity to enhance gas detection systems by integrating traditional alert mechanisms with wireless communication technologies to enable remote notifications.

By combining these features, G.A.R.D. strives to elevate safety, convenience, and responsiveness while also optimizing efficiency and user accessibility in gas leak monitoring.

### Objectives of the study

This study aims to design and implement an IoT-enabled gas (LPG) leakage detection system with real-time alert monitoring features through app integration to minimize fire-related risks: (1) to develop an IoT-enabled gas leakage detection and real-time notification system; (2) to integrate an application that serves as the user's platform for real-time alert notifications; and (3) to evaluate the performance of the system in terms of (a) detection accuracy and (b) app notification responsiveness.

### Review of Related Literature

#### Gas leak-related fire cases

Gas leaks remain one of the most significant and dangerous hazards in industrial and confined environments due to their potential to cause fires and explosions. Liaw et al. (2023) revealed that corrosion-induced pipeline failure, combined with lapses in Process Safety Management (PSM), led to the incident, causing billions in damages. They highlighted systemic weaknesses in hazard analysis, mechanical integrity, and emergency preparedness.

In another case study conducted by Ddakani et al. (2021), a gas pressure was examined using ALOHA software to simulate gas leakage and fire situations. Their findings revealed that seasonal conditions significantly influence the extent of threat zones, with larger impact areas recorded during hot weather for gas leaks and during cold weather for fire incidents.

Similarly, the study examined gas leak scenarios and fire risks, stressing the critical importance of early detection systems, infrastructure design, and emergency response measures. This highlights the importance of context-specific modeling in risk management. Collectively, these studies emphasize the urgent need for proactive safety measures, especially in urban areas where industrial gas systems are located near residential communities.

Meanwhile, Çalık (2025) found that as little as 10 kg of leaked methane could create a lethal overpressure zone within 15 minutes, leading to a probability of over 90% fatality for individuals within a 1-meter radius. The case underscored the importance of timely gas detection, adequate ventilation systems, and emergency protocols tailored for confined industrial environments, emphasizing the significance of precautionary measures in high-risk settings.

In another related study, Cai et al. (2022) conducted both laboratory and simulation-based analyses of the impact of gas concentration levels and ventilation efficiency on explosion risks and fire behavior in indoor environments. The study showed that gas concentration levels and ventilation efficiency significantly affect the severity of explosions, flame spread, and internal damage. These findings are

crucial for improving building design, evacuation plans, and firefighting response procedures during gas-related emergencies, offering valuable insights into structural safety and emergency response strategies in industrial and residential areas prone to gas leaks.

All of these studies highlight critical factors in gas leak-related fire incidents and the importance of effective risk management. Liaw et al. (2023) and Ddakani et al. (2021) stress the role of systemic failures in safety management and infrastructure, emphasizing that seasonal conditions and confined spaces influence the severity of leak-related fire incidents. Çalık (2025) emphasizes the need for early detection systems and adequate ventilation to mitigate risks, especially in high-risk environments such as urban areas and confined industrial spaces. Lastly, Cai et al. (2022) further highlight how gas concentration and ventilation efficiency are key factors in controlling explosions and fire behavior.

In summary, all of these studies underscore the importance of proactive safety measures, risk assessments, and advanced detection technologies to reduce the impact of gas leaks and help prevent fire incidents.

#### Integration of IoT in gas leak detection

Jena et al. (2022) pointed out that accidents involving LPG have become a significant social concern because of its widespread domestic and industrial use. Leaked LPG can ignite easily with even the smallest spark. Although odorants are added to assist in detecting leaks, many users fail to observe safety measures, which leads to incidents. To mitigate these risks, the development and use of the Internet of Things (IoT) enable gas sensors to provide continuous monitoring and send instant alerts through smartphones, making detection more efficient and reliable compared to traditional methods.

According to Aakash et al. (2025), an IoT-enabled gas leak detection system can be applied to both homes and industries. It is equipped with gas sensors that continuously monitor air quality and transmit data to a microcontroller, which communicates through wireless protocols. Upon detecting a leak, the system can immediately send real-time notifications and take preventive actions that can be modified remotely, using simple tools to help minimize risks. The system improves accuracy through multi-sensor fusion and artificial intelligence (AI), outlining a feasible and scalable path toward more intelligent and safer spaces.

Jena et al. (2022) emphasize that LPG leaks continue to pose risks, as traditional detection methods and user negligence often lead to accidents, making IoT-based monitoring essential. Similarly, Aakash et al. (2025) present a more advanced model that allows real-time tracking through mobile apps and web dashboards. These studies demonstrate that IoT strengthens safety by offering smarter, more efficient, and reliable gas leak detection.

#### Application of LoRa in wireless alert systems

According to Gonzalez et al. (2020), LoRa is a technology designed for long-range wireless communication. It is affordable, reliable, and energy-efficient, making it suitable for safety monitoring systems. By enabling long-range wireless data transmission, LoRa provides timely warning alerts to help prevent accidents, particularly in areas with limited or weak Wi-Fi connectivity.

LoRa is useful as a wireless alert system, as it can send data over long distances of up to 20 km while using minimal power, as stated by Kolobe et al. (2020). Devices equipped with LoRa can last up to 10 years, making them reliable for long-term monitoring. Studies show that LoRa is suitable for wireless sensor networks in both rural and urban settings, although it still requires further testing in some areas. It is resistant to noise, which helps ensure that messages are

transmitted accurately, making it appropriate for gas leak detection and other real-time alerts.

Taken together, these studies underscore LoRa’s effectiveness as a wireless alert system. Gonzalez et al. (2020) emphasized its affordability and efficiency in safety monitoring, while Kolobe et al. (2020) focused on its long-range, low-power, and durable performance. Overall, both studies demonstrate that LoRa is a practical and reliable communication technology for real-time alerts, including gas detection and disaster monitoring.

**Temperature and humidity in gas sensors**

Abdullah et al. (2020) analyzed how temperature and humidity influence the performance of gas leak sensors at different concentrations. They found that most sensors show decreased performance as temperature and humidity rise, resulting in inaccurate and unreliable detections. They emphasized the importance of environmental conditions in the effectiveness of gas leak detectors and the need for calibration and compensation to maintain accurate detection in real-world environments.

Similarly, Furuta et al. (2022) illustrated how gas sensors are affected by environmental factors such as temperature and humidity, sometimes even more than by the gas they are intended to detect. The study showed that excessive humidity makes it difficult for gas to be detected on the sensor surface, while temperature changes can affect conductivity and baseline resistance, causing inaccurate results. These conditions may lead to false alarms; however, the use of compensation and calibration models can help maintain sensor accuracy.

Abdullah et al. (2020) and Furuta et al. (2022) both highlighted that temperature and humidity affect gas leak sensors, showing reduced response as these environmental factors increase. Rising humidity can block gas absorption, and temperature changes can affect the sensor’s conductivity and stability, leading to inaccurate detection.

**Application Through Offline Connection**

Offline mobile applications rely on app integration that allows different modules to communicate and function without an internet connection (Sheharyar, 2025). This can be achieved by using local storage and device-level services. It allows notifications, data input forms, and analytics to work together without the internet. This integration prevents interruptions in critical situations, supports users with unstable internet connections, and ensures access to important notifications.

According to the article by Think-It (2025), offline app integration allows applications to function without relying on the internet through local storage, background processes, and queued data synchronization. This enables users to continue performing important tasks even in areas with weak connections. The app saves information on the device, allowing it to load faster and reducing the risk of data loss. Offline integration also supports real-time actions, such as alerts or notifications. This makes offline applications reliable, user-friendly, and efficient, especially for critical functions like monitoring, reporting, or emergency notifications.

Both Sheharyar (2025) and Think-It (2025) explain that offline application integration allows apps to function without the internet by using local storage and background processes. They highlight that this integration keeps notifications, data entry, and real-time actions working even in weak connections. Both sources emphasize that offline apps make applications more accessible, reliable, and safe for users.

**Theoretical Framework**

This study adopts the Internet of Things (IoT) framework and Gas

Diffusion Theory, complemented by principles of gas behavior and environmental conditions. The IoT framework enables real-time monitoring of gas leakage through sensors, communication protocols, and data transmission, sending timely alerts to users’ smartphones and ensuring safety and efficiency without constant human supervision (Ray, 2018).

Fick’s Law of Diffusion states that molecules naturally move from regions of high concentration to regions of low concentration, with the flux proportional to the concentration gradient (Jin et al., 2023). In the case of LPG leaks, this principle explains how gas can spread and accumulate in enclosed areas, highlighting why early detection and strategic placement of sensors are essential for safety.

Dalton’s Law of Partial Pressures clarifies that each gas in a mixture contributes to the total pressure according to its partial pressure (Smith et al., 2018). This principle helps explain how LPG behavior, along with the presence of other gases such as water vapor, can affect sensor readings and accuracy.

The Clausius–Clapeyron relation further illustrates how temperature and humidity influence sensor performance (Çengel & Boles, 2019). Warm air holds more water vapor, and high humidity levels can compete with LPG molecules on the sensor surface, potentially causing false readings.

Gas detection also involves surface interactions that may include endothermic processes, where the sensor absorbs energy when gas molecules interact with its surface (Korotcenkov, 2020). This energy absorption affects how sensitive the sensor is, how quickly it responds, and how accurate the readings are, offering a thermodynamic explanation of how environmental conditions can affect its performance.

Overall, these theories provide a clear scientific and technological basis for understanding the different factors that influence gas behavior and sensor performance. This strengthens the study’s development of a reliable gas leak detection and real-time notification system designed to enhance safety in households and communities.

**Conceptual framework**

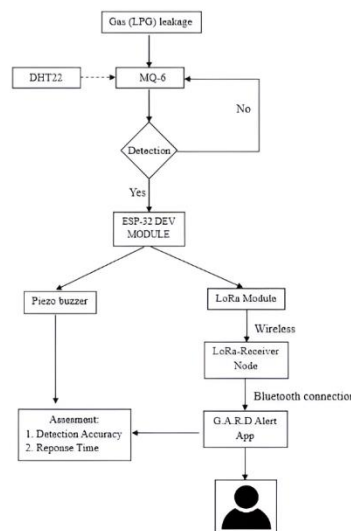


Figure 1. Conceptual framework

The figure illustrates the workflow of the device, which is centered on the ESP32 microcontroller. The ESP32 functions as the central processing unit, receiving input from the MQ-6 gas sensor, while the DHT22 sensor provides environmental parameters such as temperature and humidity to ensure more reliable readings. The sensors are installed in proximity to the LPG cylinder to enable the detection of potential gas leakage. Upon detection, the microcontroller activates an audible alarm through a piezoelectric buzzer and powers a five-LED indicator to convey the system status. Simultaneously, it transmits a wireless alert signal via a LoRa module. The LoRa main circuit then sends the signal to another LoRa module, which communicates with the ESP32 Dev Module before transmitting the alert notification to the mobile application.

### Scope and Limitation

This study focuses on the development and implementation of a smart gas detection and notification system based on ESP32 technology. The device is specifically designed to be installed 1 foot above the ground and half a foot away from the LPG (Liquefied Petroleum Gas) tank to optimize accuracy, as gas is denser than air and tends to accumulate near the floor. The system monitors and detects LPG presence indoors, providing real-time alerts through visual, audio, and digital notifications.

The research scope is limited to evaluating functionality, sensitivity, and response time in detecting LPG. It excludes other hazardous gases and industrial-scale applications. To improve reliability, the device integrates a DHT22 sensor for temperature and humidity monitoring, calibrated to typical Philippine household conditions (25–30 °C, 30–90% RH). Testing excludes conditions such as direct sunlight, sudden cooking heat, or outdoor weather changes.

The system is designed for household use, providing portable, wireless alerts for gas leak detection. However, its performance may not be suitable for larger properties or industrial environments, where operating conditions and safety standards differ significantly. Additionally, the Bluetooth connection can be constrained by range limitations and environmental factors inherent to Bluetooth technology and is not configurable within the scope of this study. While the system could potentially operate over longer distances, its performance and reliability may still be affected by Bluetooth barriers, which must be considered when sending real-time alerts.

## METHODOLOGY

### Research Design

This study employs a non-iterative developmental design. According to Dwissink (2025), this design follows a linear process in which the product is developed in a single cycle without trial phases or feedback loops, making it suitable when the scope is clearly defined. Integrating this technology into a functional IoT-enabled gas leakage detection system rather than repeatedly redesign the product. Since the system is already finalized and functioning as intended, the results are presented as they are, allowing the researchers to evaluate the product's performance without relying on external feedback. Due to time constraints, an iterative process involving repeated testing and refinement could not be conducted, making non-iterative approach the most practical for the study.

### Statistical Treatment

This study uses descriptive statistics to analyze the data collected from the trials of the gas detection alert system. Descriptive statistics summarize quantitative data by showing patterns, central tendency, and variability within a dataset, without making inferential conclusions (Illowsky & Dean, 2021). This approach allows the performance of the device under controlled conditions to be clearly examined.

The study employs the mean and standard deviation as its primary statistical measures. The mean represents the average accuracy across multiple trials, while the standard deviation reflects the consistency of the readings. These measures provide a basis for evaluating the device's effectiveness as a gas leak detector capable of sending real-time alert notifications.

### Materials

The materials used in this study include prototyping components such as a breadboard and jumper wires. The main circuit consists of an ESP32 Dev Module, MQ-6 gas sensor, DHT22 temperature and humidity sensor, LED indicators (two green and one yellow), and a piezoelectric buzzer. For wireless communication, LoRa SX1278 modules were utilized. The receiver circuit includes an ESP32 Dev Module, LoRa SX1278 module, lithium-ion batteries, a battery holder, and a DC-to-DC buck converter. Additionally, printed circuit fabrication materials such as copper board, ferric chloride, and pin headers were used.

The equipment used in this study includes a handheld drill with 0.5 mm and 1 mm drill bits for circuit fabrication, a battery charger for powering the system components, and a soldering iron with appropriate soldering wire for assembling electronic connections.

### Developmental Procedure for the Gas Detector with Alert System

The development of the gas leak detection system with alert functionality involved the integration of multiple hardware and software components. The system was built using an ESP32 microcontroller, an MQ-6 gas sensor for LPG detection, and a DHT22 sensor for monitoring temperature and humidity. Additional components included a piezoelectric buzzer for audible alerts, five LED indicators for visual status display, and LoRa modules to enable long-range wireless communication between the transmitter and receiver nodes.

The MQ-6 sensor was interfaced with the ESP32 to detect the presence of gas, while the DHT22 sensor was connected via I<sup>2</sup>C protocol to monitor environmental conditions. Output devices, including the buzzer and LEDs, were connected to designated GPIO pins to provide real-time alerts and system status indications.

For wireless communication, a LoRa module was integrated with the ESP32 using the SPI interface. The transmitter node was configured to send alert signals to a receiver node, which was linked to a mobile application developed using Kodular. The application interface was designed through Kodular's Designer and Blocks environment, allowing real-time monitoring and notification through Bluetooth connectivity.

The system circuit was initially designed and implemented on a printed circuit board (PCB). Standard PCB fabrication techniques were followed, including layout transfer, etching using ferric chloride solution, drilling, and component soldering.

The ESP32 was programmed to process sensor data, compare readings against predefined threshold values, and trigger alerts when abnormal conditions were detected. Wireless notifications were also transmitted to the connected mobile application.

To evaluate system performance, the prototype was tested under controlled conditions with the assistance of the Bureau of Fire Protection. The device was assessed based on detection accuracy and response time to determine its reliability and efficiency in identifying gas leaks.

### System Wiring Diagram

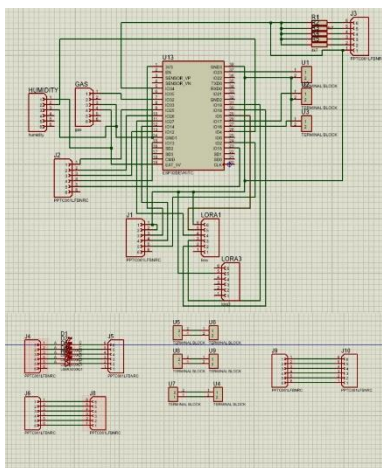


Figure 2. Physical connection of the gas leak detection with alert system.

Figure 2 shows the wiring of the gas leak detection prototype. The ESP32 microcontroller collects data from the MQ-6 gas sensor and the DHT22 temperature and humidity sensor. Visual alerts are provided by LEDs, while an audible alarm is generated by a piezo buzzer. The ESP32 also connects to a LoRa SX1278 module to wirelessly send alerts to a receiver node, which then forwards the warning to a smartphone via Bluetooth.

### Printed Circuit Designing

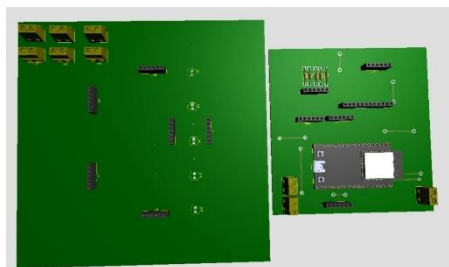


Figure 3. PCB design of sender and receiver circuit

The design shows the device’s electronic connections on a PCB. MQ-6 and DHT22 sensors, connected to the microcontroller’s GPIO pins, serve as inputs for continuous monitoring. Outputs include LEDs and a buzzer for visual and audible alerts. The microcontroller also interfaces with a LoRa module via GPIO pins to transmit alerts wirelessly.

### App Invention



Figure 3. Sample Application interface

To utilize the IoT capabilities, the researchers developed a customized mobile application using Kodular Web. The app can establish Bluetooth connections between any Android smartphone and detected Bluetooth-enabled devices. It supports pairing with a single device at a time and displays notifications each time a gas leak is detected. The connection operates offline, requiring only a bluetooth connection between only android devices.

### RESULTS AND DISCUSSIONS

This chapter presents the results of G.A.R.D., showing that both the device and application functioned successfully under different conditions, including variations in distance and temperature. The system detected gas leaks within 2–4 seconds and the notification was sent within the same 2–4 second interval. In relation to the study by Riding et al. (2026), the alarm response occurred in less than 2 seconds and notification alerts were also sent within 2–3 seconds, while in terms of distance, the system detect gas leaks at 5–15 cm, with a success in detection rate within this range, but detection failed when it reached 20 cm. The present study showed a detection success with no missed trials, and consistent performance at 10-60 meters, it is less effective outside this range. The app responded promptly, confirming the warning and sending a notification to the owner. These outcomes demonstrate that the system is not only functional but also reliable under real-life conditions.

Table 1. G.A.R.D. System Trial of Device

Trial	Time (in seconds)	Temp	Alarm	Missed
1	4.11	31.8°C	Yes	No
2	2.98	31.8°C	Yes	No
3	3.88	31.6°C	Yes	No
4	3.61	31.5°C	Yes	No
5	3.40	31.5°C	Yes	No
$\bar{x}$	3.60			
$\sigma$	0.44			

Note:  $\bar{x}$  (x-bar) represents the average (mean), while  $\sigma$  (sigma), the standard deviation measures how much the data values are spread out or vary from that mean.

Table 1 presents the performance of the G.A.R.D. device across all five trials, with a mean of 3.60 and a standard deviation of 0.44. This small standard deviation indicates that the device produced very similar results across trials, showing only minor differences and demonstrating consistency. The short detection time suggests that the system can efficiently recognize changes or triggers almost immediately after they occur. The results were most consistent during the 3rd to 5th trials, ranging from 3.40 to 3.88, while the first and second trials recorded 2.98 and 4.11, respectively. This demonstrates that the system remained highly responsive across repeated exposures to the same leak conditions.

Table 2. Mean and standard deviation

Distance (in meters)	M	SD
10	10.69	0.69
20	11.82	0.47
30	13.28	0.44
40	13.46	1.29
50	11.62	1.16
60	11.22	0.92
70		
80		

Table 2 presents the data across trials of application responsiveness. The system performed most consistently between 10 and 30 meters, with a mean ranging from 10.69 to 13.28, low detection times, and minimal variability (values less than one). Although time responsiveness increased and variability grew beyond 30 meters, the

system remained

functional up to 60 meters, showing less consistent average performance of 11–13 and a standard deviation close to or greater than one. At 70–80 meters, the system failed to deliver valid notifications, indicating no data and concluding that it was ineffective.

## CONCLUSIONS

This study aimed to design and implement an IoT-enabled LPG gas leakage detection system with real-time, app-integrated alert monitoring, intended to minimize fire-related risks. Analysis of the collected data showed that, with proper calibration and integration of the system's sensors and modules, all input and output components worked cohesively, allowing the device to perform as intended. The system effectively detected LPG leaks and transmitted notifications with minimal delay within its optimal operational range.

The gas sensor's detection accuracy remained consistent across repeated trials, with detection times ranging from 2 to 4 seconds when gas was released half a foot away from the device, demonstrating the sensor's reliability under the tested conditions. The alert notification system performed reliably within its effective range of 10 to 30 meters, with optimal performance. Notifications were consistently received up to 60 meters from the main device, though delays were observed between 40 and 60 meters. Beyond 60 meters, occasional failures occurred, primarily due to environmental factors, obstacles, signal interference, and device positioning.

## Recommendations

Based on the results and conclusions of the study, the researchers recommend enhancing both the device and its application to ensure that real-time notifications are fully supported on iOS devices in addition to existing platforms, and to add a push notification feature. It is also suggested to integrate a more precise, gas-specific sensor—preferably one designed to detect a single target gas—to improve accuracy and reduce detection delays. Furthermore, the researchers recommend upgrading the device's mesh communication capability by using a more advanced antenna to extend and stabilize the effective range covered by the receiver node. Time limitations constrained the researchers' ability to optimize the device for maximum portability. Overall, an iterative design approach is suggested to further compact the system.

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## A PRELIMINARY HEALTH RISK ASSESSMENT OF HEAVY METALS VIA INGESTION AND DERMAL ABSORPTION OF WATER IN THE AGUSAN RIVER, MINDANAO, PHILIPPINES

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### ABSTRACT

Heavy metal-contaminated water can threaten community health. This study assessed human exposure to four heavy metals: copper, nickel, chromium, and total mercury in the Agusan River via ingestion and dermal routes for adults and children. Using secondary sediment data. Chronic daily intakes (CDI) were computed, and US EPA reference doses were used to calculate hazard quotients (HQ) and hazard index (HI), as well as lifetime cancer risk (CR). All HQs and HIs were below <1. Ingestion HIs ( $10^{-6}$  for both age groups) indicate negligible oral risk. Dermal HIs reached 0.07–0.13 in adults and 0.08–0.16 in children at the downstream site, still well below 1. No HI exceeded 1. Cancer-risk show for Cr were below  $<10^{-6}$ , far below EPA concern. These findings show that Agusan River water poses no significant non-cancer or cancer risk under current conditions. However, continued pollution control and monitoring are recommended due to the presence of bioaccumulation, which allows toxins such as heavy metals to reach hazardous levels in organisms over time.

**Keywords:** Agusan River; heavy metals; health risk assessment; Hazard Index; ingestion; dermal exposure

### INTRODUCTION

Heavy metal pollution from mining, smelting, and industrial waste has increasingly contaminated freshwater areas, which creates a serious threat to ecosystems and especially to human health (Järup, 2003; Titilawo, Soneye, & Adeleke, 2018). Even the trace of low levels of toxic elements can be harmful for humans; for example, cadmium and lead are highly toxic at low concentrations and bioaccumulate over time in body tissues (Järup, 2003). Many heavy metals continue to pollute the environment and can enter the human body through water, food, or even through the skin, which can cause chronic effects such as cancer, organ failure, and even neurological impairment over a lifetime. (Toxicological profiles. 2025; WHO, 2011). These specific types of global concerns are urgent where large populations, such as in mindanao depend directly on rivers and lakes for drinking, cooking, bathing, and fishing (Xavier University - Ateneo de Cagayan, 2025).

This global problem occurs in developing countries, where safe water systems are very limited. Specifically, the World Health Organization reports that roughly two billion people worldwide lack safely managed drinking water, forcing many communities to rely on contaminated waters (WHO, 2011). These communities often face challenges of vulnerability and environmental unfairness; poor and marginalized groups are affected by water pollution because they only have a few options and limited resources (Liang, 2017; Mariano, 2019). In these settings, it shows that the increasing water contamination directly affects public health and environmental equity issues. Where clean water is scarce, and the community is forced to use contaminated water, which may be used for domestic needs, implying risks to adults and especially to children.

In the Philippines, river use is still widely practiced, especially in rural regions, despite the constant pollution. The Agusan River in

Caraga, within northeastern Mindanao, is a major example of a river that communities highly depend on for domestic uses such as household water, fishing, and even agriculture. Recent data in the lower Agusan River have reported increased levels of metals, including copper (Cu), nickel (Ni), total mercury (tHg), and chromium (Cr) (Cabuga et al., 2019). In fact, Cabuga et al. (2019) found that the secondary data of Cr, Ni, Cu, and tHg in the Agusan River failed international safety limits, showing potential areas of high contamination. These findings suggest potential health hazards, yet people continue to use the river for daily use, and no prior study has turned this data into a usable formal human health risk assessment, which people are in need of, to have an awareness and proof of the environmental equity and their vulnerability.

This study showcases an international standardized method for turning river contamination data into clear and usable human-health risk estimates, rather than just plain numerical data of the contamination. Utilized and applied in the Agusan River, this approach uses contamination data testing with a step-by-step way of estimating how people are exposed to contaminants and what areas of risk they might face over time. It provides results that are easy and usable to compare across different communities, making it easier to see where risks are higher compared to others. Because the method follows a clear and constant process, it can be used by researchers, government agencies, local groups, or even people to spot what areas are highly affected so they know where they might focus on monitoring, having clean-up efforts, or even health campaign programs. This study demonstrates how this method can be applied and utilized not just in one river but in many others, helping turn raw numerical contamination data into useful information. Making it

easier to use across different areas and more helpful for planning and developing solutions.

For this study, we focused on four specific heavy metals: tHg, Cu, Ni, and Cr. This was chosen due to their increased level of contamination and their effects. tHg, released primarily by gold mining, is a dangerous neurotoxin that accumulates in the human body when exposed. In the Agusan River, gold mining in the Diwalwal district is known to introduce high tHg. Downstream surveys found waterborne tHg up to 2900 µg/L and sediment tHg exceeding 20 mg/kg, which is far above EPA concern (Appleton et al., 1999). Copper, on the other hand, enters rivers from mining and industrial activities, though an essential nutrient, excess Cu can cause organ damage such as gastrointestinal and hepatic damage. While Ni exposure, from mining, stainless steel production, and industrial waste, remains a health concern that can trigger allergic contact, irritate the lungs and nasal passages, and is proven to be a potential carcinogen. Lastly, Cr is often spread by tanneries and metal processing plants; it is highly carcinogenic and can cause skin, respiratory, systemic, and organ damage. Each of these heavy metals is a concern in Mindanao: tHg from gold mining, Cu and Ni from mining and mineral activities, and Cr from industrial activities. The Agusan River, one of Mindanao's major water sources, plays a role in communities, agriculture, fisheries, and ecosystems, making the assessment of this heavy metal contamination needed for the public and the environmental health.

Despite the constant contamination, no prior paper has conducted a human health risk assessment for heavy metals in the Agusan River using international standard criteria, such as those from the U.S. EPA. Prior work (e.g., Cabuga et al., 2019) has documented sediment contamination of the Agusan River itself, but has not shown actual human exposures or risk metrics for people to use. This gap leaves unanswered questions about the potential health impacts on adults and especially the children. This study addresses this gap by applying a quantitative human-health risk assessment to existing sediment data, converting these measurements into usable information to determine the chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), and lifetime cancer risk (CR) to identify which specific areas can become a public health problem.

To evaluate these hazards, environmental health studies commonly use quantitative risk-assessment methods based on the international U.S. EPA criteria. These method determines exposure doses by relevant pathways of the human body by ingestion of water, dermal absorption through the skin, or inhalation of gases or particles. For each contaminant and pathway, the HQ is computed as the ratio of the exposure dose to a reference dose for that contaminant. The reference dose is a health-based threshold from the U.S. EPA, which estimates the daily intake that is unlikely to cause effects over a lifetime. If the HQ is less than 1, the non-cancer risk is considered negligible, but if it is higher than 1, there is a potential for hazardous effects. When multiple contaminants and pathways are involved, the HI, the sum of the individual HQ, provides if one is affected by the non-carcinogenic risk. For carcinogenic contaminants, one must get the CDI and multiply it by a cancer slope factor (CSF) to yield a gradual CR. The CSF from the U.S. EPA shows the probability of cancer per unit dose, allowing estimation of lifetime cancer risk from chronic exposure. These metrics form the international standard quantitative health-risk assessment for heavy metals in water (USEPA, 1989, 2011).

U.S. EPA risk equations, such as CDI, HQ, HI, and CR, are metrics that use contaminant concentrations in water (mg/L) because they estimate exposure through ingestion and contact with water (USEPA, 1989, 2011). But, due to the unavailability of data in the Agusan River, the data focused on sediments, reported in mg/kg, rather than from the water. Because of this, the sediment data could not be used in the standard U.S. EPA metrics. To address this, the sediment

concentrations were first converted into water concentrations using a mass to volume conversion based on an assumed sediment bulk density of 1.3 g·cm<sup>-3</sup> (Soil Survey Staff, 2024). While this conversion allows the application of the U.S. EPA risk assessment, the results of this study should be interpreted with caution, as they are based on converted data rather than direct measurements. For this reason, the findings are considered preliminary and are intended to provide an initial understanding of risks.

## METHODS

### Study Site

This study was derived from the data along the lower Agusan River, in northeastern Mindanao. The Agusan River is widely used as a resource for fisheries, transportation, agriculture, and domestic uses across Agusan del Sur, Agusan del Norte, and Butuan City. Despite its importance, the lower Agusan River is increasingly exposed to pollution from mining, smelting, and industrial activities. These conditions make the Agusan River an important site for assessing the potential human health risks caused by the heavy metals.

This study used the sediment concentration data reported by Cabuga et al. (2019) for three stations along the Agusan River, which are freshwater, brackish water, and marine water as a secondary data source; this study neither conducted nor replicated the sampling. The mean sediment values reported by Cabuga et al. (2019) were used as concentrations for our risk assessment and were converted from mg/kg (sediment) to water concentrations to estimate the contamination into human-health risk metrics (CDI, HQ, HI, and CR) without new sampling.

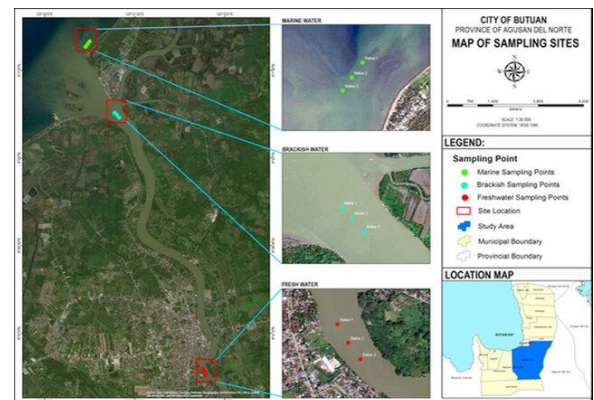


Figure 1. Location of Map Sampling Sites (Source: Cabuga et al. 2020)

Table 1. Sampling Sites in Agusan River during April-May 2018 (Cabuga et al. 2019)

Site Station	Station Identification	Geographical Coordinates
Fresh Water Station	Downstream of Brgy. Buhangin, Butuan City	8°56'16.3"N 125°32'46.9"E
Brackish Water Station	Brgy. Pagatpatan, Butuan City	9°00'34.1"N 125°31'12.5"E
Marine Water Station	Brgy. Dahekan, Magallanes, Agusan del Norte	9°02'04.5"N 125°30'49.9"E

The secondary data from Cabuga et al. (2019) was utilized because it has sampling stations that have different types of water sources, including freshwater, brackish water, and marine water. For each station, three samples were collected and averaged within the area, making the data more reliable and consistent. This allows the study to know how heavy metal contamination varies across these different conditions. The study applies these data to assess potential human health risks through ingestion and dermal exposure. Table 1 summarizes the sampling sites and their characteristics.

**Human Health Risk Assessment**

This study uses the U.S. EPA Human Health Risk Assessment (HHRA) process to evaluate the potential health effects from tHg, Cu, Ni, and Cr in the lower Agusan River. Following the standard U.S. EPA HHRA step-by-step process It starts with hazard identification, exposure assessment, and then risk characterization. The study estimates the CDI for two pathways, which are ingestion and dermal absorption, and two population groups, which are adults and children. Non-cancer risk is indicated by HQ and summed as HI. While the cancer risk is indicated by CR, which is estimated by multiplying CDI by the CSF. These results will identify stations and populations of greatest concern and provide a basis for which to monitor.

**Hazard Identification**

The first step of HHRA is to identify the hazardous contaminants and their adverse effects. In this study, we focus on four heavy metals, which are tHg, Cu, Ni, and Cr, and gathered data from Cabuga et al. (2019) in the lower Agusan River, which contained increased levels of these metals, with Cr and Cu being the highest concentrations. Heavy metals are constant environmental contaminants that can bioaccumulate and cause serious health problems. For example, exposure to tHg or Ni can have adverse effects on cellular functions and lead to poisoning. We therefore chose tHg, Cu, Ni, and Cr as the main contaminants in this study.

**Exposure Assessment**

The second step of HHRA is exposure assessment, which measures how much of each heavy metal people might ingest or absorb through the skin. We utilized two exposure pathways, which are oral ingestion and dermal absorption, and two life stages, which are children and adults. The water-equivalent contaminants were then used as the concentration in the CDI calculations for both ingestion and dermal pathways (Mariano, 2019).

**Table 2. The definition and value of exposure parameters (Liang et al., 2017; Titilawo et al., 2018; Mariano, 2019)**

Parameter	Definition	Adult	Children
C	Heavy metal concentration in water (mg/L)	—	—
IR	Ingestion rate of the water being studied (L/day)	2.5	0.78
ED	Exposure duration (years)	26	6
EF	Exposure frequency (days/year)	350	350
CF	unit conversion factor (L/cm <sup>3</sup> )	0.000001	0.000001
BW	Average body weight (kg)	80	15
AT	Average time (days)	25500	25500
AF	Skin adherence factor (mg/cm <sup>2</sup> )	0.07	0.2
SA	Exposed surface area of skin (cm <sup>2</sup> )	19652	6365
ABS	Dermal absorption factor	0.1	0.1
SF	Carcinogenicity slope factor (mg/kg/day) (Cu)		n/a
	Carcinogenicity slope factor (mg/kg/day) (Pb)	0.0085	
	Carcinogenicity slope factor (mg/kg/day) (Cd)	0.38	
	Carcinogenicity slope factor (mg/kg/day) (Cr)	0.5	
RfD	Chronic Oral reference dose (mg/kg/day) (Cu)		0.04
	Chronic Oral reference dose (mg/kg/day) (Pb)		0.0036
	Chronic Oral reference dose (mg/kg/day) (Cd)		0.001
	Chronic Oral reference dose (mg/kg/day) (Cr)		0.003
	Chronic dermal reference dose (mg/kg/day) (Cu)		0.012
	Chronic dermal reference dose (mg/kg/day) (Pb)		0.000525

$$\text{Note: } CDI_{\text{dermal}} = \frac{(C_w \times SA \times K_p \times ET \times EF \times ED \times CF)}{BW \times AT} \quad CDI_{\text{ingestion}} = \frac{(C_w \times IR \times EF \times ED)}{BW \times AT}$$

**Risk Characterization**

The third step of HHRA is risk characterization, which uses the CDI with parameters sourced from USEPA's Integrated Risk Information System (IRIS) to estimate the potential human health effects in non-cancer and cancer risk. In this study, two evaluations were used for each metal, pathway by ingestion and dermal, and population group by adults and children (USEPA, 1989; Titilawo et al., 2018).

For non-carcinogenic risk, it compares the estimated CDI of a contaminant with its Rfd. It is calculated as:  $HQ = CDI / Rfd$ . An  $HQ < 1$  indicates unlikely to cause non-cancer adverse effects. An  $HQ \geq 1$  suggests concerns and requires attention. When multiple contaminant exposure pathways are present, such as the four heavy metals chosen in this study, individual HQs are summed to provide an HI, which is indicated as the combined non-cancer risk from multiple contaminants being exposed to. The parameters are  $HI < 0.1$  (negligible), 0.1–1.0 (low), 1.0–4.0 (medium), and  $> 4.0$  (high), which are cited by Kamunda et al. (2016) and in Mariano (2019).

For Carcinogenic risk, we only chose Cr and Ni as the heavy metals due to their being carcinogens. The lifetime cancer risk is estimated by multiplying the lifetime CDI by the CSF:  $CR = CDI \times CSF$ .

The parameters for lifetime cancer risk are between  $1 \times 10^{-6}$  and  $1 \times 10^{-4}$  as an acceptable range. Values below  $1 \times 10^{-6}$  are considered negligible, and values above  $1 \times 10^{-4}$  are unacceptable (USEPA, 2011).

The overall methodological approach of this study, from the secondary data gathering to the HHRA process of potential health risks, is summarized in Figure 2 below.



**Figure 2. Flowchart of the overall methodological process for the Agusan River.**

**RESULTS AND DISCUSSION**

**Concentration of Heavy Metals in the Sediment**

The first step of HHRA is identifying the heavy metals that will be used in this study. The sediment heavy metal concentrations gathered from Cabuga et al. (2019) for the Lower Agusan River were used as the data for this study's risk assessment. These heavy metals Cu, Ni, Cr, tHg are in mean values at three different stations, including freshwater, brackish water, marine water, and were converted to water-equivalent values or mg/L by assuming a sediment bulk density of 1.3 g/cm<sup>3</sup>. These values are then compared below to the allowable limits established in DAO No. 2016-08 to assess their safety.

**Table 3. Heavy Metal Concentrations Converted to mg/L Assuming an Average Soil Bulk Density of 1.3 g/cm<sup>3</sup>**

Heavy Metal	Standard (mg/L)	Fresh Water mg/kg	Brackish Water mg/L	Marine Water mg/kg	mg/L		
Cu	0.02	56.22	73.086	60.78	79.014	35.78	46.514
Ni	0.2	43.22	56.186	48.67	63.271	88.78	115.414
Cr	0.01	77.56	100.828	76.67	99.671	98.33	127.829
tHg	0.002	0.21	0.273	0.77	0.1001	BDL	BDL

Note: \*BDL - Below Detection Limit

Based on Table 3, the findings reveal that the Cu, Ni, Cr, and tHg exceeded the limits set by the Department of Environment and Natural Resources (DENR, 2016). Cr and Ni show especially high concentrations at the marine station. On the other hand, tHg is

highest at the freshwater station and exceeds detection limits at the marine site. Copper is elevated across sites but shows a decline toward the marine station. These increased levels of heavy metals, show long term bioaccumulation of contaminants in aquatic organisms or the environment, and a constant risk of pollution into the water. This then increases exposure to nearby communities in Mindanao through both ingestion and dermal contact. Meaning there is inadequate and ineffective monitoring throughout the three stations, affecting both the ecosystem and human health.

**Health Risk Assessment**

**Chronic Daily Intake**

The second step of HHRA is calculating the daily intake a person might ingest or absorb. Starting with the calculated CDI via ingestion for Cu, Ni, Cr, and tHg that people might ingest throughout their lifetime, which are shown in Tables 4 and 5.

**Table 4. Heavy Metal Intake Through Ingestion (CDI ingestion) for Adults**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$8.0 \times 10^{-7}$	$9.0 \times 10^{-7}$	$5.0 \times 10^{-7}$
Ni	$6.0 \times 10^{-7}$	$7.0 \times 10^{-7}$	$1.3 \times 10^{-6}$
Cr	$1.1 \times 10^{-6}$	$1.1 \times 10^{-6}$	$1.4 \times 10^{-6}$
tHg	$3.0 \times 10^{-8}$	$1.0 \times 10^{-8}$	BDL

Note. BDL = Below detection limit.

**Table 5. Heavy Metal Intake Through Ingestion (CDI ingestion) for Children**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$3.0 \times 10^{-7}$	$3.0 \times 10^{-7}$	$2.0 \times 10^{-7}$
Ni	$2.0 \times 10^{-7}$	$3.0 \times 10^{-7}$	$5.0 \times 10^{-7}$
Cr	$4.0 \times 10^{-7}$	$4.0 \times 10^{-7}$	$5.0 \times 10^{-7}$
tHg	$1.0 \times 10^{-8}$	$4.0 \times 10^{-9}$	BDL

Note. BDL = Below detection limit.

For both adults and children, the highest ingestion CDIs are Ni and Cr, with the marine station indicating the highest values for these two metals. While for Cu is minor, and tHg ingestion is negligible given its small value. These ingestion CDIs remain below the U.S. EPA oral RFD for heavy metals, indicating that these ingestion values are unlikely to cause non-carcinogenic risk under the exposure parameters used. Even so, based on the data given, children are more vulnerable than adults because of their higher doses per body weight, so even low CDIs still need to be monitored closely.

**Table 6. Heavy Metal Intake Through Ingestion (CDI Dermal) for Adults**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$4.48 \times 10^{-4}$	$4.85 \times 10^{-4}$	$2.85 \times 10^{-4}$
Ni	$3.45 \times 10^{-4}$	$3.90 \times 10^{-4}$	$7.08 \times 10^{-4}$
Cr	$6.00 \times 10^{-4}$	$6.00 \times 10^{-4}$	$8.00 \times 10^{-4}$
tHg	$2.00 \times 10^{-6}$	$1.00 \times 10^{-6}$	BDL

Note. BDL = Below detection limit.

**Table 7. Heavy Metal Intake Through Ingestion (CDI Dermal) for Children**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$5.11 \times 10^{-4}$	$5.52 \times 10^{-4}$	$3.25 \times 10^{-4}$
Ni	$3.93 \times 10^{-4}$	$4.44 \times 10^{-4}$	$8.07 \times 10^{-4}$
Cr	$7.00 \times 10^{-4}$	$7.00 \times 10^{-4}$	$9.00 \times 10^{-4}$
tHg	$2.00 \times 10^{-6}$	$1.00 \times 10^{-6}$	BDL

Note. BDL = Below detection limit.

Next up are the Dermal CDIs, which are values that humans might absorb through their skin daily, and are larger values than the ingestion CDIs due to their larger exposed surface area (Exposure Assessment Tools by Routes - Dermal | US EPA, 2025). Tables 6 and 7 show that Ni and Cr again show the highest dermal CDIs, with it still being highest in the marine water station, while Cu shows moderate dermal CDIs, and tHg shows negligible due to its small value. When compared to the U.S. EPA dermal RFD, these values are below the study's parameters, but combined exposures and repeated contact, especially among children, still need to be investigated further and monitored.

**Hazard Quotient**

The third step of HHRA is getting the HQ, which gives data on

whether non-carcinogenic risk can be seen. Each HQ for each metal is measured as the ratio of its CDI to the U.S. EPA RfD. In other words,  $HQ = CDI/RfD$  (Mariano, 2019). By U.S. EPA Rfd, HQ values below 1 are unlikely to cause adverse effects, whereas  $HQ \geq 1$  indicates a potential health concern. We calculated HQs for Cu, Ni, Cr, and tHg for adults and children via ingestion and dermal absorption. These are shown in Tables 8-11.

**Table 8. Hazard Quotient for Adults via Ingestion Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$2.00 \times 10^{-5}$	$2.25 \times 10^{-5}$	$1.25 \times 10^{-5}$
Ni	$1.67 \times 10^{-4}$	$1.94 \times 10^{-4}$	$3.61 \times 10^{-4}$
Cr	$1.10 \times 10^{-8}$	$1.10 \times 10^{-8}$	$1.40 \times 10^{-8}$
tHg	$1.00 \times 10^{-5}$	$3.33 \times 10^{-5}$	BDL

Note. BDL = Below detection limit.

**Table 9. Hazard Quotient for Children via Ingestion Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$7.50 \times 10^{-6}$	$7.50 \times 10^{-6}$	$5.00 \times 10^{-6}$
Ni	$5.56 \times 10^{-5}$	$8.33 \times 10^{-5}$	$1.39 \times 10^{-4}$
Cr	$4.00 \times 10^{-9}$	$4.00 \times 10^{-9}$	$5.00 \times 10^{-9}$
tHg	$3.33 \times 10^{-6}$	$1.33 \times 10^{-5}$	BDL

Note. BDL = Below detection limit.

For both adults and children, all HQ ingestion values are very low, as shown in Tables 8-9. Ni is still producing the highest ingestion HQ, especially in the marine station, followed by Cu, but now in brackish water. Cr and tHg HQs are negligible as they are at such a very low value. Suggesting that all heavy metals are well below the HQs RFD, meaning that ingestion of river water for either group does not pose a significant hazard.

**Table 10. Hazard Quotient for Adult via Dermal Absorption Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$3.73 \times 10^{-3}$	$4.04 \times 10^{-3}$	$2.38 \times 10^{-3}$
Ni	$6.57 \times 10^{-2}$	$7.43 \times 10^{-2}$	$1.35 \times 10^{-1}$
Cr	0	0	0
tHg	$2.22 \times 10^{-4}$	$1.11 \times 10^{-4}$	BDL

Note. BDL = Below detection limit.

**Table 11. Hazard Quotient for Children via Dermal Absorption Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Cu	$4.26 \times 10^{-3}$	$4.60 \times 10^{-3}$	$2.71 \times 10^{-3}$
Ni	$7.49 \times 10^{-2}$	$8.46 \times 10^{-2}$	$1.54 \times 10^{-1}$
Cr	$7.00 \times 10^{-10}$	$7.00 \times 10^{-10}$	$9.00 \times 10^{-10}$
tHg	$2.22 \times 10^{-4}$	$1.11 \times 10^{-4}$	BDL

Note. BDL = Below detection limit.

For Dermal absorption, it shows a higher HQ than ingestion due to the surface area, shown in Tables 10-11 (Exposure Assessment Tools by Routes - Dermal | US EPA, 2025). For adults, Ni is still the highest, especially in the marine station, with Cu still being the second highest in brackish water. Cr and tHg are still extremely small values compared to the parameter given. For children, on the other hand, it's higher than that of the adults due to their greater skin surface area-to-body-weight ratio (Yun et al., 2022). Even so, children having a higher dermal HQ all calculated dermal HQs for both age groups and both pathways are much less than 1.0, indicating that non-carcinogenic risks are currently low and negligible by the U.S EPA guidance, which are unlikely to cause adverse effects.

**Hazard Index**

The third step of HHRA also includes HI, the combined HQ to show that people affected aren't just absorbing or ingesting one contaminant, but multiple contaminants. Table 12 below shows the measured HI values for the Agusan River at the three sampling stations in freshwater, brackish water, and marine water, and two exposure pathways. By their parameters, an  $HI \leq 1$  is considered an acceptable value, whereas an  $HI > 1$  indicates a potential concern.

**Table 12. Hazard Index for Ingestion and Dermal Absorption across all Age Groups**

Heavy metal	Freshwater	Brackish water	Marine water
Adult via Ingestion	$2.60 \times 10^{-6}$	$2.70 \times 10^{-6}$	$3.20 \times 10^{-6}$
Children via Ingestion	$1.00 \times 10^{-6}$	$1.00 \times 10^{-6}$	$1.20 \times 10^{-6}$
Adult via Dermal Absorption	$3.56 \times 10^{-6}$	$3.74 \times 10^{-6}$	$4.47 \times 10^{-6}$
Children via Dermal Absorption	$7.93 \times 10^{-2}$	$8.93 \times 10^{-2}$	$1.56 \times 10^{-1}$

For ingestion, it can be seen having HI for both adults and children in extremely low values. Being the largest ingestion, HI is only 0.00037 in adults in the marine water. This means all of the ingestion is well below 1, which indicates a negligible non-carcinogenic risk. While dermal exposure shows higher HI values than ingestion, it is still all well below 1. Being the highest dermal HI is 0.156 for a child at the marine water, so according to the U.S. EPA, it still remains a negligible non-carcinogenic risk. Having both negligible, which does not pose a significant health risk.

### Cancer Risk

The third last step of HHRA is CR, which estimates the risk of developing cancer from a lifetime exposure to carcinogens. The study estimated the CR for Ni and Cr by the international standard U.S. EPA slope factors (Mariano, 2019). According to the U.S. EPA, risks below 0.000001 are considered negligible, and values above 0.0001 are unacceptable (TCEQ, 2024).

**Table 13. Cancer Risk for Adult via Ingestion Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Ni	$5.00 \times 10^{-9}$	$6.00 \times 10^{-9}$	$1.10 \times 10^{-8}$
Cr	$1.00 \times 10^{-8}$	$9.00 \times 10^{-9}$	$1.20 \times 10^{-8}$

**Table 14. Cancer Risk for Children via Ingestion Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Ni	$2.00 \times 10^{-9}$	$2.00 \times 10^{-9}$	$4.00 \times 10^{-9}$
Cr	$4.00 \times 10^{-9}$	$4.00 \times 10^{-9}$	$5.00 \times 10^{-9}$

**Table 15. Cancer Risk for Adult via Dermal Absorption Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Ni	$2.93 \times 10^{-7}$	$3.31 \times 10^{-7}$	$6.02 \times 10^{-7}$
Cr	$5.26 \times 10^{-7}$	$5.20 \times 10^{-7}$	$6.67 \times 10^{-7}$

**Table 16. Cancer Risk for Children via Dermal Absorption Pathway**

Heavy metal	Freshwater	Brackish water	Marine water
Ni	$3.338 \times 10^{-7}$	$3.774 \times 10^{-7}$	$6.856 \times 10^{-7}$
Cr	$5.99 \times 10^{-7}$	$5.92 \times 10^{-7}$	$7.59 \times 10^{-7}$

The findings indicate that Cr has a higher carcinogenic risk than Ni in the Agusan River, especially through dermal exposure. Being the highest values are in the marine water station and peaked at 0.000000759 in children; even so, these values are still well below the indicated limits by the Rfd, which is 0.0001. Meaning these values do not indicate a carcinogenic risk and are negligible.

The findings and results of the HHRA indicate that during the Hazard Identification part, it was seen that the heavy metal concentration exceeded the standards established in DAO No. 2016-08, even so the next part, which is the exposure assessment and risk characterization showed that the CDI, HQ, HI, and CR values are well below the established parameters by the U.S. EPA meaning that it does not pose either non-carcinogenic health risk or carcinogenic health risk. Despite these findings, the data itself also showed specific areas that need to be monitored, as the highest concentrations of heavy metals were located mostly at the marine water station, and it was also found that children were found to be more vulnerable to exposure, given the higher values compared to the adults. Among the contaminants in this study, Ni and Cu showed the highest non-carcinogenic values, while Cr had the highest carcinogenic risk. Given the constant pollution of these heavy metals and the probability of them bioaccumulating,

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these values still need to be monitored to prevent long term issues in the future.

## CONCLUSIONS

This study utilized and applied the HHRA of heavy metals by the U.S. EPA guidance. Specifically, Cu, Ni, THg, and Cr in the Agusan River, utilizing secondary data from Cabuga et al. (2019). The process focused on two exposure pathways, which are ingestion and dermal absorption, for both non-carcinogenic risk and carcinogenic risk for adults and children. During the hazard identification part, it was shown that heavy metals exceeded the standards established in DAO No. 2016-08. Even so, the next parts, exposure assessment and risk characterization shows that CDI, HQ, HI, and CR are well below the parameters by the U.S. EPA guidance. Meaning it does not pose a significant risk for both non-carcinogenic risk and carcinogenic risk. The study itself showed that among the metals studied, Ni and Cu had the highest values for non-carcinogenic risk, while CR had the highest potential for carcinogenic risk. The data also showed that the highest concentrations of heavy metals are largely located at the marine water station, and that children had higher vulnerability to these contaminants than adults themselves.

From the secondary data that we used, this study showcases an internationally standardized method for turning raw river contamination data into something clear, usable human-health risk assessment. By utilizing and applying a step-by-step process to evaluate the exposure given and identify what specific risk areas need to be monitored, it provides well-readable and easily compared results to different communities. Meaning that this study not only identifies the important parts that need to be evaluated and what areas need to be improved, but also, because this method follows a constant and easy process, it can serve as an important tool for researchers, government, and local groups. It has been shown that using standardized guidelines can be applied not only to the Agusan River, but also to many other river systems that need to be assessed to turn those raw numerical data into useful information to be used whether to find what areas need to be monitored or what needs to be improved more. While the current risks showed low probability to pose a significant risk, it is still necessary to be monitored because these heavy metals have the potential to bioaccumulate, so continued safety and development of solutions are recommended.

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## DEVELOPMENT OF AN ARDUINO-BASED PROTOTYPE FOR REAL-TIME MONITORING AND EARLY DETECTION OF PASTEURIZED MILK SPOILAGE

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### ABSTRACT

Milk spoils easily due to changes caused by bacteria, making early detection important for safety and for reducing waste. This study developed an Arduino-based prototype that monitors pasteurized milk in real time using a pH sensor and a temperature sensor. The system was tested on five milk samples with different storage conditions over a 48-hour period. Calibration results showed that the pH sensor produced stable and accurate readings. During testing, pH levels dropped as spoilage increased, while temperature helped show how storage conditions affected the speed of spoilage. The prototype correctly identified fresh, spoiling, and spoiled samples in most trials, reaching an accuracy of 92%. These findings show that the device can serve as a low-cost and practical tool for everyday use. It offers a simple way to check milk quality, promote food safety, and prevent unnecessary waste at home or in small stores.

**Keywords:** milk spoilage detection, Arduino system, pH sensor, temperature monitoring, food safety

### INTRODUCTION

#### Background of the Study

Milk is one of the most widely consumed beverages globally due to its high nutritional value. However, it tends to spoil easily due to microbial contamination. The shelf life of pasteurized milk is measured between 12 to 14 days under cold conditions, but it differs with warm temperatures. Once the milk is stored under 32 °C for an hour, it is recommended to dispose of the milk as it would pose a silent risk in households and businesses (Dairy Food Safety, n.d.).

These contaminations may pose health risks and economic losses, especially when spoilage is not monitored and detected early. Improper storage or exposure to inconsistent temperatures are possible causes to accelerate milk spoilage. Spoiled milk shows changes in temperature, pH level, and gas concentration, which serve as indicators of microbial activity. Monitoring the parameters through sensor-based systems enables early detection of spoilage.

Many consumers still rely on smell, taste, or expiration dates to check if milk is spoiled. Some also look for changes in color or texture. However, these signs usually appear when spoilage has already progressed. Because of this, early detection is important to prevent foodborne illness and reduce food waste (Davis, 2025). Without reliable tools, households and small vendors may throw away safe milk too early or fail to detect spoiled milk in time.

Without reliable tools, households and vendors face difficulties in making accurate judgments, which leads to early disposal of safe milk or delayed detection of spoiled milk that poses health risks.

Existing studies have shown that sensors and IoT technologies can aid in monitoring food quality, providing faster and more reliable results. These innovations have emerged as a response to the fast-paced movement of globalization, as individuals become more aware

of food distribution, including its composition and the food waste, along with its spoilage.

Additionally, adding this feature is intended to prolong shelf life and detect spoilage in real time, especially with handling dairy products for everyday and commercial consumption (Weston et al., 2021).

Arduino provides a low-cost platform that can integrate sensors to detect changes in temperature and pH, making it suitable for real-time milk monitoring. As a microcontroller, it serves as the central unit that collects, processes, and interprets data from multiple sensors.

Although there are promising innovations with sensors and IoT for food quality monitoring, the lack of action and specification on milk spoilage detection is what keeps these innovations from staying only as a prototype. Mainly, many innovations focus only on fruit and vegetable detection, not extending to goods that are used in daily life.

Additionally, the affordability of the detector is also being measured, which is the most common factor that researchers must consider, keeping in mind that this development is targeted for a household and commercial setup. Furthermore, considering the systems used to develop these prototypes are deemed as hard to navigate, which is not a good indicator for an easy-to-use detector for early detection of milk spoilage in dairy distribution.

This study aims to develop an Arduino-based smart prototype that can monitor milk in real time, detect early signs of spoilage, while integrating sensors such as pH level for the substance's liquid solution, and a temperature—DS18B20 sensor, considering the conditions in which the milk was stored. These sensors are developed to help ensure food safety while reducing waste, as this step is not only for the benefit of the technology but also for the environment in which we live.

## Objectives of the Study

The study aims to design, develop, and evaluate an Arduino-based smart prototype capable of detecting pasteurized milk spoilage in real time through the monitoring of pH and temperature. Specifically, it seeks to: (1) Develop a fully functional prototype by integrating the Arduino microcontroller with a pH sensor and a DS18B20 temperature sensor to monitor milk quality under different storage conditions. (2) Evaluate the performance, accuracy, and compatibility of the pH and temperature sensors—individually and when operating simultaneously—in detecting spoilage indicators in pasteurized milk. (3) Assess the prototype's reliability in classifying milk into three spoilage statuses (fresh, spoiling, and spoiled) based on real-time sensor data, and determine its overall accuracy across multiple testing intervals. (4) Analyze the relationship between pH changes, temperature exposure, and the observed spoilage progression to validate the effectiveness of the prototype for practical household and commercial use.

## Literature Review

### Milk Spoilage and Quality Assessment

Temperature control is a must to maintain the quality of the milk, and it also helps indicate the conditions of which and how the milk was spoiled. From that, a study from Dairy Food Safety (n.d), tackled that pasteurized milk will only last for about 12 to 14 days under cold conditions, roughly 4 °C or lower. However, milk that is stored in storage with 32 °C conditions for an hour can pose threats and risks in terms of health. (Undeniably Dairy, n.d.).

Milk nutrients are also prone to contamination, where aflatoxins and heavy metals pose significant health risks. Existing laboratory techniques for detection are accurate, they are often slow, costly, and require skilled personnel. Hence the potential use of nanotechnology to enable faster, portable, and more efficient methods for milk quality assessment (Darwesh et al., 2025).

pH-based methods are widely used in detecting food spoilage. For instance, Silva et al. (2022) propose that a pH-based colorimetric assay can serve as an indicator of microbial load in milk by correlating pH deviations with bacterial presence, while Jaganiyash et al. (2020), the correlation among pH, acidity, volatile organic compounds (VOCs), temperature, and humidity in raw cow milk during storage reveals their potential as indicators of spoilage.

Recent studies also highlight the existence of bacteria in milk even in cold storage. According to Ahmed et al. (2024), *Pseudomonas fluorescens* also thrive even under chilled temperatures. In addition, findings from Lan et al. (2025) found bacterial growth, dominated by *Streptococcus* and *Acinetobacter*, increasing after day 13 of cold storage.

Furthermore, Hashim et al. (2022) reported that milk spoilage can be detected through pH, sensory changes, image analysis, and machine learning methods. Correspondingly, Mao (2025) highlights the shift to smart and automated methods. Mao (2025) emphasizes microbial contamination, poor temperature control, such as inadequate cooling, and defects in packaging as the primary causes of milk spoilage.

These causes may pose health risks and threats, from acute gastrointestinal issues to chronic effects such as immune dysfunction and toxin exposure.

Recent studies identified pH, temperature, and VOCs as key indicators of milk spoilage (Silva et al., 2022; Jaganiyash et al., 2020; Hashim et al., 2022). Microbial activity also occurred during milk spoilage, which was further confirmed by Ahmed et al. (2024) and Lan et al. (2025), who observed bacterial growth in milk even under chilled storage.

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To address these challenges, Mao (2025) and Hashim et al. (2022) emphasized smart containers and automated detection for better food safety. Supporting this, Arduino-based systems (Deen et al., 2023; Sari et al., 2024) demonstrate real-time monitoring of food spoilage, proposing practical and low-cost solutions for milk spoilage detection.

### Sensor Technologies for Food Quality Monitoring

Jayan et al. (2023) highlighted that gas sensors can detect spoilage gases such as ammonia and volatile organic compounds (VOCs) in real time, enabling rapid assessment of milk freshness. Building on this, Mani et al. (2025) emphasized the use of gas and pH sensors in intelligent packaging systems to continuously monitor spoilage gases and acidity changes.

Both studies underscore the importance of real-time monitoring for food safety, though challenges such as sensor drift, calibration difficulties, and performance under varying storage conditions remain, suggesting the need for further technical improvements.

Recognizing these limitations, researchers have explored more complex electronic sensing systems. Gil et al. (2025) discussed e-nose, e-tongue, and e-eye technologies, noting that combining them, for example, by integrating e-nose with e-tongue or e-eye, enhances the accuracy of food quality assessments. Yet, this approach introduces challenges, including complex data processing, sensor fusion issues, and sensitivity to environmental changes.

In contrast, studies by Jayan et al. (2023) and Mani et al. (2025) focused on individual spoilage indicators, highlighting the spectrum between specialized and multi-sensor approaches.

To make monitoring more practical and affordable, microcontroller-based systems have been developed. Deen et al. (2023) created an Arduino-based system to detect spoilage in bananas, apples, tomatoes, milk, and curry, showing that milk freshness could be assessed through changes in odor and acidity. Similarly, Mohammed et al. (2018) developed a pH sensor prototype using Arduino to monitor meat spoilage under different temperatures.

Expanding this concept, Sari et al. (2024) introduced a multi-parameter Arduino Mega system for milk, addressing global dairy waste, although it remains limited to basic milk types.

Despite these technological advances, the wide adoption of food sensors remains limited. Weston et al. (2021) noted that most sensors still target single parameters like temperature, humidity, gases, or pH, which restricts their comprehensiveness. This observation aligns with Jayan et al. (2023) and Mani et al. (2025), where targeting specific spoilage factors was effective but limited in scope.

Meanwhile, Gil et al. (2025) and Sari et al. (2024) demonstrate that integrating multiple sensors improves both accuracy and versatility, suggesting that the future of food monitoring lies in multi-parameter systems capable of adapting to diverse conditions.

Several studies have developed smart food monitoring systems using sensors and microcontrollers. For example, Deen et al. (2023) created an Arduino-based system that detects spoilage in fruits, vegetables, and milk by measuring odor and acidity. Sari et al. (2024) developed a multi-parameter monitoring system for dairy products. While these systems show promising results, many focus on multiple food types or involve complex sensor combinations. These observations highlight the need for a simpler and more focused monitoring system designed specifically for pasteurized milk.

### Microcontroller-Based Smart Packaging for Food Safety

Mkhari et al. (2025) examined the rapid development of intelligent packaging systems, highlighting sensors, indicators, and RFID

technology for improved food preservation. They also emphasized nanotechnology, showing that nanoscale materials strengthen packaging and reduce environmental impact, allowing it to protect food and extend freshness, especially for perishable products like milk.

Palanisamy et al. (2024) expanded these technologies with Automatic Identification and Data Collection systems that monitor temperature, pH, gases, and microbial activity to assess freshness. They explored time-temperature indicators, pH-sensitive films, and gas sensors for carbon dioxide and ammonia, which detect spoilage through color changes or optical responses. Combined with microcontrollers, these technologies enable real-time monitoring.

Building on these ideas, Neelima et al. (2025) studied sensor-based systems tracking temperature, humidity, light, and gas levels to detect early spoilage. They tested MQ3 gas sensors for ethanol and methane, integrated with an Arduino platform that displayed results on an LCD and sent mobile notifications. The system works well, but needs adjustment for different foods, as each produces unique spoilage compounds.

Garg et al. (2023) applied a similar Arduino-based approach using MQ3 sensors to detect methane, adding a Wi-Fi module for app monitoring and results on a 16x2 LCD. Unlike Neelima et al., they relied only on MQ3 sensors and suggested adding temperature, pressure, and moisture sensors for better accuracy. These studies show that Arduino systems are reliable for spoilage detection but perform best with diverse sensors and food-specific designs.

Overall, Mkhari et al. (2025) and Palanisamy et al. (2024) focused on material innovations and diverse sensors, while Neelima et al. (2025) and Garg et al. (2023) emphasized microcontroller-based gas detection. All highlight combining multiple technologies to enhance intelligent packaging reliability.

Future research should develop food-specific systems, particularly for milk, monitoring pH, ammonia, and volatile compounds. Microcontroller-based designs targeting these factors can improve safety, extend shelf life, and reduce waste while maintaining quality.

**Research Framework**

**Theoretical framework**

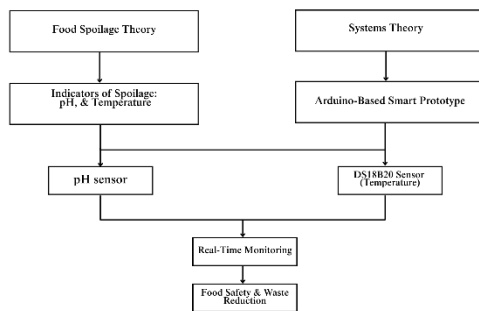


Figure 1. Theoretical Framework

This study is anchored by two main theoretical foundations: Food Spoilage Theory and Systems Theory. Food Spoilage Theory, introduced by Louis Pasteur, explains that microorganisms cause milk spoilage by breaking down proteins and lactose, producing compounds such as ammonia (NH<sub>3</sub>), carbon dioxide (CO<sub>2</sub>), and acids that lower pH. These changes justify the use of sensors like pH and DS18B20 (temperature) for monitoring spoilage.

Meanwhile, Systems Theory by Ludwig von Bertalanffy (1968)

views the Arduino-based smart prototype as a system with inputs (milk samples), processes (sensor readings and data interpretation), and outputs (real-time spoilage detection). Together, these theories strengthen the foundation of developing a smart prototype for early and reliable milk spoilage monitoring.

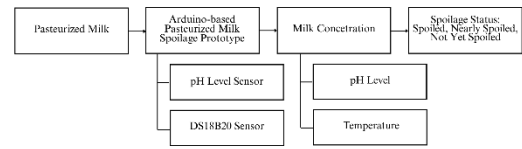


Figure 2. Conceptual Framework

This conceptual framework illustrates how sensor readings from DS18B20 (temperature sensor), and a pH sensor contribute in determining the spoilage status of pasteurized milk. These readings are processed by an Arduino-based smart prototype, which interprets the data to assess the freshness and spoilage of pasteurized milk. Storage conditions may influence the accuracy of the assessment.

Pasteurized milk serves as the subject being monitored, which provides a basis for sensor readings and spoilage assessment through Arduino-based milk prototype for spoilage monitoring.

**Scope and Limitations**

The study will focus on the development and testing of an Arduino-based prototype designed to detect spoilage in milk. The system will integrate two main sensors: a pH sensor (to monitor changes in acidity), and the DS18B20 temperature sensor (to measure ambient storage temperature). These sensors will work together to track critical parameters such as pH level, and temperature that indicate milk spoilage.

The scope of the study is limited to pasteurized milk-based beverages and does not extend to raw milk, flavored milk products, or other types of food and beverages.

The prototype will be tested under practical storage conditions, particularly room temperature environments. Some samples will initially be refrigerated before testing to observe how temperature changes affect spoilage. However, the study will not test other environmental factors such as humidity, direct sunlight, or different storage containers. However, certain limitations may affect its performance. The system will not account for all external factors that may influence milk spoilage, such as varying humidity, light exposure, or handling practices.

In addition, the sensors used may have limitations related to calibration and accuracy. The results of this study are therefore confined to monitoring selected indicators and may not represent all possible variables influencing milk quality.

**METHODOLOGY**

**Research Design**

This study used an experimental-developmental research design, which combined creating a prototype and evaluating its performance.

The developmental part focused on designing and building an Arduino-based smart container with pH and temperature sensors to detect milk spoilage signs and the milk's status. This included setting up the sensors, calibrating them, and ensuring the prototype functioned properly.

The experimental part involved testing the prototype on different pasteurized milk samples over time. The data collected from the sensors was analyzed to evaluate how accurately and effectively the prototype could detect milk spoilage. The results helped determine the potential of using the prototype for monitoring milk in household or commercial settings.

### Materials

The materials used in the development of the prototype include the following: (1) Arduino Nano ATmega328P microcontroller. (2) PH-4502C liquid pH sensor with E201-BNC electrode. (3) DS18B20 waterproof digital temperature sensor. (4) 16×2 LCD display with I2C interface. (5) Jumper wires. (6) Breadboard. (7) Light-emitting diodes (LEDs).

### Methodological Framework

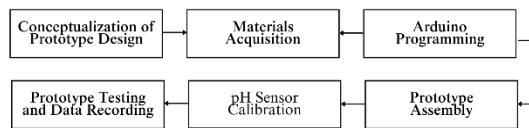


Figure 3. Methodological Framework

The development of the Arduino-based smart prototype involved the conceptualization and design of the system, followed by the acquisition of the necessary materials. The Arduino was programmed to process and display readings from the integrated sensors, specifically the pH sensor and DS18B20 temperature sensor, which were essential for detecting milk spoilage.

After assembling the sensors and components, the pH sensor was calibrated using standard buffer solutions to ensure accurate and precise measurements, with the calibration results integrated into the Arduino code.

The prototype was then tested using pasteurized milk samples, with multiple measurements taken to ensure accuracy and reliability, confirming the system's capability for real-time monitoring and early detection of milk spoilage.

### Parameters

This study focused on detecting spoilage in pasteurized milk by monitoring two key parameters. The parameters tested include pH level and temperature.

A pH sensor monitors acidity, as fresh pasteurized milk typically has a  $\text{pH} \geq 6.5$  (Fox & McSweeney, 2015; Rosca et al., 2019), which decreases as bacterial activity produces lactic acid (Parveen et al., 2023). Milk with a pH of 6.0–6.4 is considered to be in the early stages of spoilage, while a  $\text{pH} \leq 6.0$  indicates that the milk is definitively spoiled.

The DS18B20 digital temperature sensor monitors storage conditions. Milk stored at  $\leq 7^\circ\text{C}$  is considered within the safe zone and represents the optimal storage condition (Fröhlich et al., 2017). Temperatures between  $7.1\text{--}15^\circ\text{C}$  fall within a moderate-risk zone, where microbial growth accelerates and spoilage may occur more quickly. Exposure above  $15^\circ\text{C}$  constitutes a high-risk zone, significantly promoting bacterial proliferation and increasing the likelihood of spoilage (Cornell Dairy Extension, 2023; Fröhlich et al., 2017).

Both sensors were interfaced with an Arduino microcontroller, which continuously processed the data for real-time monitoring. Changes in pH or temperature were detected immediately, and the system provided instant alerts through a display when thresholds were

exceeded. Unlike traditional sensory inspection or laboratory testing, this setup enabled continuous, automated monitoring, allowing early detection of spoilage, reducing health risks, and minimizing milk wastage.

### Schematic Diagram

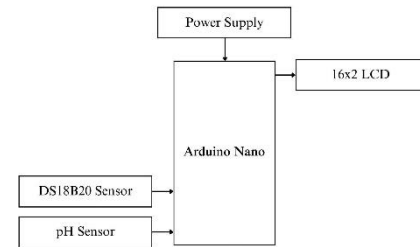


Figure 4. Schematic Diagram

The diagram illustrates the framework of the prototype device. Arduino Nano served as the main microcontroller responsible for receiving, processing, and transmitting data.

The pH sensor and DS18B20 temperature sensor were connected to the Arduino Nano as primary input devices. They collected data on milk acidity and temperature, which functioned as key indicators of spoilage. The collected data were transmitted to the Arduino Nano, where they were processed and compared against predefined spoilage thresholds.

The processed readings were displayed on a 16×2 LCD with an I2C interface, providing real-time information on milk quality. Additionally, an LED was integrated to serve as a visual alert, indicating when the milk exceeded the spoilage thresholds or when specific status changes occurred.

### Arduino Programming

The Arduino microcontroller was programmed using the Arduino IDE to control the sensors and process real-time data from the system. The program continuously reads values from the pH sensor and DS18B20 temperature sensor, comparing them against predetermined threshold values for spoilage detection. A decision-making algorithm filtered out noise using moving averages and triggered alerts when readings indicated potential spoilage.

Live sensor readings and status alerts were displayed on a 16×2 LCD with an I2C interface, providing users with real-time monitoring information. LED indicators were also used to signal milk spoilage status: red indicated spoiled milk, yellow signified nearly spoiling milk, and green represented fresh milk. The LCD was programmed to cycle through multiple pages to enhance clarity and user guidance. The pH Level page displayed the current pH reading, while the Spoilage Status page indicated the milk's condition based on pH, showing "Safe to Drink!" for fresh milk, "Nearly Spoiled" for spoiling milk, and "Do Not Drink!" for spoiled milk. The Temperature page presented temperature readings only when the milk was fresh or nearly spoiling, while the Temperature Risk page identified whether the milk was in a "High Risk/Risk Zone" with the reminder "Keep in Cool Area," or in a "Safe Zone" with the reminder "Stay in Cool Area." This programming enabled automatic and continuous monitoring of pasteurized milk, delivering real-time indicators of spoilage and storage conditions without requiring manual intervention.

### Implementation and Device Testing

The prototype was systematically assembled, beginning with the proper wiring of components to the Arduino Nano using jumper wires. The pH sensor was connected to an analog pin, while the DS18B20 temperature sensor was attached to a digital pin with a

pull-up resistor to ensure stable readings. To optimize pin usage, the 16x2 LCD with I2C interface was integrated using jumper wires to display real-time data.

After assembly, the program was uploaded to the Arduino using the Arduino IDE, enabling the system to read and process sensor data and display processed information on the LCD.

### Sensor Calibration

Before testing, the pH sensor was calibrated using standard pH buffer solutions of 4.01 and 6.86. For each buffer, 20 readings were taken to calculate the slope and intercept, which were then integrated into the Arduino code to ensure accurate pH measurements throughout testing.

### Trial Runs

Following calibration, initial trial runs were conducted to verify the functionality of all components. This included assessing sensor responsiveness, confirming the accuracy of displayed readings, and observing the LED indicators for spoilage status—green for fresh, yellow for nearly spoiling, and red for spoiled. Necessary adjustments, particularly in the code, were made to ensure smooth communication between hardware and software components. By the end of this phase, a functional prototype was established, capable of monitoring milk quality indicators in real time.

### Device Testing

Five milk samples were used to evaluate the prototype under varying conditions, with each sample tested five times at 12-hour intervals over a 48-hour period. The samples were selected to represent different storage histories and stages of spoilage, allowing the researchers to observe how the prototype responded to fresh, early spoiling, and fully spoiled milk. Repeating the measurements five times per sample helped improve data reliability while keeping the procedure manageable within the available time and resources. Specifically, Sample 1 consisted of freshly purchased milk maintained at room temperature throughout the testing period. Sample 2 was purchased two days prior and initially stored under refrigeration, then kept at room temperature after the first test. Sample 3 was also purchased two days prior but initially stored without refrigeration before being maintained at room temperature after the first test. Sample 4 was purchased seven days prior and initially refrigerated, then transferred to room temperature after the first test. Lastly, Sample 5 was purchased two weeks prior, initially stored unchilled, and subsequently kept at room temperature after the first test.

During testing, the sensors continuously monitored pH and temperature in real time. Data were collected for each interval, allowing trends in spoilage progression to be analyzed across samples and storage conditions. The combination of pH readings, temperature trends, and LED indicators provided a comprehensive assessment of milk quality, enabling evaluation of the prototype's accuracy, reliability, and responsiveness in detecting spoilage. This approach highlighted the system's potential for practical, real-time monitoring while identifying areas for further refinement.

### Accuracy and Effectiveness Testing

The accuracy and effectiveness of the smart milk spoilage detection system were evaluated through sensor calibration, status classification, and measurement consistency.

### pH Calibration

The pH sensor generates analog readings that vary according to milk acidity. Calibration was performed using standard buffer solutions with known pH values (e.g., pH 4.0, 7.0, and 9.0). A linear regression approach was applied using the slope-intercept formula:  $y = m x + b$ . Where  $y$  is the actual pH value,  $x$  is the raw analog reading,  $m$  is the

slope, and  $b$  is the intercept. The slope and intercept were calculated using:

$$m = \frac{6.86 - 4.01}{\text{Ave.Analog}8.86 - \text{Ave.Analog}4.01} \text{ or}$$

$$m = \frac{4.01 - 6.86}{\text{Ave.Analog}4.01 - \text{Ave.Analog}6.86}$$

and  $b = 4.01 - m(\text{Ave. Analog}4.01)$  or  
 $b = 6.86 - m(\text{Ave. Analog}6.86)$ ,

where average analogs are calibration points from the standard buffers. The resulting equation converts raw sensor readings into accurate pH values.

### pH Status Classification and Effectiveness

The calibrated pH readings were classified into three categories: (1) FRESH:  $\text{pH} \geq 6.5$  (2) SPOILING:  $6.0 \leq \text{pH} < 6.5$  (3) SPOILED:  $\text{pH} < 6.0$

The system's effectiveness was evaluated by comparing its classification against observed status. Effectiveness was calculated as:  $\text{Effectiveness \%} = \frac{\text{number of Aligned Classified Sample Test}}{\text{Total Number of Trail Runs}} * 100$

### Measurement Consistency

To assess precision, repeated pH measurements for each milk sample were used to calculate the mean and standard deviation (SD):

$$\text{Mean } (x) = \frac{\sum_i x}{n} \text{ and SD} = \sqrt{\frac{\sum(x_i - x)^2}{n-1}}$$

where  $x_i$  represents individual readings and  $n$  is the number of measurements per sample. This ensured that the sensor provided reliable and consistent readings.

### Compatibility Testing

Compatibility testing focused on ensuring that all system components worked together seamlessly. The pH sensor was integrated with the Arduino microcontroller, LEDs, and LCD display. Integration tests then verified that pH readings triggered the correct status messages and LED indicators in real-time. Lastly, continuous operation was observed to ensure proper synchronization between data acquisition, processing, and display outputs.

### Ethical Considerations

Safety, integrity, and responsible conduct were prioritized throughout the development and testing of the Arduino-based prototype. Pasteurized milk samples were used solely for experimental purposes and were handled carefully to avoid any health risks, while spoiled milk was properly disposed of to prevent contamination and environmental impact.

During validation and testing, the researchers followed established laboratory safety protocols described in published procedures to ensure proper handling of samples, sensors, and equipment. All electronic components—such as the Arduino board, pH sensor, and temperature sensor—were assembled and tested using appropriate safety practices to minimize risks including overheating, short circuits, or electrical faults.

Data collected from the sensors were recorded truthfully, processed accurately, and reported without fabrication or manipulation. Environmental responsibility was also observed by minimizing electronic waste, reusing components when possible, and selecting safe, non-toxic, and durable materials for the prototype housing.

The prototype is not intended to replace official laboratory-based food safety evaluations but rather to demonstrate a practical method for supporting safe monitoring practices through early detection of spoilage. By upholding honesty, safety, and adherence to recognized

research guidelines, the study maintains credibility and contributes meaningfully to scientific and educational development.

## RESULTS AND DISCUSSION

This section presents the results of the calibration process, spoilage monitoring, accuracy evaluation, and classification performance of the Arduino-based milk spoilage detection prototype. The findings show how the system responded to changes in pH and temperature and how these measurements contributed to determining milk freshness across different samples.

### Calibration Results

Calibration ensured that the pH sensor produced accurate and stable readings before it was used to detect milk spoilage. Two buffer solutions with known pH values of 6.86 and 4.01 were tested twenty times each to examine the sensor's consistency.

The sensor showed excellent stability in both buffer tests. For the pH 6.86 buffer, readings across twenty trials varied very little, with a standard deviation of 0.0173, indicating that measurements were consistently close to the expected value. This demonstrates the sensor's reliability for mid-range pH levels, which is important for assessing fresh milk. The pH 4.01 buffer also produced highly consistent readings, with an even lower standard deviation of 0.0139, showing that the sensor remained accurate in acidic conditions—critical for detecting spoiled milk. In both cases, the measured pH values closely matched the true buffer pH.

The calibration results demonstrated a correct linear relationship between the sensor's analog output and pH level. The calculated slope of  $-0.00948$  indicates that the analog reading decreased as acidity increased, while the intercept of 14.684 was consistent across both buffers, confirming a proper calibration curve. These values were implemented in the Arduino code to accurately convert analog readings into pH measurements during testing.

### Monitoring of Milk Samples Over 48 Hours

Five different milk samples were observed for 48 hours at 12-hour intervals. Their storage history varied, which allowed the prototype to be evaluated under different spoilage conditions. Each sample was checked for pH, observed status, and the prototype's verdict.

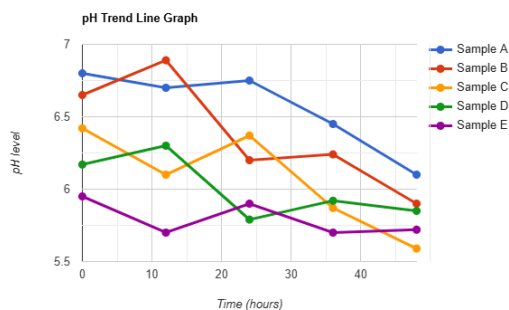


Figure 5. Trend of pH Readings During the 48-Hour Monitoring Period

The pH readings show a consistent downward trend across all milk samples throughout the 48-hour monitoring period. Fresh samples started with higher pH values and gradually decreased as spoilage progressed, while sample C showed an earlier and sharper drop, indicating faster deterioration. Samples D and E remained in the lower pH range from the start, confirming their spoiled or spoiling condition. Overall, the pattern demonstrates that acidity increases over time for all samples, clearly reflecting the natural progression of milk spoilage.

### Accuracy of the Prototype

Out of 25 trials, 23 prototype classifications aligned with the observed status of the milk samples. An accuracy rate of 92 percent indicates that the system is dependable. The two misaligned results came from samples with borderline pH values, which can be difficult to distinguish in real settings.

### Consistency of Fresh, Spoiling, and Spoiled Categories

To further examine the reliability of the pH sensor, the readings were grouped according to the prototype's verdict and analyzed based on mean and standard deviation.

The sensor demonstrated reliable performance across all stages of milk freshness, with consistent readings that reflect expected pH trends. Fresh milk samples exhibited an average pH of 6.758 with a low standard deviation of 0.087, indicating that the sensor consistently measured values within the fresh range. This confirms that the pH threshold for fresh milk is stable and dependable, providing a solid baseline for comparison with samples in later stages of spoilage.

Milk samples in the early spoiling stage showed slightly more variation, which is expected due to the transitional nature of this phase. The average pH of these samples was 6.2475 with a standard deviation of 0.140, demonstrating that the sensor could still detect subtle changes in acidity. These results indicate that the prototype is capable of identifying early spoilage conditions, offering a reliable indication before milk reaches full spoilage.

Fully spoiled milk samples were consistently below pH 6.0, with a mean of 5.81 and a standard deviation of 0.116. The low variation in readings confirms that the sensor accurately detected the increased acidity resulting from bacterial activity. Collectively, these results demonstrate that the prototype provides stable and dependable measurements across the full spectrum of milk freshness, effectively distinguishing between fresh, early spoiling, and spoiled samples.

### Importance of Temperature in Spoilage Detection

Temperature was used to support the interpretation of pH data. Samples stored in cooler conditions below 7 degrees Celsius spoiled more slowly. Samples exposed to room temperature spoiled faster due to increased bacterial activity.

The temperature readings of the five milk samples reflected their initial storage conditions and the expected behavior of milk when exposed to room temperature over time. Samples A, C, and E, which were stored at room temperature from the start, maintained relatively stable temperatures between 28.5 °C and 30.4 °C throughout the 48-hour period. These consistently warm temperatures correspond with the faster rate of spoilage observed in their pH data, as higher temperatures accelerate microbial activity.

In contrast, Samples B and D began at significantly lower temperatures—7.0 °C and 6.5 °C, respectively—due to prior refrigeration. Over the next 12 to 24 hours, both samples gradually warmed to ambient conditions, reaching temperatures between 25 °C and 29 °C. This steady increase illustrates the transition from safe, chilled storage to conditions that promote bacterial growth and aligns with the delayed pH changes observed in these samples.

Once all samples equilibrated near room temperature, their temperatures stabilized with minimal fluctuations. This pattern confirms that the environment has the most significant impact on spoilage progression during the first 24 hours. Overall, the temperature data support the conclusion that exposure to temperatures above 15 °C increases spoilage risk, while chilled samples exhibit delayed spoilage until they reach ambient conditions. These results also highlight the utility of the DS18B20 sensor as a

supplementary indicator that contextualizes pH changes and helps explain differences in spoilage rates among samples.

### Overall Prototype Performance

The prototype showed reliable performance throughout the experiment. The pH sensor produced accurate and consistent readings, while the temperature sensor provided useful environmental context. The LCD and LED indicators displayed results clearly and responded correctly to each spoilage stage.

Compared with other sensor based food monitoring systems reported in previous studies, the prototype showed similar reliability while using fewer and simpler sensors. This suggests that accurate spoilage monitoring can still be achieved using a low cost and straightforward design.

The results demonstrate that the Arduino-based prototype can successfully detect milk spoilage in real time. It can classify milk as fresh, spoiling, or spoiled with strong accuracy. Its low-cost, simple components, and consistent performance make it suitable for both household and commercial use. The findings show that the system can help reduce milk waste, improve food safety, and give users a dependable way to check milk quality.

### CONCLUSION

This research study successfully developed an Arduino-based smart milk spoilage detector that utilizes a pH sensor and a DS18B20 temperature sensor to monitor real-time changes in pasteurized milk. The prototype demonstrated reliable output, as shown by the correct display of sensor readings on the LCD and the activation of LED indicators according to the spoilage status.

To ensure reliability and accuracy, pH buffer solutions were used to calibrate the sensor before testing. The prototype achieved an overall accuracy of 92 percent, showing that it can correctly classify milk as fresh, spoiling, or spoiled.

The findings support its effectiveness by analyzing that pH sensors indicate a strong and consistent predictor of spoilage, and temperature serves only as a supporting factor that influences spoilage rate based on the way the milk was stored. Additionally, although the breadboard setup serves as a functional assembly of the prototype, the quality and long-term durability may be affected.

Overall, this development shows a simplified but reliable approach, not leaning on utilizing complex sensors, but instead using familiar ones seen regularly to test a product that people also use on a daily basis. This prototype also shows strong potential for a practical, low-cost, and real-time milk spoilage detector for household and commercial applications. Its high alignment rate, calibrated pH accuracy, and consistent temperature readings signify that it can help support early detection of spoilage, reduce milk waste, and improve food safety, which not only to consumers' well-being, but also to environmental sustainability.

### Recommendations

Based on the findings of this study, several recommendations are proposed to enhance the performance and applicability of the prototype. Sensor stability and protection can be improved by upgrading the pH probe and temperature sensor with more durable protective casings to prevent damage during repeated use, while the use of food-grade materials is advised to ensure safer and more sanitary measurements. Future researchers are encouraged to increase the number and variety of milk samples, including different brands, storage conditions, and expiration dates, to strengthen the reliability and accuracy of results. Extending the monitoring period beyond 48

hours, such as up to 72 or 96 hours, may also provide a clearer understanding of spoilage progression over time. In terms of hardware, developing a more compact, durable, and portable design, along with incorporating a rechargeable power source, would improve usability. The integration of data logging features, such as Bluetooth, WiFi, or SD-card modules, is also recommended to enable automatic recording, real-time monitoring, and easier data storage. Additionally, exploring other spoilage indicators—such as turbidity, conductivity, or gas sensors—can enhance detection accuracy and provide a more comprehensive analysis. Future developments may also focus on designing a smart container or storage system with built-in sensors, allowing continuous and hands-free monitoring of milk spoilage in practical, everyday settings. Lastly, regular calibration of the pH sensor is essential to maintain measurement accuracy, particularly for long-term use or repeated testing.

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## DEVELOPMENT OF AN AUTOMATED ATTENDANCE MONITORING SYSTEM USING ULTRA HIGH FREQUENCY RFID FOR COLEGIO DE SAN JUAN DE LETRAN MANILA

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### ABSTRACT

The objective of the study is to create and assess the use of an Automated Attendance Monitoring System (A.A.M.S.) through the utilization of Ultra High Frequency (UHF) Radio Frequency Identification (RFID) technology. The proposed system has been created to address common concerns associated with the traditional process of attendance checking. The A.A.M.S. utilizes a UHF RFID reader, tags, a raspberry Pi 4, and a web-based system to collect the attendance of Colegio students in real-time through walk-through method detection. Non-iterative development research design was utilized, and system analysis, development, and evaluation were performed. Data gathering was carried out through observation and distribution of Likert scale questionnaires to selected faculty members in order to determine the accuracy, functionality, usability, and reliability of the system. The system went through series of trial sessions to test the accuracy of RFID technology in being detected. The results showed that the system obtained a 93.3% RFID detection accuracy and a 100% success rate in achieving data logging accuracy. The results of the faculty evaluations indicated substantial agreements in the usability of the system, software application, and hardware reliability, with the overall mean ratings obtained classified under “Strongly Agree” categories. The study concludes that the implementation of the UHF RFID-Based A.A.M.S., as a system for attending attendance monitoring in the Senior High School environment, is indeed feasible and effective and worthy of institutionalization/institution-wide implementation with further enhancement for wider implementation.

**Keywords:** UHF RFID, Automated Attendance Monitoring System, Attendance System, Web-Based Application

### INTRODUCTION

#### Background of the Study

Throughout the history of education, monitoring the attendance of students has been essential as it allows institutions to track and record the presence of students, which is necessary for academic success of students. Traditionally, the method used in monitoring attendance has been manual, often through roll-calls or signing attendance sheets. Be that as it may, Aniñon et al. (2020) stated that various issues are present in the manual method: individuals take advantage of its flaw, committing hoax and forgery. These issues will lead to unjust practices including submitting a falsified attendance report for schools to wrongly reward students that exert minimal effort in their studies. Furthermore, they explained that tracking attendance manually consumes

a significant portion of the class hours, and the record can also get lost, misplaced, or skip a student's name, causing inconvenience in the long run.

As technology continuously grows, educational institutions have begun to adapt to automated systems for administrative processes. For instance, some adapted the use of biometrics which identifies individuals based solely on their distinct physical characteristics (e.g., fingerprints and facial recognition). This way, a high level of accuracy is certain and falsification is prevented. However, biometric systems have a drawback on their own. Implementing it requires heavy financial investment and it can sometimes be inaccurate due to

an individual having a physical deformation.

Another common approach is the use of Radio Frequency Identification (RFID) powered technology; it emerged as a solution for more convenient attendance monitoring. Contrary to manual ways, RFID-enabled systems allow for quick and accurate identification, that way, the occurrence of human error and potential forging of data reduces. Yet, this system also has a drawback, where students may impersonate others or lend their IDs to friends.

Typically, existing RFID attendance systems utilize Low Frequency (LF) or High Frequency (HF) tags; however, their limited detection ranges and slower data transmission rates make them unsuitable for simultaneously processing a significant number of students at classroom entryways.

In the setting of Colegio de San Juan de Letran, a prestigious institution, attendance monitoring is necessary for both student and faculty performance. At present, the biometric-enabled attendance system is limited to teachers, while students still depend on manual methods. LF and HF RFID technologies, albeit offering improvements over manual methods, their limited frequencies are not optimal for the dimensions of classroom doors. A potential approach is the use of Ultra High Frequency (UHF) RFID, which gives longer range and faster processing.

The shift to UHF technology is supported by recent empirical research; for instance, Calo, Barbosa, and Llevado (2021)

demonstrated that utilizing UHF RFID for in-classroom attendance significantly enhances tracking reliability and effectively eliminates proxy attendance due to its superior cross-verification capabilities. Therefore, this study aims to bridge that gap by assessing the feasibility and effectiveness of UHF RFID in monitoring classroom attendance.

### Objectives of the Study

The main objective of this study is to develop an automated classroom attendance monitoring system using UHF RFID combined with a web-based application as a database of the students for Colegio de San Juan de Letran Manila.

This study aims to develop a hardware module that utilizes UHF RFID technology to record student attendance in real time and monitor students' classroom entry and exit. The system is designed to prevent falsification of attendance records, reduce the time required for recording attendance, and provide a more convenient method of tracking student presence. It will also include a website for storing records, displaying each section's class schedule, and showing the time of students' ins and outs. Additionally, the system will allow authorized school faculty to view and edit attendance records, generate summaries of attendance data, and integrate a seat plan to help teachers identify students and visualize absentees in real time. Furthermore, the automated attendance monitoring system will be assessed in terms of its accuracy in detecting RFID tags and processing student data in real time, usability in terms of effectiveness, efficiency, and user-friendliness of the website interface, reliability in maintaining stable and error-free recording and storage of attendance data, and functionality in evaluating the performance and completeness of both hardware and software components in meeting attendance monitoring requirements.

### Literature Review

#### RFID Technology as a Tool for Automated Attendance Monitoring

A variety of frequency ranges are used by RFID systems, with each type having unique features. In accordance with RFID Label (2021), Low Frequency (LF) RFID works at 125–134.2 kHz and has a short read range of about 10 cm, but it is not easily affected by metal or liquids. High Frequency (HF) operates at 13.56 MHz and can reach slightly farther, often used for things like access cards. Ultra High Frequency (UHF), on the other hand, works between 860–960 MHz and can read multiple tags over longer distances, which is useful for big areas.

El Mrabet and Ait Moussa (2020) designed an IoT-School Attendance System Using RFID Technology that records student attendance automatically. Findings show that using RFID makes attendance faster and reduces errors compared to manually calling names. With the system's ability to record multiple students at once, it saves teachers a lot of time and makes keeping track of attendance much easier. This feature is helpful in larger classrooms where manually keeping track of attendance can be slow and prone to mistakes.

Furthermore, another research conducted by Calo, Barbosa, and Llevado in 2021 also implemented an "In-Classroom Faculty Attendance Monitoring System" using Ultra High Frequency ("UHF") RFID technology, which is also used in this research. In this research, it has been found that "the greater read range and capability to read multiple tags simultaneously make UHF RFID an attractive solution for academic environments where speed and accuracy are critical." This research directly supports the rationale for using UHF RFID technology rather than using any other frequency bands in the development of this A.A.M.S.

Attendance-related settings offered by Hutabarat, Hendri, and Pribadi (2025) in their research conducted in a real classroom environment within STMIK TIME Campus gives empirical evidence of RFID efficiency, where the efficiency of an RFID-based attendance system was measured. As a matter of fact, this research has validated that the overall processing of each attendance transaction is completed in a matter of 1-2 seconds, and all the main features of the system, including login management, attendance, and recap, are functioning properly without any failure. According to this research, it is evident that the overall quality of RFID technology in attendance management is significantly improved in academic environments, thus validating the viability of the methodology used in this research.

#### Efficiency, security, and accuracy of automated attendance systems

Creatrix Campus (2022) stated that an automated attendance system compared to manual methods is superior in terms of speed, accuracy, and security. The conventional manner or manual attendance checking requires teachers to allocate class time to calling names individually or passing around an attendance sheet, which consumes several minutes of class time. Manual methods tend to be unreliable, since some students respond on behalf of their absent classmates. Such unfair practices create situations that become problematic in large classroom settings where teachers encounter challenges to verify students that are present.

Automated attendance systems address these limitations by implementing technologies such as RFID cards and biometric systems to ensure student identification when recording attendance. These automated technologies eliminate human error while providing immediate data in a digital database, therefore making records more secure, more organized, and easily accessible at any time. Interest in the disclosed advantages reported in the article, the system has also been targeted to save time, prevent falsification, and give accurate and efficient attendance monitoring, thus being a fair and effective tool in the classroom for monitoring.

The aforementioned benefits are further corroborated by the empirical research conducted by Chakraborty, Rahman, Joy, and Islam (2024), wherein they have explored the integration of RFID technology with Arduino microcontrollers for enhancing security and efficiency in attendance management. It is evident from their research that if a unique identification code is assigned to each and every RFID tag, then it is very difficult to indulge in any kind of forgery or duplication of attendance records. Moreover, the smooth integration of all parts of the system also adds to the reliability of the system. The relevance of this research is very high in respect to the objective of the current research, wherein it is proposed to avoid forgery by incorporating a unique Electronic Product Codes assigned to each and every UHF RFID tag.

### Research Framework

#### Theoretical framework

Introduced by Davis (1989) as cited in Lin and Yu (2023), the Technology Acceptance Model is a model that describes how people accept and use a technology in terms of two key determinants, which are: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). It finds its roots in the Theory of Reasoned Action (TRA) that was proposed by Martin Fishbein and Icek Ajzen. The model points out that such factors essentially result in the formation of users' attitudes toward the technology, which, in turn, influences their behavioral intention to use the technology, and consequently, the actual system usage occurs.

Perceived Usefulness is the extent to which an individual presumes that using a given technology or system will improve their performance or productivity. For instance, some businesses might

consider adopting mobile marketing if they perceive that these services will draw more customers and improve their sales. This leads to a beneficial financial outcome for the business. On the other hand, Perceived Ease of Use refers to the extent to which an individual presumes that using the technology or system given will be free from effort. To give an example, an individual utilizing a McDonald's kiosk, these systems are designed with close visualization of the menu and simple buttons, which makes it easy for customers to order or even complete a transaction without the assistance of a cashier. These perceptions of usefulness and ease of use drives their willingness to use the technology or system.

An RFID-based attendance system allows automation and gets rid of the problems of manual processes, such as falsification and missing attendance sheets, which directly address the perceived usefulness component of the Model. TAM also integrates external variables that can affect both PU and PEOU, such as characteristics of the user, characteristics of the system, and organizational factors that may influence the adoption of the technology.

In this study, TAM serves as a framework to understand how the students, faculty and administrators of Colegio de San Juan de Letran Manila may accept and use the automated UHF RFID attendance monitoring system. The system's ability to reduce the time spent on attendance checking and prevent falsification falls into the perceived usefulness aspect, while the automation of the RFID technology is in the perceived ease of use aspect. By applying TAM, this study aims to evaluate user acceptance factors and to design the system to expand the adoption rates among stakeholders.

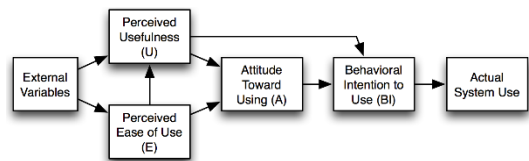


Figure 1. Technology Acceptance Model

As illustrated in Figure1, the process begins when a student's RFID tag is detected by the UHF RFID reader. Upon detection, the reader captures the Electronic Product Code (EPC) and transmits the data to the Raspberry Pi for processing. The system then verifies whether the EPC corresponds to a registered student within the database. If the tag is valid, the system retrieves the associated student information and identifies any active schedule linked to the student at the time of scanning.

Once an active schedule is confirmed, the system determines the appropriate type of attendance entry whether it is a time-in, time-out, or return-from-break record. It then generates or updates the corresponding attendance record, including details such as the student's ID, name, time of scan, and attendance status. This information is subsequently stored in the database, after which the system updates the web-based platform to reflect the student's most recent attendance activity.

In contrast, if the EPC does not match any registered student or if no active schedule exists at the time of scanning, the system generates an error response and displays the appropriate message on the terminal interface.

To support usability and ensure immediate feedback, the system incorporates both audio and visual indicators. A successful scan triggers a buzzer sound, with distinct tones assigned to time-in, time-out, and return-from-break events. Invalid or unregistered tags

prompt a separate alert tone. Additionally, if multiple RFID tags are detected simultaneously, the system emits multiple corresponding buzzer signals, assisting in identifying potential misuse or unauthorized tag carrying.

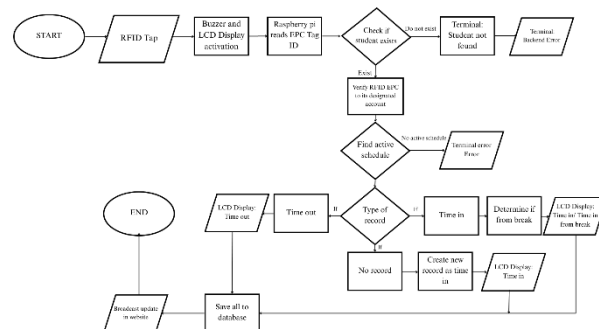


Figure 2. Conceptual framework of the study

(UHF-RFID) for Colegio de San Juan de Letran Manila during the academic year of 2025-2026. The system aims to integrate automatic attendance taking by way of walk-through with real-time tracking of data, time in and time out detection, data logging, a feedback system, and student identification. The researchers will utilize one UHF-RFID reader only, and create a web-based application for data management. Selected faculty members will be selected by the researchers to evaluate the system by performance testing during regular classes and using a Likert-scale assessment to determine the system's functionality and usability.

The study will only cover the attendance of SHS students of the Colegio. At the same time, excluding external and internal factors that are beyond the researcher's control, such as scattered attendance detection, students forgetting, leaving, losing, or refusing to wear their RFID tags, student's room cross checking due to backend and database error, and excusing students will not be measured as part of the system's performance evaluation. The study will not include faculty attendance monitoring and integration with the existing school management systems. Additionally, the study will not delve into a detailed comparison with alternative attendance technologies.

## METHODOLOGY

### Research Design

The study will utilize a non-iterative developmental research design as a guide the development and evaluation of the automated attendance monitoring system using Ultra High Frequency Radio Frequency Identification (UHF RFID) technology for Colegio de San Juan de Letran Manila.

A non-iterative (single-cycle) design is a type of approach within developmental research that follows a linear path consisting of analysis, development, and evaluation. It focuses on creating a final product in a single complete sequence and then subjecting it to a comprehensive, one-time evaluation.

Through this approach, the researchers can determine whether the system demonstrates the expected performance in terms of accuracy, functionality, and usability. The evaluation results will give concrete evidence on the system's feasibility, which guides future studies without engaging in revisions.

### Analysis and Formulation

This part identifies the need for an automated attendance monitoring system. The foundations are drawn from the theoretical framework and review of related literature sections to justify the development of the UHF RFID technology integrated with a web-based platform.

### Development

The prototype of the A.A.M.S. will be designed and built. The hardware will consist of a UHF RFID reader, RFID tags, Buzzer module, LCD module, and a Raspberry Pi for data processing. The system will then be connected to a created web-based application where the attendance logs, student records, and schedules are stored, managed, and displayed.

### Evaluation

The product will be subjected to trials and a one-time comprehensive evaluation to determine its accuracy and functionality in a classroom environment, and to assess the web-based application's user interface.

### Procedures

The development of the Automated Attendance Monitoring System (A.A.M.S.) will consist of two primary components: the hardware and the web-based application.

For the hardware development, the system will utilize the M5Stack UHF RFID Unit (JRD-4035) as the primary reader, which has a detection range of approximately 1.5 to 2 meters and can process up to 200 tags simultaneously. Additional components include UHF RFID tags compatible with ISO 18000-6C standards, a Raspberry Pi 4, an LCD module, and a buzzer module. In terms of hardware assembly, the RFID reader will be embedded in a wall to maximize detection range and minimize scattered readings, making it optimal for classroom doorway coverage. The reader will be connected to the Raspberry Pi, which will process tag data and communicate with the web application. The buzzer will provide auditory feedback upon detection, while the LCD module will display confirmation messages to inform users that their tags have been successfully scanned.

For the web application development, a web-based database will be established to manage attendance logs and student records. The database will store relevant data such as student ID numbers, names, sections, courses, schedules, seat plans, and attendance status. The web application will be designed to provide faculty members with access to the attendance system. Its features will include real-time monitoring of student entry and exit, automatic attendance logging linked to class schedules, a student directory with a live seat plan, password-protected summaries of attendance logs, dedicated accounts for each section, and options for manual attendance entry and removal within the system.

System programming will be divided into two parts: the hardware side and the web-based application. Both components will be developed to ensure seamless communication, real-time attendance logging, and secure data management. On the hardware side, the Raspberry Pi 4 will function as the central processing unit, acting as a bridge between the RFID reader and the web application. Python will be used to manage serial communication with the reader, process EPC data from RFID tags, and determine whether a time-in or time-out event has occurred. The processed attendance data, including student ID number, name, timestamp, and status, will be formatted in JSON and transmitted to the backend server via REST API requests. In cases of network interruption, the Raspberry Pi will temporarily store the data locally and automatically synchronize it once connectivity is restored.

On the web application side, development will involve an integrated backend, database, and frontend system to ensure smooth operation. The backend will be built using FastAPI (Python), which will handle

communication with the Raspberry Pi and process attendance data before storage. The database will utilize SQL to maintain structured records such as student information, class schedules, and attendance logs. For the frontend, the Next.js framework will be used to design the interface, manage styling, and enable user interactivity, resulting in a responsive and user-friendly system for faculty and administrators.

### Data Gathering Procedures

The developed A.A.M.S. will undergo multiple trials in a controlled setup to verify its accuracy and speed of RPi data processing, and the reliability of the buzzer feedback in actual conditions. These variables will be tested through 3 sessions of trial runs. Each session will involve 5 registered RFID tags to determine whether the system correctly logs and exits. The results of the trials will provide evidence of the system's accuracy in detecting RFID tags and accurately recording attendance on the website.

A Likert-scale will be used to collect feedback on two main aspects: System Functionality - based on how well the system performs its intended function (real-time logging, proper RFID tags detection) Website User Interface (UI) - based on clarity, ease of navigation, and user friendliness of the web-based application.

The Likert-scale will be administered exclusively to teaching faculty of Colegio de San Juan de Letran Manila, as they are the primary users and evaluators of the system.

### Research Instrument

In this study, the researchers will use Observation and a Likert-scale questionnaire as instruments for data gathering. The purpose of using these two instruments is to collect both technical performance data of the system and personal insights of its intended users. By synthesizing the results, the researchers will be able to evaluate the A.A.M.S in terms of its practicality and user friendliness when applied in a real classroom setting.

For the observation, the system will be tested by the researchers using registered RFID tags to measure its accuracy in recording attendance. This will help determine how well the A.A.M.S. performs its intended functions in real circumstances. For the Likert-scale questionnaire, Google Forms will be used and distributed to selected faculty members of Colegio de San Juan de Letran Manila. This questionnaire will allow the researchers to gather valuable feedback from teachers regarding the system's functionality and the ease of use of the website's user interface.

### Sampling Method

This study will adopt a purposive sampling method in terms of selecting participants who can best provide insightful feedback regarding the A.A.M.S. This non-probability method is most appropriate because the nature of the study requires input from individuals with direct experience and expertise in terms of classroom management and attendance monitoring.

The respondents will include faculty members from any Department of the Colegio de San Juan de Letran Manila. As they are the foremost users of the system, and their assessments are needed for establishing the practicality, usability, and functionality of the system within the school. A set of criteria for selection is developed by the researchers in selecting participants that fit the purposes of the study. The faculty members who will be eligible are those who: (1) Are currently teaching in any department during the Academic Year 2025-2026. (2) Have first-hand experience with the existing, manual methods of attendance monitoring. (3) Be willing to participate in the evaluation of the system and provide feedback.

The first advantage of purposive sampling is that it is practical

for focused developmental research. It efficiently allows the research to collect rich and relevant data from an informed population without the need for large, randomized samples. This will be of great assistance in this research because it would allow the researchers to target those people whose professional inputs are directly relevant to refining and assessing the system's performance in terms of accuracy, usability, and functionality.

According to Memon et al. (2023), purposive sampling has been helpful in quantitative and developmental research into practical problems. While generalization of findings to all populations cannot be done statistically, this design allows an investigation into the efficiency of the system within its specific context, which furthers in-depth understanding of its potential integration into the academic setting of Colegio de San Juan de Letran.

**Ethical Considerations**

Informed consent shall be acquired from all selected faculty members who will participate in this study, which ensures that their participation is on a voluntary basis and that they are fully aware of the purpose of the study. The research will adhere to R.A. 10173, otherwise known as the Data Privacy Act of 2012, through the strict security measures regarding the attendance information to be gathered within the system, as well as the response sheets from the faculty evaluations. Data will be utilized solely for the evaluation of the A.A.M.S and shall be accessible only to the researchers.

**RESULTS AND DISCUSSION**

**Website User Interface (Usability)**

**Table 1. Assessment on the system's website UI**

Items	Mean	SD	Interpretation
The website layout is visually appealing.	4.87	0.35	Strongly Agree
The font style and size are easy to read.	4.77	0.43	Strongly Agree
The navigation menu is clear and easy to understand.	4.80	0.41	Strongly Agree
The placing of contents is well-structured and easy to follow.	4.77	0.43	Strongly Agree
The text and background colors provide good contrast for readability	4.83	0.38	Strongly Agree
<b>Overall</b>	<b>4.81</b>	<b>0.4</b>	<b>Strongly Agree</b>

Note: Legend: 1.00-1.79 Strongly Disagree; 1.80-2.59 Disagree; 2.60 -3.39 Neutral; 3.40-4.19 Agree; 4.20-5.00 Strongly Agree

The high scores indicate that the web application successfully achieved its goal of being user-friendly and intuitive for its primary users—the faculty. The visually appealing layout and clear navigation (Mean=4.80) suggest that faculty can access attendance data and system features with minimal effort, directly supporting the Perceived Ease of Use dimension of the Technology Acceptance Model (TAM). A system that is easy to navigate reduces the time and frustration associated with administrative tasks, thereby encouraging adoption.

**Software Functionality and Reliability.**

**Table 2. Assessment on the system's website functionality and reliability**

Items	Mean	SD	Interpretation
The website loads quickly without delays.	4.67	0.48	Strongly Agree
All links and buttons work properly.	4.77	0.43	Strongly Agree
The website is responsive across different devices (mobile, tablet, desktop).	4.83	0.38	Strongly Agree
The system performs tasks without errors or bugs.	4.73	0.45	Strongly Agree
The website allows users to complete their tasks successfully (e.g., manage and monitor attendance logs).	4.90	0.31	Strongly Agree
<b>Overall</b>	<b>4.78</b>	<b>0.41</b>	<b>Strongly Agree</b>

Note: Legend: 1.00-1.79 Strongly Disagree; 1.80-2.59 Disagree; 2.60 -3.39 Neutral; 3.40-4.19 Agree; 4.20-5.00 Strongly Agree

The high rating for task completion (Mean=4.90) confirms that the software effectively meets its core functional requirements, such as managing and monitoring attendance logs in real-time. The responsiveness across devices (Mean=4.83) is a significant strength, offering flexibility for faculty to check attendance from their desks or mobile devices. The strong performance in reliability (Mean=4.73 for error-free operation) fulfills the study's objective to create a stable system that records and stores data without loss, building trust among users and reinforcing the Perceived Usefulness of the system by providing accurate and accessible data.

**Hardware Functionality and Reliability**

**Table 3. Assessment on the system's hardware functionality and reliability**

Items	Mean	SD	Interpretation
The device is easy to operate.	4.70	0.47	Strongly Agree
Auto-transition between classes saves administrative work	4.77	0.43	Strongly Agree
The device prevents falsified or proxy attendance.	4.77	0.43	Strongly Agree
The hardware reduces time spent recording attendance.	4.67	0.48	Strongly Agree
The device is reliable during class hours	4.93	0.25	Strongly Agree
<b>Overall</b>	<b>4.77</b>	<b>0.41</b>	<b>Strongly Agree</b>

Note: Legend: 1.00-1.79 Strongly Disagree; 1.80-2.59 Disagree; 2.60 -3.39 Neutral; 3.40-4.19 Agree; 4.20-5.00 Strongly Agree

The hardware results directly address the primary drawbacks of manual and lower-frequency RFID systems. The high score for preventing falsification (Mean=4.77) demonstrates that the UHF RFID system, with its unique EPC codes and anti-tampering features, successfully mitigates the risk of proxy attendance. Furthermore, the significant reduction in time spent recording attendance (Mean=4.67) and the auto-transition feature (Mean=4.77) validate the system's core purpose: to automate a tedious administrative process. The exceptional reliability score (Mean=4.93) is critical for continuous, uninterrupted operation in a busy school environment, ensuring that attendance data is captured consistently throughout the day.

**Table 4. Observation Table (RFID Detection Accuracy)**

Session	Total Attempts	Valid Detections	Missed Detections	Data Logging Success	Buzzer Feedback (Yes)
1	5	5	0	5/5 (100%)	5/5 (100%)
2	5	4	1	4/4 (100%)	4/5 (80%)
3	5	5	0	5/5 (100%)	5/5 (100%)
<b>Total</b>	<b>14</b>	<b>14</b>	<b>1</b>	<b>14/14 (100%)</b>	<b>14/15 (93.3%)</b>

Note: Legend: Total Attempts – Number of RFID scans conducted. Valid Detections – Successfully detected RFID tags. Missed Detections – Undetected RFID tags. Data Logging Success – Detected tags correctly recorded in the database. Buzzer Feedback – Audio signal triggered upon detection

The system achieved an overall detection rate of 93.3%, successfully identifying 14 out of 15 registered tag attempts. This high accuracy validates the choice of UHF RFID technology for efficient, walk-through attendance logging in a classroom doorway setting. Most significantly, the data logging reliability was 100%, meaning every single successful detection was accurately captured and recorded in the web database without any loss of data. This fulfills the critical objective of creating a reliable system for recording attendance. The single missed detection in Session 2 could be attributed to factors like temporary signal obstruction or tag orientation, but the overall performance confirms the hardware's robustness for daily use.

The prototype's high performance aligns with recent empirical evaluations of RFID-based attendance technologies. The 100% success rate achieved in data logging reliability reflects the benchmarks established by Ajayi et al. (2025), who empirically verified that integrated RFID and microcontroller systems ensure real-time server logging with virtually no data loss. Furthermore, the 93.3% detection accuracy during the walk-through method is consistent with the findings of Hutabarat, Pribadi, and Hendri (2025). Their testing in a university campus environment confirmed that modern RFID systems process high-volume attendance data with exceptional accuracy and an average processing time of merely fractions of a second, validating the efficiency of the A.A.M.S. prototype deployed in this study.

## CONCLUSIONS

This study successfully developed and evaluated an Automated Attendance Monitoring System (A.A.M.S.) using Ultra High Frequency (UHF) RFID technology for Colegio de San Juan de Letran Manila. The system, comprising a UHF RFID reader, a Raspberry Pi processor, and a web-based application, was designed to address the limitations of manual attendance checking and existing lower-frequency RFID systems.

The evaluation results conclusively demonstrate that the system is highly accurate in detecting RFID tags and recording attendance in real-time. It is functionally robust, performing all intended tasks such as entrance/exit logging and schedule-based auto-transition without errors. Furthermore, the system was found to be highly usable, with an intuitive user interface, and reliable, operating consistently during class hours. Most importantly, it achieved its core objectives of significantly reducing the time required for attendance monitoring and effectively preventing the falsification of records.

Therefore, the UHF RFID-based A.A.M.S. presents a feasible, effective, and superior alternative for automated attendance

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monitoring in an educational setting like Colegio de San Juan de Letran Manila.

## Recommendations

The following recommendations are proposed based on the successful development and favorable evaluation of the A.A.M.S. For the school administration, it is recommended that resources be allocated for the implementation of the system in the Senior High School department. The system's established 93.3% accuracy and 100% data-logging reliability provide a strong technical foundation for this rollout and may be further optimized when applied on a larger scale.

For future researchers, it is suggested to maximize the use of the system's highly reliable attendance data by developing advanced analytics capable of predicting student absenteeism trends, as well as more comprehensive reporting tools for administrators. Further studies may also focus on improving the hardware setup by optimizing the placement of the reader and the configuration of the antenna to increase detection accuracy from 93.3% to as close to 100% as possible, particularly by addressing edge-case scenarios that resulted in missed detections. Additionally, future work may explore the expansion of system integration through the development of secure APIs, enabling seamless data exchange and improved control by integrating the A.A.M.S. with the school's existing Student Information System (SIS).

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## Guide to Contributors

The Horizon is the official academic journal of the high school students of Colegio de San Juan de Letran, Intramuros, Manila

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2. Authors should submit two versions of the manuscript. One file (“file not for review”) should include the names of the authors (adviser and student/s), their contact information (e-mail addresses), and current affiliation (program/area and college). The other file (“file for review”) should remove any information that would identify the authors.
3. The paper should include keywords and an abstract of 100 – 200 words.
4. The article should contain approximately 6000 – 7000 words (including abstract, tables/figures, and references) and should be typed in a 12-point font, Garamond, double-spaced, with one-inch margin on all sides.
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4. The editor makes the final decision on the publication of the revised articles.

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