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SanitiBot: Development and Performance

John Chark L. Niñofranco[1]; Roger M. Betasolo Jr.[2]; Janine T. Betuin[3]; Joselito Y. Bulabos[4]; Princess Jeebeth P. Celades[5]; Jairah M. Espina[6]; Pau Benedick M. Ngoho[7]; Arleigh Jen L. Logaos[8]; Julyana Althea R. Reserva[9]; Kasandra Ken T. Torrejos[10]

[1,2,3,4,5,6,7,8,9,10]Student Researchers, San Agustin National High School, Philippines

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Abstract: This study focuses on the development and performance evaluation of SanitiBot, a sensor-activated restroom hygiene system designed to detect dirt and apply targeted cleaning to restroom surfaces automatically. The study presented the finalized system specifications and evaluated performance in terms of system reliability, sensor responsiveness, detection accuracy, actuator efficiency, and system integration stability. A research and development design, supported by descriptive, quantitative, and qualitative approaches, was employed. The study was conducted at San Agustin National High School in Sagbayan, Bohol, where the prototype was installed in a pre-approved restroom testing environment. Data were gathered using observation checklists, performance testing record sheets, and daily monitoring logs completed by the researchers. Pilot testing was conducted before the main testing phase to ensure the consistency and reliability of the research instruments. The collected data were analyzed using descriptive performance metrics. The results showed that the overall performance of SanitiBot was rated Good, with a composite mean of 2.8. System reliability, sensor responsiveness, detection accuracy, and system integration stability received good ratings, while actuator efficiency was rated Fair. The system demonstrated stable operation and reliable automated cleaning responses during the testing period. Despite limitations such as environmental factors, limited testing scope, and short testing duration, the findings indicate that SanitiBot is a functional and promising sanitation system for school restrooms and may serve as a basis for further development.

***Keywords**: SanitiBot, Sensor-Activated Restroom System, System Performance, Automated Sanitation, Research and Development.*

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I. INTRODUCTION

Providing clean and safe restrooms is an important aspect in schools, homes, and communities because it has a direct impact on the people's health and well-being. In schools, for instance, providing clean restrooms is necessary for maintaining proper hygiene and preventing spread of diseases. According to Shkalim Zemer et al. (2023), proper hygiene education and clean restrooms have a significant impact on improving the health and comfort of children. Despite its significance, sanitation still remains a challenge worldwide, with over 1.5 billion people lacking access to basic sanitation facilities (World Health Organization, 2024).

The health and well-being of the community remain at risk due to sanitation problems in the Philippines. Health experts have reiterated the importance of upgrading public toilets and water facilities to avoid outbreaks of diseases. This is also observed at the local level, particularly in public schools where restroom facilities are not regularly maintained because of resource constraints and heavy usage.

In San Agustin National High School (SANHS) in Sagbayan, Bohol, the sanitation of restrooms has become a serious concern for the students. Based on the observations and interviews made by the researchers, it was found that many restrooms in the school are often not usable because of clogged pipes, lack of water, and poor maintenance. Approximately 90% of the students reported that the school restrooms are often dirty or not functioning. If this persists, it could lead to health issues and reduced attendance of students and school employees.

Some studies have revealed that the poor state of restrooms in schools not only impacts the health of students but also their mental well-being and engagement. Wada et al. (2021) revealed that students tend to avoid restrooms when they are not clean, leading to stress and anxiety. Boone et al. (2025) stated that poor cleaning of toilets leads to the spread of harmful microorganisms, but proper cleaning can decrease the risk of infection by over 94%. Zomer et al. (2023) stated that students avoid restrooms when they are not clean, leading to severe health problems.

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While many studies have cited the impact of inadequate sanitation in schools, most studies have been focused on manual cleaning processes, behavior, and sanitation policies. There is a lack of studies on the application of technology-based sanitation systems in Philippine public schools. This study seeks to fill this gap by developing and testing the SanitiBot, an automated restroom cleaning system activated by sensors for San Agustin National High School, utilizing an Arduino-based control unit and an ESP32-CAM for dirt detection, while also ensuring the privacy of students by not taking identifiable images.

Through the implementation of a technology-based sanitation solution, this research study seeks to offer a more efficient, consistent, and safe means of ensuring clean school restrooms. The findings of this research study may assist school administrators, maintenance personnel, and the relevant authorities in implementing long-term automated sanitation solutions that promote the health and comfort of students.

This study is significant in promoting safe and in hygienic sanitation practices inside the public schools and aligns with the national health and data-privacy policies under Presidential Decree No. 856, which mandates proper sanitation standards in public facilities. It also complies with the Republic Act No. 10173, or the Data Privacy Act of 2012, by ensuring that the SanitiBot's camera system is used to solely for the environmental monitoring and not for a personal identification.

➢ *Research Questions*

This research aimed to develop and assist the performance of SanitiBot in detecting unclean conditions in comfort rooms and automatically dispensing for them.

Specifically, this study sought to answer the following questions:

- What is the profile of the SanitiBot in terms of:

✓ circuit design;
✓ logic flow, and
✓ physical and mechanical specs?

- How does the SanitiBot perform in terms of:

✓ system reliability;
✓ sensor responsiveness;
✓ detection accuracy;
✓ actuator efficiency; and
✓ system integration stability?

- What recommendations can be proposed based from the findings of the study?

➢ *Null Hypothesis*

The Sensor-Activated Restroom System device does not perform well.

II. REVIEW OF RELATED LITERATURE

Keeping restrooms clean and safe is an important aspect for the health and hygiene. According to research, proper health and hygiene practices and clean restrooms can help improve the well-being of children (Shkalim Zemer et al., 2023). Despite this, sanitation is still a significant issue worldwide, as more than 1.5 billion people lack access to basic sanitation facilities (WHO, 2024).

In the Philippines, sanitation still remains a pressing issue. Due to the increase in cholera cases, enhancing the public toilets and the water systems was emphasized by Dr. Mary Ann Bunyi. In the year 2022, the Health Department documented that a 3,729 cholera cases, indicating that a poor sanitation can cause the spread of a waterborne disease (Ombay, 2022).

At the local level, similar issues are seen at San Agustin National High School in Sagbayan, Bohol. Many school restrooms are often unusable and unhygienic due to clogged pipes, limited water supply, and poor maintenance. Interviews conducted by the researchers showed that 90% of students consider the restrooms dirty or unusable, which may cause health risks to both students and school staff.

Related studies support these concerns. According to Wada et al. (2021), poor sanitation in schools leads to increased stress and anxiety among students, causing them to stay away from school and, when they do go, to delay using the restroom. Boone et al. (2025) indicated that poor toilet cleaning habits can lead to increased contact with harmful germs, whereas proper cleaning can lower the risk of infection by over 94%. Zomer et al. (2023) also stated that students often avoid dirty restrooms, which may result in health problems.

Despite the fact that many studies have found that unsanitary restrooms in schools affect the health and learning of students, most studies are focused on behavior, policies, and manual cleaning processes. There is a need for studies on technology-based sanitation solutions for the public schools. In this regard, the objectives of this study are to design a restroom system that is sensor-activated and uses SANHS, which employs an ESP32-CAM to identify the dirt, while maintaining the privacy of the students by not taking identifiable pictures.

The findings of this research can help in improving the condition of the school restrooms by providing a clear and technology-based sanitation program. It can also assist school administrators and government officials in formulating a long-term sanitation solution that will protect the health and comfort of students.

III. RESEARCH METHODOLOGY

➢ *Research Design*

This study utilized a Research and Development (R&D) Design using the Engineering Development Model. The Research and Development Design focuses on planning, designing, creating, testing, and improving the Sensor-Activated Restroom Hygiene System (SanitiBot). The performance of SanitiBot was evaluated through a series of functional and operational tests focusing on system reliability, sensor responsiveness, detection accuracy, actuator efficiency, and system integration stability. These evaluation criteria were used to assess how well the system performed under actual operating conditions, identify areas needing enhancement, and verify the overall effectiveness and stability of the integrated system.

➢ *Sample*

The sample of the study consisted of one student restroom located at San Agustin National High School in Sagbayan, Bohol, which served as the primary testing site for the Sensor-Activated Restroom Hygiene System (SanitiBot). This location was selected to represent an actual school restroom environment where regular usage and sanitation demands are present.

The system was tested through a total of ten (10) trial runs to ensure consistency, accuracy, and reliability of performance. Each trial involved a complete system operation cycle, including sensor detection, system response, actuator activation, and overall system integration. Conducting multiple trials allowed the researchers to observe repeated system behavior, minimize random errors, and verify the stability and dependability of SanitiBot throughout continuous use.

➢ *Materials*

The ESP32-CAM (OV2640 AI-Thinker) served as the central microcontroller and image-processing unit of the system. It captured real-time images of the rice crops, executed the embedded machine learning model, and controlled the activation of the spraying mechanism through digital output signals.

Fig 1 ESP32-CAM Microcontroller

An image recognition model developed using the Edge Impulse platform was used to detect dirty surfaces. The model was trained using field-acquired images and evaluated for accuracy prior to deployment. Once validated, the trained model was embedded into the ESP32-CAM to enable on-device inference without reliance on external networks.

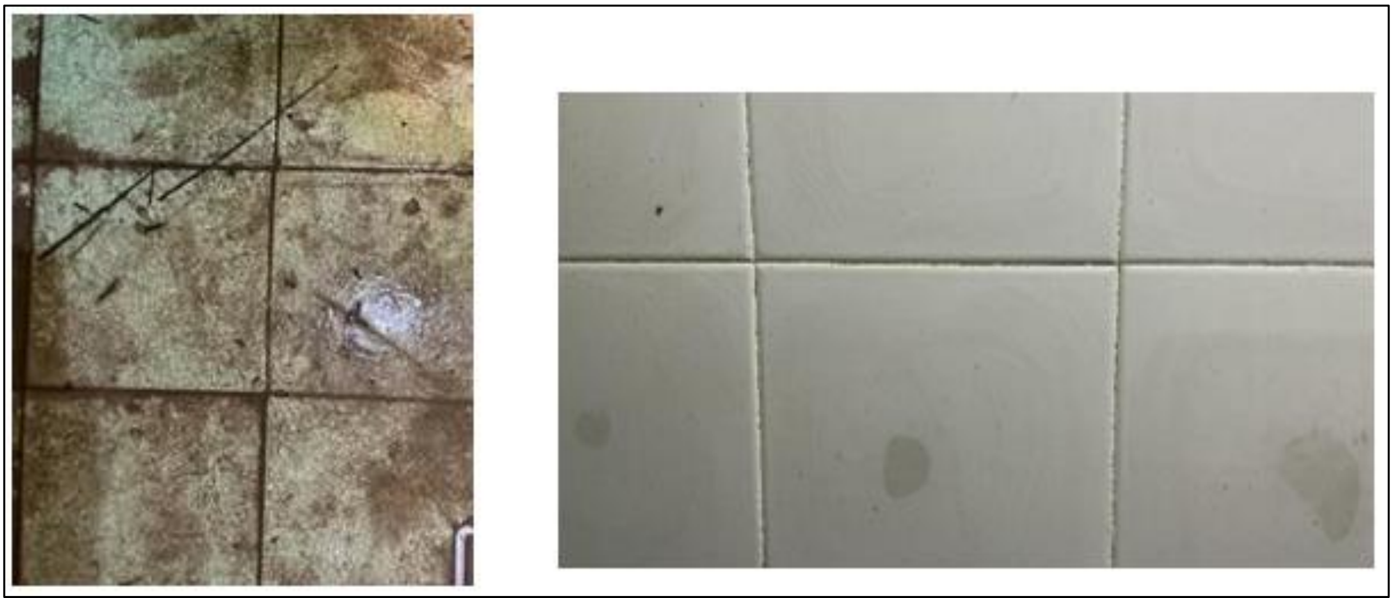

Fig 2 Image Recognition Model

Step Down Buck Converter were used to reduce the 12V power supply to 5V for the Arduino and other electronics. This converter allowed safe and reliable switching during pump activation while protecting sensitive electronic components.

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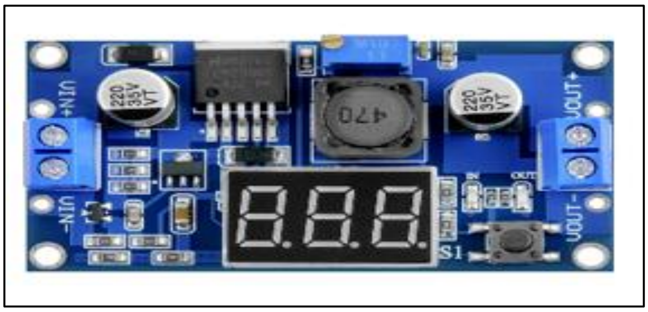

Fig 3 Buck Converter

A 12 V DC pump functioned as the system detects dirt. The pump was calibrated to dispense approximately 1 L/min of water and soap per activation to ensure consistent and controlled application. A spray nozzle was attached to direct the hose precisely toward the detected dirty area.

Fig 4 DC Pump

The power subsystem consisted of 12 V battery. This configuration provided stable and continuous power for off-grid operation while preventing overcharging and deep battery discharge. A metal frame and weather-resistant enclosure supported and protected the electronic and mechanical components during outdoor deployment.

Fig 5 Power Subsystem

➢ *Procedures*

The process of research began with the analysis phase, where the researchers analyzed the current status of restroom sanitation and identified the hygiene problems in the selected school restroom. The researchers reviewed previous studies and existing automated restroom sanitation systems to identify system vulnerabilities and research gaps. This phase of research assisted in identifying the functional requirements of the Sensor-Activated Restroom Hygiene System and designing the overall system based on actual sanitation requirements and risks.

The design and development phases entailed the planning and execution of the SanitiBot system. The design of the circuit, logic, and placement of critical components such as the Arduino microcontroller, camera module, sensors, servo motors, pumps, and power supply were carefully planned. A ceiling-mounted structure was designed to ensure safety and system stability during operation. The system was developed and programmed, including sensor calibration, servo motor control, and automated cleaning system logic. Initial assembly and configuration of all components were carried out to ensure proper integration between hardware and software. Functional testing was also performed to confirm that the system responded correctly to sensor inputs and control commands.

The entire SanitiBot system was installed in a selected school restroom during the implementation phase. To guarantee correct hardware and software synchronization, each component was tested independently before being incorporated into the entire system. To guarantee precise dirt detection and efficient cleaning, the sensors, nozzle angle, and water pressure were calibrated. During ten trial runs, the system was able to identify areas that needed to be cleaned, detect dirt, and spray water or soap. Assessing the system's performance was the main objective of the evaluation phase. Each sample underwent a 10 trials over a two-week testing period of time. The results were recorded and analyzed to determine the system’s accuracy, efficiency, and reliability. Any issues observed during testing were documented for potential system improvements.

➢ *Data Collection and Analysis*

After completing all test runs, the system’s output logs were compiled, sorted, arranged, and tabulated. They were subjected to statistical treatment to answer the questions proposed in the study. The statistical tools that were employed are the confusion-matrix metrics and descriptive statistics. These analyses allowed the researchers to quantify the accuracy, consistency, and overall performance of the SanitiBot system.

The results provided objective data to identify areas of strength and aspects that may require further improvement. To determine the level of effectiveness of the SanitiBot device based on system reliability, sensor responsiveness, detection accuracy, actuator efficiency, and system integration stability, the mean and standard deviation formula were used.

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- *Mean:*

$$\bar{x} = \frac{\sum x}{n}$$

- *Standard Deviation:*

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

IV. RESULTS AND DISCUSSION

The Figure 6 represents the complete power distribution, control logic, and actuation process of the automated cleaning system, which is powered by a 12-V DC battery acting as the main energy source for both high-power and low-power components; power from the battery passes through an inline fuse for overcurrent protection and then splits into two branches, one supplying 12 V directly to the water pump for high-current operation and the other feeding a buck converter that steps the voltage down to a regulated 5 V for the Arduino, servo motors, and ESP32 camera module, all of which share a common ground for reliable signal reference.

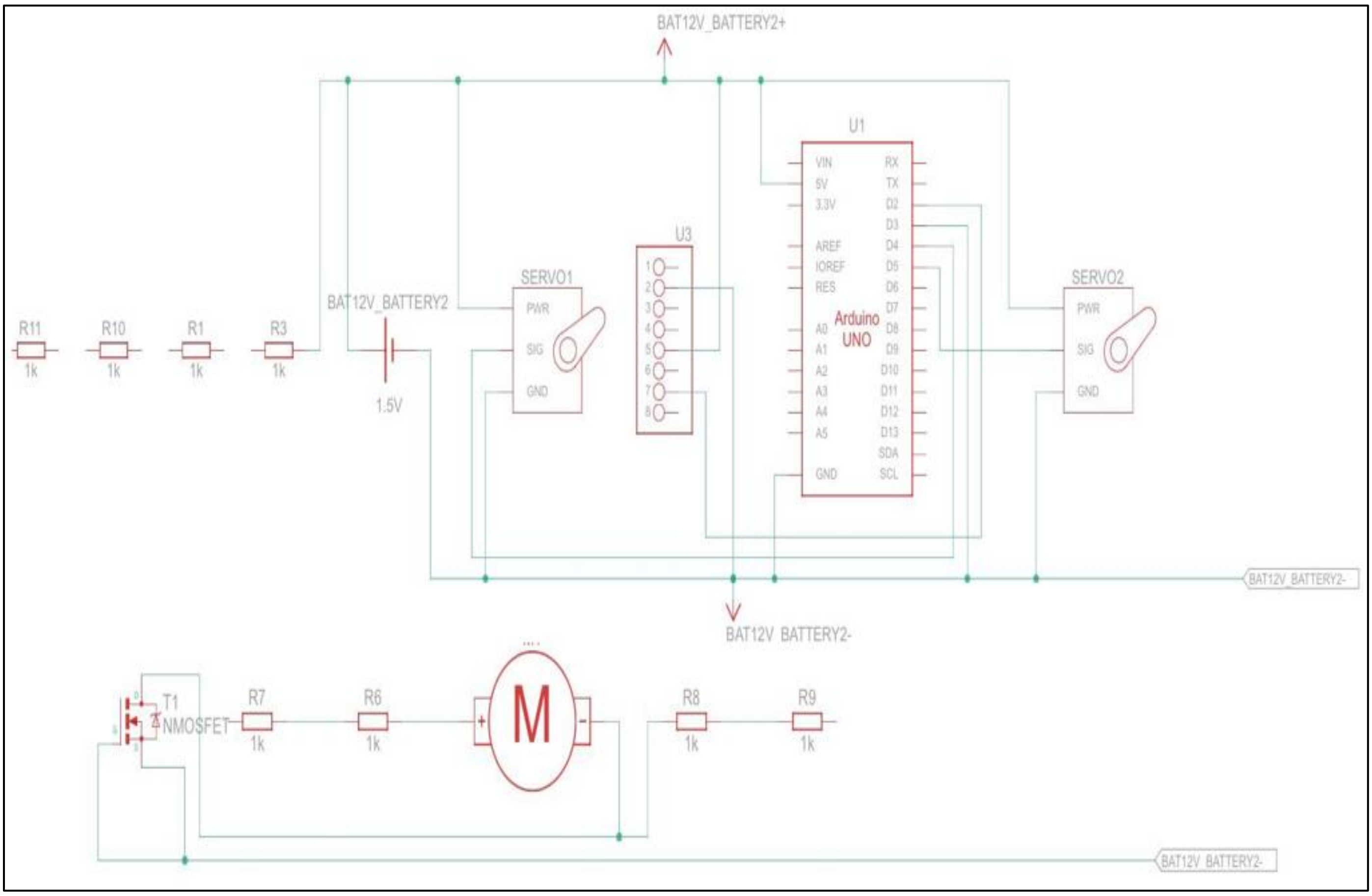

Fig 6 Circuit Diagram

The pump is controlled using a MOSFET, with the pump's positive terminal connected to the fused 12-V supply and the negative terminal connected to the MOSFET drain, while the source is connected to ground, allowing the Arduino to safely switch the high-current pump on and off.

The Arduino acts as the brain of the system, sending PWM signals to control the horizontal and vertical servo motors that move the camera and cleaning mechanism along a planned snake-like path. At the same time, the ESP32 camera continuously captures images and looks for dirt in the area. When dirt is detected, the ESP32 sends a HIGH signal to the Arduino, which then turns on the MOSFET and supplies power to the water pump. This process shows how sensing, decision-making, and physical action work together smoothly in real time.

The Figure 7 illustrates the system flow of the SanitiBot, showing how power, sensing, decision-making, and actuation work together. The system starts when the internal switch in the control room is turned on, supplying power to the Arduino Uno/Mega and its shields, which initialize the system.

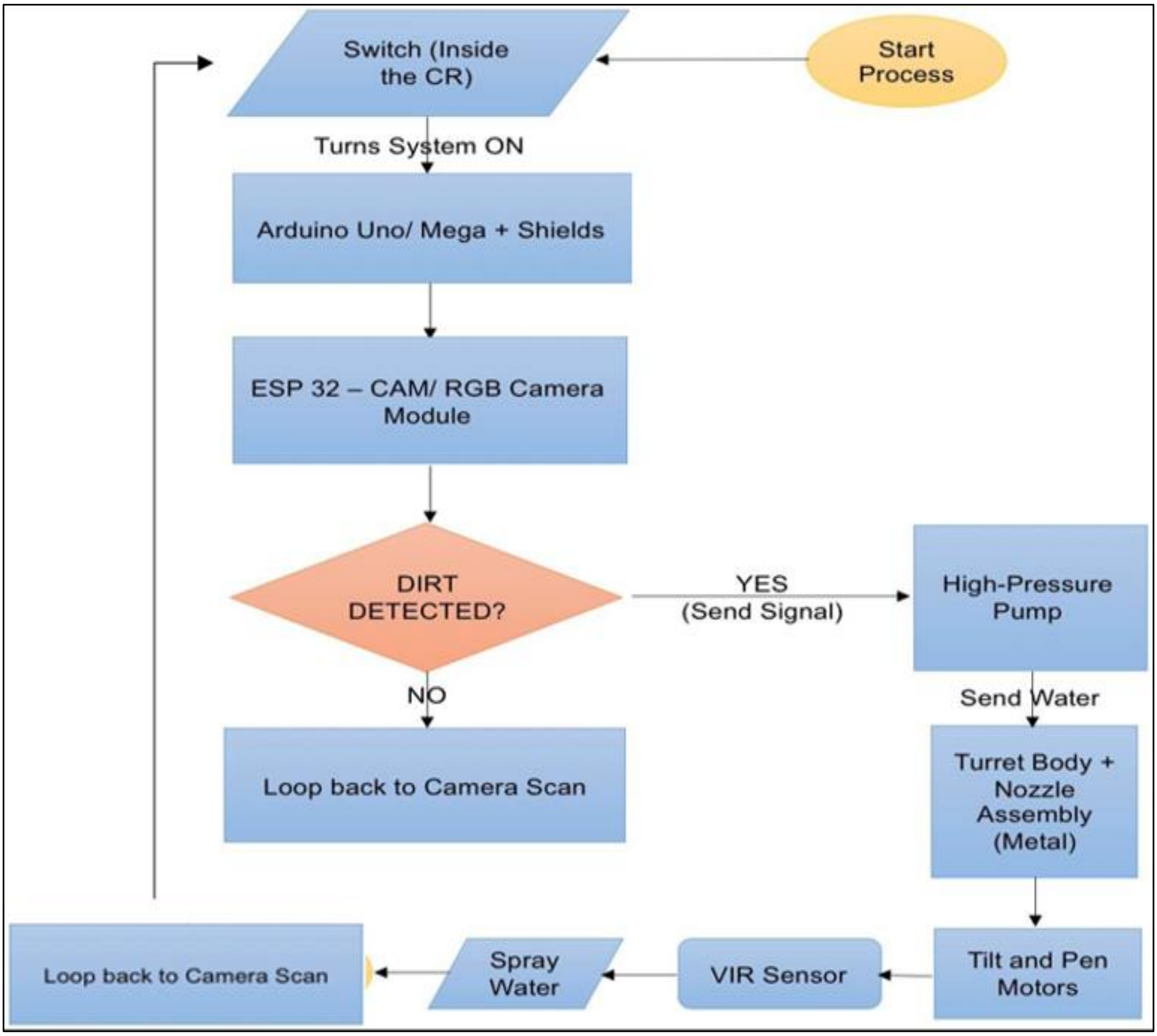

Fig 7 Logic Flow

The ESP32-CAM continuously scans the area to find dirt on the floor and walls. If no dirt is found, the system loops back to continue scanning, saving power and water. When dirt is detected, the ESP32-CAM sends a signal to the Arduino, which turns on the MOSFET and starts the high-pressure water pump. The pump sends water to the nozzle, and the pan and tilt servo motors move it toward the dirty area, forming a closed-loop system where sensing, control, and cleaning work together in real time for efficient automated cleaning.

The Figure 8 shows the three-dimensional prototype design of the SanitiBot, which is mounted on the left wall of the restroom behind the door to provide a wide and clear view of the interior.

Fig 8 Physical and Mechanical Specs

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This elevated placement allows the ESP32-CAM to effectively monitor both floor and wall surfaces while also protecting the system from water exposure during cleaning. Mounting the unit at the top helps prevent water from reaching the electronic parts, which increases durability and improves safety during operation. For added safety, the high-pressure pump, water supply, MOSFET, and lead-acid battery are placed outside the restroom to reduce electrical risks, protect them from moisture, and allow safe gas release while the battery is charging. Overall, the design focuses on good camera coverage, electrical safety, and protection from water damage, ensuring the system works reliably in a safe and practical automated restroom cleaning setup.

The Figure 9 illustrates the performance of the SanitiBot based on the five performance aspects. Based on the results, the SanitiBot obtained a composite mean of 2.8, which is described that as a Good. This shows that the system performed well during the testing and was able to meet its objective as the automated sanitation solution.

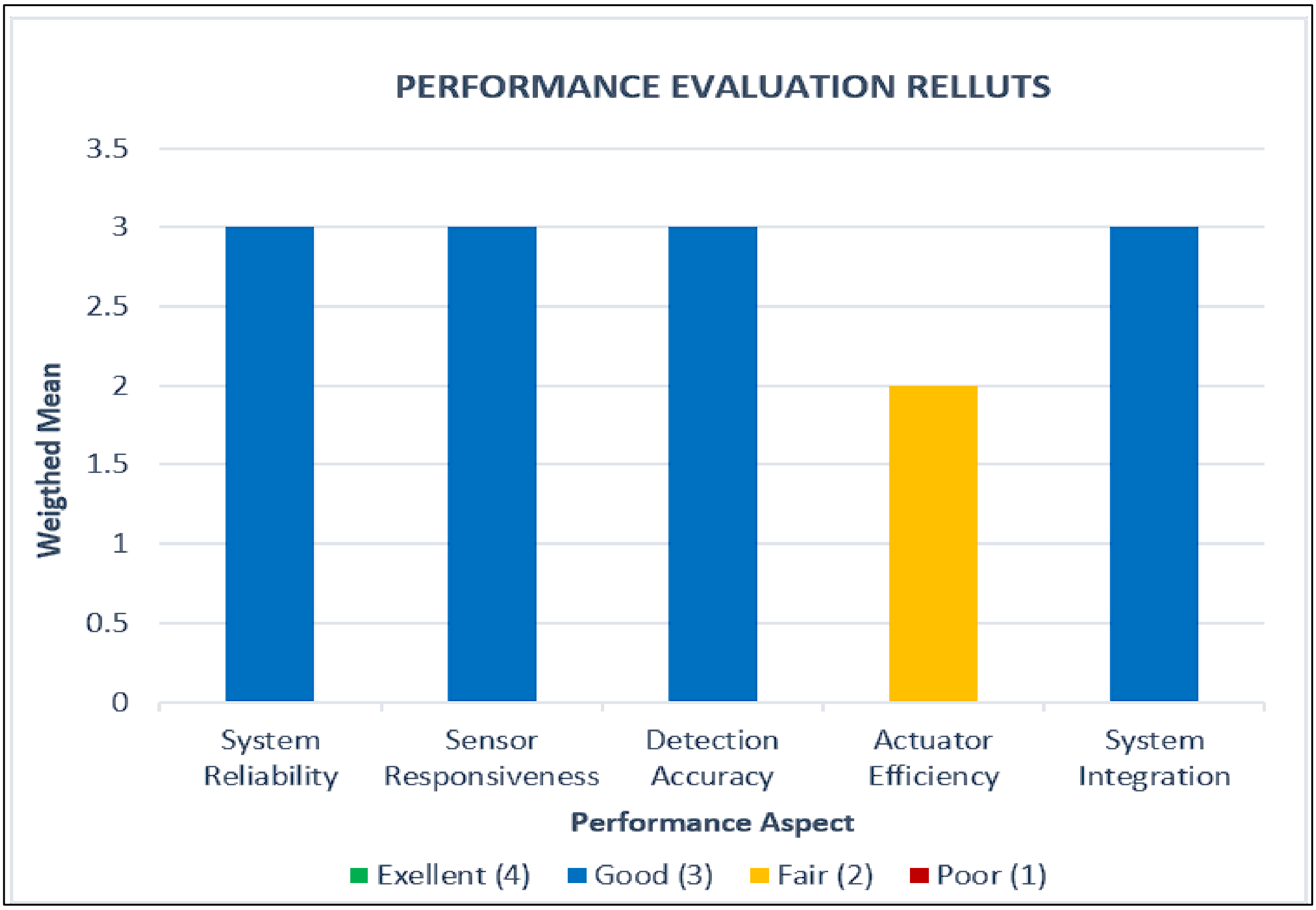

Fig 9 Performance Evaluation Result of the SanitiBot

The results show that the systems reliability, sensor responsiveness, detection accuracy, and system integration all received a weighted mean of 3, which is described that as Good. This means that the SanitiBot was able to operate steadily during the testing period with a minimal error, showing that the system components are reliable. The sensors were able to respond automatically, once a dirt or unsanitary conditions were detected, the cleaning process starts without any delays. This timely response helps to prevent the dirt from building up inside the restroom surfaces. For system integration it indicates that the sensors, microcontroller, and actuators worked well together as one system. In terms of detection accuracy, the system was able to identify the areas that needing cleaning while avoiding unnecessary spraying on clean surfaces.

Among of the five performance aspects, actuator efficiency received the lowest rating, with is a weighted mean of 2, described that as a Fair. This shows that while the servo motors and water pump were able to meet its function, their performance was not always efficient. In some cases, the spraying mechanism moved slowly or the water pressure is not as strong enough to clean the surfaces in one attempt to spray.

Overall, the results show that the SanitiBot is a working and effective automated sanitation system. Although the actuator efficiency still needs an improvement, the system performed well in terms of reliability, responsiveness, accuracy, and integration. Based on these findings, the null hypothesis stating that the system does not perform well is rejected. The results also show that the SanitiBot has a good potential to be used in a real restroom sanitation setting.

V. CONCLUSION AND RECOMMENDATIONS

This study shows that the SanitiBot can work well as an automated cleaning system by coordinating its different components. The system is able to detect dirt and automatically clean the area with little human involvement, which makes it useful for maintaining hygiene in schools, public areas, and other shared spaces. Even if some parts of the SanitiBot perform better than others, the overall operation demonstrates that the system can still function effectively and support cleaning tasks efficiently.

Even though the overall performance of the SanitiBot is rated as fair, the results indicate that it is still capable of performing automated sanitation tasks. The study also shows that improvements in areas may make the SanitiBot more reliable and effective. If this system may enhance, the system may have the potential to become a practical solution for reducing human effort in cleaning and promoting better hygiene in public and private spaces.

Based on the result obtained from the study, some recommendations are made to further enhance the SanitiBot Cleaning System. The responsiveness and reliability of the system, especially in varying lighting conditions, should be enhanced because, at times, the camera struggled to identify the dirt spots quickly. The image recognition capabilities of the camera should be improved. Moreover, the water control mechanism of the system, such as the flow control mechanism, should be improved to avoid wastage of water. Furthermore, simple AI-based image recognition techniques may also be explored to improve the accuracy of the system. Finally, future researchers are encouraged to conduct their studies in more restrooms for a longer period of time to assess the long-term efficiency and robustness of the system.

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APPENDICES

APPENDIX A
SAMPLE COMPUTATION

➢ *System Reliability*

Test	Successes	Score (%)
1	3/4	75
2	3/4	75
3	2/4	50
4	3/4	75
5	4/4	100
6	3/4	75
7	3/4	75
8	3/4	75
9	4/4	100
10	3/4	75

s = 3.54

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➢ *System Responsiveness*

Test	Score (%)
1	70
2	72
3	75
4	74
5	71
6	73
7	76
8	72
9	74
10	73

s = 2.03

➢ *Detection Accuracy*

Test	Score (%)
1	75
2	78
3	72
4	76
5	74
6	73
7	77
8	75
9	74
10	76

s = 1.83

➢ *Actuator Efficiency*

Test	Score (%)
1	70
2	73
3	72
4	75
5	74
6	71
7	76
8	72
9	73
10	74

s = 2.01

➢ *System Integration Stability*

Test	Score (%)
1	71
2	73
3	74
4	72
5	75
6	70
7	76
8	72
9	73
10	74

s = 1.95

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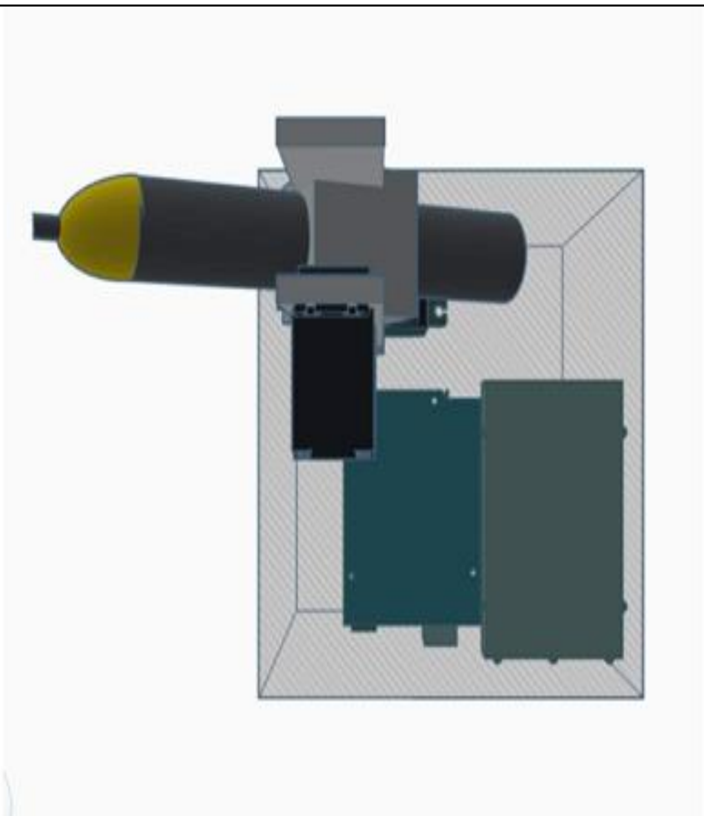
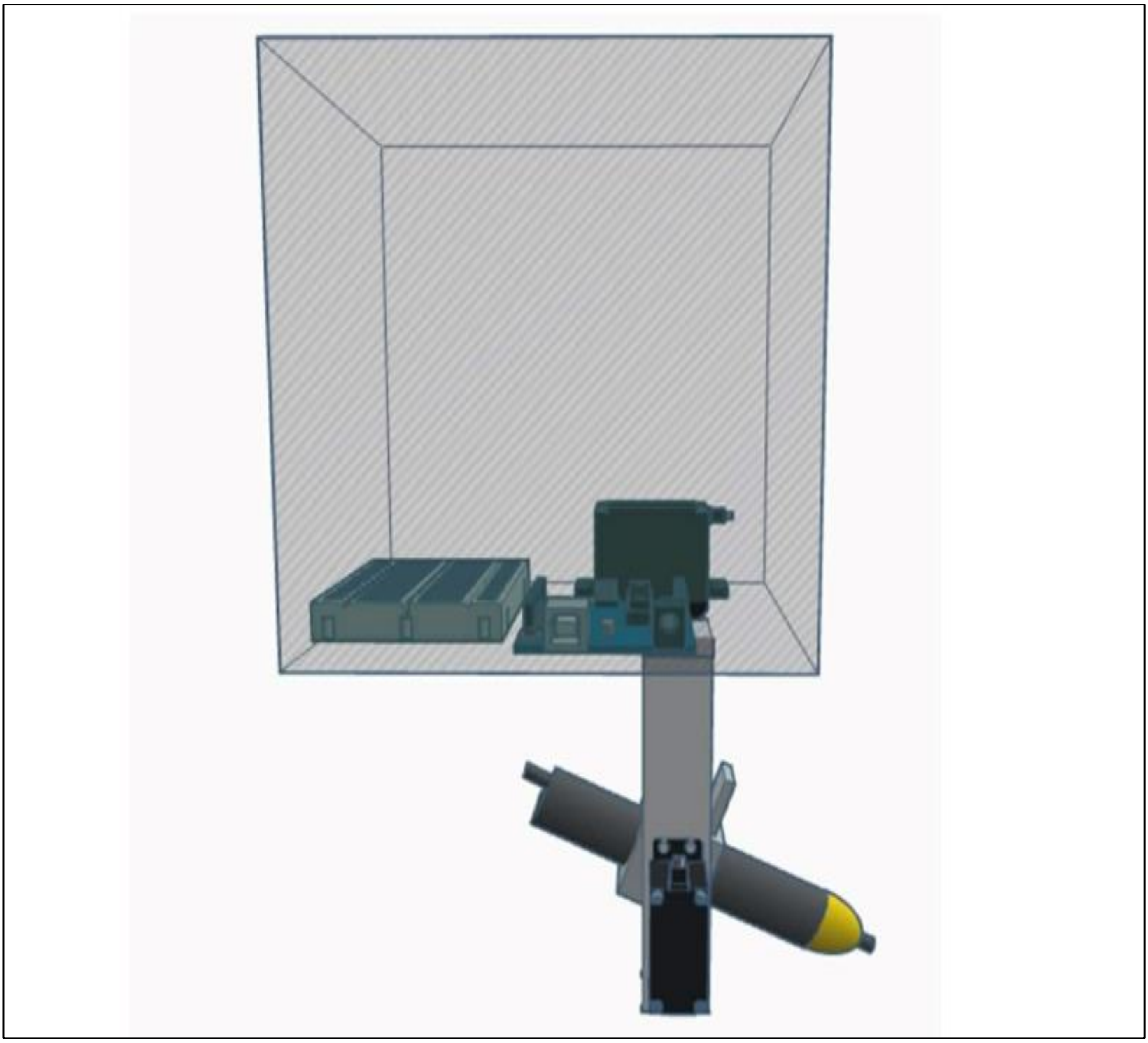
APPENDIX B DESIGN/FEATURES OF THE SYSTEM

➢ *Front View*

➢ *Plan View*



➢ *Electronic Case*



➢ *Electronic Case*

By enclosing the Arduino Mega, ESP32-CAM, and other electronic components within a protective case, the system gains durability and safety. The case shields the electronics from dust, water splashes, and accidental contact, reducing the risk of short circuits or damage. This means that during operation, the SanitiBot can perform its tasks reliably without interruptions caused by environmental factors. In essence, the electronic case ensures that the system remains stable, secure, and long-lasting, enhancing the overall efficiency and dependability of the prototype.