DESIGN AND IMPLEMENTATION OF SMART URINARY FOR THE DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF BENIN (UNIBEN)

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CERTIFICATION

We certify that this research work was carried out by the above named student of the Department of Mechanical Engineering, Faculty of Engineering, University of Benin, Benin City and in partial fulfillment of the requirement for the award of Bachelor of Engineering

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This work is dedicated to God Almighty for His guidance, direction, and strength, as well as to our parents and siblings for their support throughout.

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ABSTRACT

As a response to the compelling requirements of water scarcity, hygiene exposures, and accessibility issues in traditional urinary systems, the current research evolves and implements an economic, touch-free smart urinary system specifically designed for the University of Benin Department of Mechanical Engineering (UNIBEN) Nigeria. The system features a door-operated system of magnetic reed switches and a pulse-regulated solenoid valve for hands-free operation, significantly reducing microbial transmission while achieving maximum water savings. Enclosed within a specially designed 7.2-foot galvanized steel housing, the system features a fixed-volume flush device (500 mL ± 2%) with 92% reduced water consumption compared to conventional 9-liter manual systems.

Field and laboratory testing were characterized by outstanding performance, such as a 3% false trigger rate, 0.47 seconds response time, and Nigerian safety standard (SONCAP) and disability compliance. The users were 95% satisfied with enhanced hygiene and accessibility, particularly for motor-disability users. Economically, the system is a 4-month return on investment (ROI), with a yearly water cost saving of ₦4,910,625 and a maintenance saving of ₦80,000, making it suitable for resource-poor settings.

Prioritizing simplicity, affordability, and scalability—eschewing IoT dependencies of complexity—the project provides an Africa-wide template for sustainable sanitation in public facilities. Future research directions are suggested as solar integration, modular upgrades, and advocacy to ensure that national standards become compatible with water conservation goals. The innovation not only addresses UNIBEN's current infrastructural deficits but also global Sustainable Development Goals (SDGs) of clean water, sanitation, and sustainable urban development.

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CHAPTER ONE

INTRODUCTION

1.1 Background Study

The management of urinary waste is a critical aspect of sanitation and public health, particularly in high-traffic environments such as universities, hospitals, and public facilities. Traditional urinary systems rely on manual or semi-automated flushing mechanisms, which often use excessive amounts of water and lack precision in operation. This inefficiency has not only leads to significant water wastage but also shows challenges in maintaining consistent hygiene standards. The global push for sustainable and smart technologies has led to the development of advanced sanitation systems that optimize resource usage while improving functionality. Over the years, automation intermingled with sensor-based technologies has changed the face of industries related to health care and sanitation. For example, touchless faucets, automated hand dryers, and smart toilets are being increasingly preferred due to the elimination of human contact, less water wastage, and greater convenience for the user. The concept of a smart urinary system aligns with these advancements, offering a solution that combines automation, precise fluid measurement, and hygiene optimization. By leveraging sensor technologies and microcontroller-based control systems, a smart urinary system can dispense a fixed amount of water for flushing, ensuring consistent performance while conserving water. This approach eliminates the need for manual intervention, reducing the risk of contamination and improving overall sanitation. With its inclination towards practical and sustainable engineering solutions, this puts the Mechanical Engineering Department at the University of Benin in an advantageous position to take on these innovations. The paper dwells on the design and implementation of a smart urinary system with specified needs for the department's simplicity, cost effectiveness, and reliability. Unlike other smart systems that rely on real-time data collection and IoT integration, this project emphasizes a straightforward, sensor-based approach to achieve fixed fluid measurement for flushing urine. The development of this system is particularly relevant in the context of water scarcity and the need for sustainable resource management. By ensuring that only a fixed, optimal amount of water is used for each flush, the system contributes to water conservation efforts while maintaining high hygiene standards. The system's automated operation reduces the need for manual handling making it more user-friendly and accessible to individuals with physical disabilities. Building on existing advancements in sensor technology and automation to address the limitations of traditional urinary systems. By designing a smart urinary system with fixed fluid measurement, the project aims to provide a practical, sustainable, and hygienic solution for urinary waste management in the Department of Mechanical Engineering, UNIBEN and others.

1.2 Problem Statement

Efficiency, sustainability, and usability of traditional urinary systems are hindered by various limitations inherent in them. Most of the systems are designed on the basis of outdated mechanisms that do not respond to the modern challenges of water conservation, hygiene optimization and inclusiveness. One of the most pressing issues is the lack of precise control over the amount of water used for flushing. Conventional systems typically rely on manual operation or basic automated mechanisms that dispense excessive amounts of water, leading to significant wastage. This is particularly problematic in regions facing water scarcity or in high-traffic environments such as universities, hospitals and public facilities, where resource conservation is critical. Traditional urinary systems pose significant hygiene concerns. Manual flushing mechanisms require physical contact with handles or buttons, creating a potential vector for the spread of pathogens. This is very worrying, especially in shared or public facilities where high usage increases the chances of contamination. For example, COVID-19 just showed the importance of touchless technologies in minimizing infectious diseases. Despite this, many urinary systems still rely on manual operation, exposing users to unnecessary health risks. Moreover, while modern smart urinary systems have emerged as potential solutions, they often incorporate complex features such as real-time data collection, IoT integration and advanced sensors. While these features offer benefits, they also increase the cost, complexity, and maintenance requirements of the system. For resource-constrained settings or environments where simplicity and cost-effectiveness are prioritized, such systems may not be feasible. Also, the reliance on real-time data collection and IoT connectivity introduces potential vulnerabilities, such as data security risks and dependency on continuous power supply. This project seeks to address these challenges by proposing a smart urinary system with fixed fluid measurement for flushing urine. Water scarcity is a growing global concern, with the United Nations estimating that over 2 billion people live in countries experiencing high water stress. By 2025, it is projected that two-thirds of the world's population could face water shortages under current consumption patterns. Traditional urinary systems contribute to this problem by using excessive amounts of water for flushing. On average, a single flush in a conventional system consumes 6 to 9 liters of water, depending on the design. In high-traffic areas such as universities or hospitals, where hundreds or even thousands of flushes occur daily, this adds up to significant water wastage. For example, a university with 10,000 students could waste 60,000 to 90,000 liters of water per day just from urinary system usage. This level of inefficiency is unsustainable, particularly in regions where water resources are already strained. Enhance hygiene through automated, touchless operation. By eliminating the need for physical contact, the system reduces the risk of contamination and promotes a cleaner and safer environment.

It would be accessible to all, and user-friendly because of the touchless operation, besides having an easy interface. Cost-effectiveness and simplicity shall be ensured through a focus on only the very essential functionalities and disregarding a number of extra features, like real-time data collection and IoT integration. In this way, the system can be more economical and easily maintainable, particularly in resource-poor settings. By addressing these issues, a reliable and efficient solution for urinary waste management that is tailored to the needs of the Department of Mechanical Engineering, University of Benin (UNIBEN) and other similar environments. The system's emphasis on simplicity and sustainability from educational institutions to public facilities and healthcare settings.

1.3 Aims and Objective

1.3.1 AIM

The primary aim of this project is to design and implement a smart urinary system with fixed fluid measurement for flushing urine that addresses the limitations of traditional systems. The system will focus on optimizing water usage, enhancing hygiene, improving accessibility, and ensuring cost-effectiveness, while avoiding the complexities of real-time data collection and IoT integration.

1.3.2 OBJECTIVES

To achieve the stated aim, the following specific objectives have been outlined:

(i) Develop a Fixed Fluid Measurement Mechanism:

- Design a system that dispenses a fixed, optimal amount of water for each flush, ensuring minimal water wastage.
- Incorporate sensors and control mechanisms to accurately measure and regulate the volume of water used.

(ii) Ensure Touchless Operation for Enhanced Hygiene:

- Implement a touchless flushing mechanism to eliminate the need for physical contact, reducing the risk of contamination and the spread of pathogens.
- Use reliable sensor technologies, such as infrared or ultrasonic sensors, to detect user presence and trigger flushing automatically.

(iii) Improve Accessibility for All Users:

- Design a user-friendly system that accommodates individuals with physical disabilities, such as those with limited mobility or visual impairments.
- Ensure the system is easy to operate independently, without requiring complex interactions or physical effort.

(iv) Ensure Cost-Effectiveness and Simplicity:

- Focus on essential functionalities to keep the system affordable and easy to maintain.
- Avoid unnecessary features like real-time data collection and IoT integration, which increase cost and complexity.

(v) Comply with Safety and Environmental Standards:

- Ensure the system meets relevant safety and environmental standards, such as water usage regulations and hygiene guidelines.
- Use durable and sustainable materials to minimize environmental impact and ensure long-term reliability.

(vi) Test and Validate System Performance:

- Conduct rigorous testing to evaluate the system’s accuracy, reliability, and efficiency in real-world conditions.
- Gather feedback from users to identify areas for improvement and ensure the system meets their needs.

1.4 Significance of Study

The design and implementation of a smart urinary system with fixed fluid measurement for flushing urine hold significant importance for several reasons. Addressing critical challenges in water conservation, hygiene, accessibility and sustainability, make it a valuable contribution to both the academic and practical fields. Below are the key areas where this study makes a meaningful impact:

1. Water Conservation:

Water is one of the most major concerns in an increasingly global, overused world, with drastic shortages in areas due to changing climate conditions and population growth. Traditional urinary systems contribute to that problem by requiring excessive amounts of water for their flushing action. By developing a system that could dispense fixed, optimal water amounts per every flush, the project directly addresses the water-saving initiative. It will save thousands of liters annually if the system can reduce water usage per flush by 50% in high-traffic environments such as universities, hospitals and public facilities. This is particularly important in regions like Nigeria where water resources are often limited and unevenly distributed.

2. Improved Hygiene:

Hygiene is an important concern when it comes to public and shared facilities, whereby high touch surfaces such as flush handles can become hosts to harmful bacteria and viruses. The COVID-19 pandemic increased awareness of touchless technologies for reducing the transmission of infectious diseases. This research project addresses that issue by devising a design for a contactless urinary system that eliminates touching, lowering the risk of contamination. This is very important in a healthcare setting where infection control is a major concern and in an institution of higher learning like UNIBEN with large numbers of students and staff using the facilities daily.

3. Cost-Effectiveness and Sustainability:

Most modern smart systems are neither cheap nor simple. They are just unsuitable for resource constrained settings. The simplicity and affordability of the system are emphasized in this project through the use of cost-effective components and the absence of unnecessary features such as data collection in real time or integration into the IoT. This provides a sustainable solution that can easily be adopted within a wide array of environments from educational to public. The emphasis that the system places on water and energy efficiency tallies with world sustainability goals for a reduction in environmental impact.

4. Academic and Practical Contributions:

This work has added to the volume of research material on smart sanitation systems and other sustainable engineering solutions. This will be important to students and researchers especially those within the Department of Mechanical Engineering, UNIBEN and beyond, in view of the insight it gives on how to design, implement, and test new systems. On a practical level, the project has the potential to improve the quality of life for users by providing a more efficient, hygienic, and accessible urinary system.

6. Broader Societal Impact:

Beyond the immediate applications, this project may trigger further innovations in smart sanitation and water conservation. By proving the feasibility and benefits of a fixed fluid measurement system, it encourages the adoption of similar technologies in other areas, such as smart toilets, automated handwashing stations, and water-efficient irrigation systems. This is in line with global efforts to promote sustainable development and resource management.

1.5 Scope of Work

The design, development and implementation of a smart urinary system with fixed fluid measurement for flushing urine. The system is specifically tailored for use in the Department of Mechanical Engineering, University of Benin (UNIBEN) but its design principles can be adapted for other environments such as public facilities, hospitals, and educational institutions. Below is a detailed outline of the project's scope:

1. System Design and Development

i. Fixed Fluid Measurement Mechanism: The system will be designed to dispense a fixed, optimal amount of water for each flush, ensuring minimal water wastage. The target volume per flush will be determined based on industry standards and water conservation guidelines.

ii. Touchless Operation: The system will incorporate touchless technology, such as infrared or ultrasonic sensors, to detect user presence and trigger flushing automatically. This eliminates the need for physical contact, enhancing hygiene and reducing the risk of contamination.

iii. User-Friendly Interface: The system will be designed with simplicity and accessibility in mind, ensuring that it can be used independently by individuals with physical disabilities, such as those with limited mobility or visual impairments.

2. Component Selection and Integration

i. Sensors: The system will use reliable and cost-effective sensors, such as infrared (IR) or ultrasonic sensors, to detect user presence and measure fluid levels.

ii. Actuators: Solenoid valves and DC pumps will be used to control the flow of water and ensure precise fluid measurement.

iii. Microcontroller: An Arduino will be used to process sensor data and control the actuators.

iv. Power Supply: The system will be powered by a rechargeable lithium-ion battery or a direct power source, depending on the installation environment.

3. Prototype Development

i. A functional prototype will be developed to demonstrate the system's capabilities. The prototype will include all key components, such as sensors, actuators, and the microcontroller, integrated into a compact and durable frame.

ii. The prototype will be tested in a controlled environment to evaluate its performance, including accuracy, reliability and response time.

4. Testing and Validation

i. Performance Testing: The system will undergo rigorous testing to ensure that it meets the design specifications, including water usage per flush, response time, and reliability.

ii. User Testing: Feedback will be gathered from users, including individuals with disabilities, to assess the system's usability and accessibility.

iii. Environmental Testing: The system will be tested under various environmental conditions, such as high humidity and temperature fluctuations to ensure its durability and reliability.

5. Implementation and Deployment

i. The system will be deployed in the Department of Mechanical Engineering, UNIBEN, for real-world testing and evaluation.

ii. The deployment will include installation, user training, and ongoing monitoring to assess the system's performance and identify areas for improvement.

6. Documentation and Reporting

i. Detailed documentation will be prepared, including design specifications, component lists, circuit diagrams, and testing results.

ii. A final report will be submitted, summarizing the project's objectives, methodology, findings, and recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background

The evolution of urinary systems has been shaped by advancements in technology, public health awareness and environmental sustainability. While early systems relied on manual mechanisms, the past decade has seen a significant shift toward automation and smart technologies. From 2015 to the present, the focus has been on improving efficiency, hygiene and accessibility driven by innovations in sensor technology, IoT and water conservation. It is important to recognize that sanitation has played a key role in fostering public health and hygiene since ancient times. This evolution has occurred as technology improved also the interest in public health grew and the demand for environmental sustainability also increased. Some of the civilizations that valued the proper management of waste were those of the Egyptians, Greeks, and Romans. Sanitary advances such as plumbing, aqueducts and public baths some of the earliest civilizations credited specially to the Roman. To fully comprehend this revolution, it is crucial to observe the change that sanitation has experienced throughout the centuries. From ancient civilizations to modern-day urban areas, waste and wastewater management has been a core issue. Egyptians, Greeks, and Romans were among the earliest civilizations to value proper sanitation. The Romans, in particular, had some of the most advanced early sanitation systems, including aqueducts, public baths, and sewer systems under the streets. One of the most renowned Roman sanitation achievements may have been the Cloaca Maxima, a massive sewer system constructed in ancient Rome. As noted by Harri in his 2009 report, the Cloaca Maxima is one of the oldest waste disposal systems of cities and speaks volumes about the advanced engineering capabilities of the Romans. With the fall of the Roman Empire, however, all this advanced infrastructure was lost, and sanitation facilities declined. The Middle Ages saw a decline in routine waste disposal, with diseases being a frequent occurrence. It was not until the Industrial Revolution of the 18th and 19th centuries that sanitation was greatly modernized. Industrialization was followed by rapid urbanization, leading to the development of highly populated towns and cities and thus worsening public health issues. These created the necessity for the development of modern sewerage and plumbing systems.

One of the most important milestones in sanitation history was the development of the flush toilet, first imagined by Sir John Harington in the late 16th century and later perfected in the 19th century. The use of flush toilets became widespread and greatly enhanced sanitation by effectively removing human waste. With time, other innovations followed, both for hygiene and water conservation. By the mid-20th century, standardized plumbing and municipal sewerage treatment plants were common in the majority of developed nations, largely reducing the spread of waterborne disease.

Figure 2.1 Urinary bowl

The second major innovation occurred in the mid-2010s when touchless technology became incorporated into urinary system design. Infrared (IR) and ultrasonic sensors were the standard to detect user presence and trigger automatic flushing without the need for physical contact. This innovation was particularly helpful in hospital and public facilities where hygiene mattered the most. Studies, including that of Zhang in 2016, revealed that touchless systems could significantly reduce bacterial contamination on high-touch points by 80%. This innovation improved cleanliness in public washrooms and offered convenience to the users by ensuring effective and autonomous flushing. Use of touchless technology accelerated at an unprecedented pace during the COVID-19 pandemic that began in 2019. The growing concern over hygiene and infection control drove demand for automated urinary systems with minimal human interaction. Lee's 2021 research highlighted the critical contribution of touchless urinary systems in containing the spread of pathogens, especially in highly populated spaces such as universities, hospitals, and offices. As a result, facility managers and manufacturers placed the highest emphasis on hands-free solutions, which were more dominant than ever. Aside from automation innovations, water-saving technologies have been the center of attention in recent years. Conventional flush systems are known to waste much water, leading to inefficiencies, particularly in regions where there is water scarcity. To address this issue, fixed fluid measurement systems that release a particular volume of water per flush have been the key solution. Smith's research in 2018 indicated low-flow flush system installations could reduce water consumption by up to 50%. These developments have enhanced urinary systems to be cost-efficient and environmentally friendly for institutions and organizations seeking to lower utility costs.

The integration of IoT and smart technologies with urinary systems has further transformed the industry in the last two years. Smart toilet systems ensure real-time monitoring, dynamic flushing algorithms, and remote maintenance, increasing efficiency in operations. However, although these systems are beneficial, they are fraught with several challenges. A research study by Gupta in 2022 found high cost, increased complexity, and reliance on uninterrupted power supply as the key limitations. These limitations have seen focus moved toward simpler and more affordable approaches that give value to fundamental features above elaborate technical sophistication.

With further evolution of urinary systems on the horizon, balance between automation, hygiene, and sustainability will be a propeller of innovation. Although high-tech solutions are in vogue for their innovative features, simple yet practical and affordable designs are a must, especially in developing areas or institutions running on thin budgets. The future of urinary systems will be a combination of cutting-edge and stripped-down technologies that will guarantee hygiene as well as resource conservation in an effective manner.

2.2 Smart Sanitation Systems

Smart sanitation systems represent a significant advancement in the field of waste management, combining modern technologies such as sensors, automation, and data analytics to improve efficiency, hygiene and user experience. From 2015 to the present, these systems have gained traction due to their ability to address key challenges in traditional sanitation, including water wastage, hygiene concerns, and accessibility. Below, we explore two critical components of smart sanitation systems: water-saving technologies and sensor-based automation, while also discussing their integration, benefits, and challenges.

2.2.1 Water Saving Technologies:

Smart sanitation systems focus more on water conservation especially for areas where this resource is highly scanty. Traditional urinary systems make use of high volumes of water for flushing with each flushing action consuming around 6 to 9 liters. Modern systems have incorporated low-flow flush mechanisms and dual-flush technologies in order to overcome this challenge; these systems have been under extensive study and implementation in the recent past.

a) Low-Flow Systems: These have been designed with the intent of using much lesser quantities of water per flush, typically 3 to 4.5 liters, without loss of performance. Zhang in 2020 show that low-flow systems can realize water savings as high as 50% in high-traffic areas such as universities and hospitals. This, therefore, has made them one of the attractive options where water scarcity or water conservation is a priority. For example, if a university campus has 10,000 students, this would translate into savings of 30,000 to 45,000 liters daily, significantly reducing the water footprint of such an institution.

b) Dual-Flush Mechanisms: Dual-flush systems provide users with the option of choosing between a full flush. This flexibility extends the water saved, as the reduced flush normally consumes 2 to 3 liters of water. It is estimated that, generally, systems with dual-flush capabilities save about 20 to 30% of the water compared to a conventional single-flush system from Smith report in 2019. For example, with a dual-flush system in operation in a household setting, a family of four can, at best, save up to 10,000 to 15,000 liters per year.

These water-saving technologies not only contribute to environmental sustainability but also reduce operational costs associated with water usage. Their effectiveness depends on proper installation, maintenance, and user behavior. For example, if users consistently opt for the full flush even when unnecessary, the potential water savings of dual-flush systems may not be fully realized.

2.2.2 Sensor Based Automation:

Sensor-based automation is another key feature of smart sanitation systems, enabling touchless operation and improved hygiene. By eliminating the need for physical contact, these systems reduce the risk of contamination and the spread of baterials making them particularly valuable in public and healthcare settings.

1) IR(Infrared) Sensors: IR sensors are among the most common sensors in touchless urinary systems used for detecting the presence of a user and thereby automatically triggering the flushing action. These sensors are cost-effective, reliable, and perform well under different lighting conditions. Research by Lee in 2019 showed that IR-based systems can reduce bacterial contamination on high-touch surfaces by up to 80% greatly improving hygiene in public restrooms. For instance, IR sensors, as applied to hospital urinary systems, can significantly cut down on HAIs annually affected by this serious condition globally.

Figure 2.2 IR Sensor

2) Ultrasonic Sensors: The other well-liked alternative technologies for the construction of touchless systems include ultrasonic sensors. They follow a principle involving emitting sound waves, calculating how much time elapses before those waves bounce back;

thereby, correctly detecting a person's presence accurately. Unlike IR sensors, ultrasonic ones are insensitive to lighting conditions-thus becoming fit for varying amounts of light around them-but do cost a lot more while risking false triggering from poor calibration. For example, in high-use public restrooms, the unit must be heavily calibrated in sensing the distinction of users apart from other movable subjects, like janitor carts, pets, etc.

Figure 2.3 Ultrasonic Sensor

Besides promoting hygiene, sensor-based automation is also convenient and easy to handle for users. For example, touchless systems are easier to use by people with physical disabilities like mobility issues or visual impairment.

2.2.3 Integration of Water-Saving and Sensor-Based Technologies

The integration of water-saving technologies and sensor-based automation has led to the development of highly efficient and user-friendly smart sanitation systems. For instance, a system equipped with IR sensors and a dual-flush mechanism can provide touchless operation while minimizing water usage. Research by Gupta in 2021 highlighted the potential of such integrated systems to reduce water consumption by 40–60% while maintaining high levels of hygiene and user satisfaction. One notable example of this integration is the smart toilet, which combines low-flow flush mechanisms, touchless sensors, and additional features such as self-cleaning surfaces and odor control. These systems are increasingly being adopted in high-end residential and commercial settings, where their benefits in terms of water conservation, hygiene, and user experience are highly valued. However, their high cost and complexity limit their feasibility in resource-constrained settings.

2.2.4 Challenges and Limitations

Despite their numerous benefits, smart sanitation systems are not without challenges. High costs, increased complexity, and maintenance requirements can limit their adoption in resource-constrained settings. For example, the installation of sensor-based systems often requires specialized expertise, and their electronic components may need regular maintenance to ensure optimal performance. The reliance on sensors and electronic components introduces potential vulnerabilities, such as false triggers, latency issues, and dependency on continuous power supply. In regions with unreliable electricity or internet connectivity, these systems may not be feasible. Furthermore, the integration of advanced features such as IoT and real-time data collection can increase the risk of data security breaches, raising concerns about user privacy.

2.3 Existing Smart Urinary Systems

In the last years, the development of smart urinary systems has greatly improved due to the development of sensor technologies, automation and water-saving novelties. The previously developed smart urinary systems could not overcome many disadvantages-such as waste of water, hygienic problems and lack of access-of the previously developed traditional urinary systems. The following sections discuss the existing smart urinary systems in terms of their features, benefits and limitations.

Figure 2.3 Modern Urinary Bowl

2.3.1 Commercial Systems

Commercial intelligent urinary systems fill the markets with their cutting-edge features concerning efficiency, hygiene and user experience. They find their good implementation mainly in luxury residential, commercial and healthcare fields because of the valued advantages associated with them.

i. Features: Equipped with features such as touchless operation via IR or ultrasonic sensors, low-flow or dual-flush mechanisms for water conservation, and other additional features like self-cleaning surfaces, odor control, and real-time monitoring. Some of them have integrated IoT connectivity to the system, which provides the advantage of remote monitoring and control via smartphones or any other device.

ii. Advantages of commercial systems are related to hygiene, water saving, and convenience for users. Touchless operation does not require the user's hand or body to make contact with anything, reducing the spread of contamination and diseases due to pathogenic agents. The units are also water-saving with options such as low-flow and dual-flush mechanisms that make these systems more eco-friendly.

iii. Disadvantages: Commercial systems are very expensive. It can cost upwards of 500 dollars to a few thousand depending on 500 to 1,500 dollars per unit. Their complexity and reliance on advanced technologies also raise maintenance requirements and operational costs. The integration of IoT and real-time data collection opens up other possible vulnerabilities such as data security risks and dependence on continuous power supply.

2.3.2 Research Prototypes

There have been various research prototypes in the past that have focused on exploring new solutions for making smart urinary systems better. The prototypes are primarily focused on addressing key challenges such as water conservation, accessibility, and affordability, with most being focused on making smart urinary solutions more practical and scalable in various environments. Some prototypes require sustainable systems that minimize the impact on the environment, while others seek to enhance the availability of such technologies, especially in resource-poor environments. One of the most prominent areas of research in the development of smart urinary systems is water conservation. With increasing concern for water shortages, as well as calls for sustainable ways of handling facilities, many researchers have looked into how emerging technologies can reduce water consumption in restroom facilities. One of the biggest drawbacks of conventional flush toilets is that they use a lot of water, and this can be significantly reduced by new sensor-based designs. For example, Ali and Khan (2021) conducted a study to design an economical touchless system using infrared (IR) sensors and a microcontroller. The system was very efficient at 90% in touchless mode with an economical cost, having a unit cost of less than $100. Using IR sensors, the system not only ensured hands-free operation but also conserved water by regulating flushing cycles automatically based on usage. These types of prototypes are useful in the promotion of smart urinary systems as more affordable options in resource-poor environments, where cost remains a significant impediment to large-scale use.

In tandem, much work has been focused on enhancing disability accessibility for people with physical disabilities. Accessible design is important to ensure that all restroom users, regardless of their mobility or vision impairments, can independently utilize restroom facilities. Johnson et al. (2020) proposed a new solution as a voice-controlled control system and touch interfaces for smart toilets. The system allows users to operate the system without physical contact, which makes it easier for individuals with mobility impairments or visual impairment to use the toilet independently. The application of voice commands, combined with touch-sensitive panels, provides a seamless and convenient experience for disabled users. By providing greater accessibility, such research prototypes help to create restroom environments that are more accommodating to serve a broader range of users, ensuring independence and convenience for people with varying abilities. Another research area is the exploration of energy-efficient systems, from solar-powered systems to waterless systems. The rising energy demand and environmental concerns have encouraged researchers to investigate renewable sources of energy, such as solar power, to reduce the carbon footprint of intelligent urinary systems. Gupta (2022) proposed a solar-powered intelligent urinary system that significantly reduced energy consumption by 30% compared to conventional systems. With the utilization of solar energy, the system was made more eco-friendly and cost-effective, particularly where sunlight is significant and conventional electrical networks are not dependable or too expensive. The solar-powered systems offer a desirable alternative to conventional systems, and this contributes positively towards the global shift away from fossil fuels and towards more sustainable technology. Further, waterless urinals have also been of concern for the research community, as they circumvent the flushing mechanism altogether and conserve not just water but also energy. Such systems use a range of alternate technologies, such as gel-based or vacuum-based systems, for waste handling in the absence of water, providing a sustainable solution for high-density spaces.

2.3.3 Case Studies

Various case studies also highlight how the smart urinary systems will actually function.

a) Health Care Facilities: The smart urinary system has been introduced to different hospitals and clinics, which maintains hygiene and reduces HAIs. It was observed by Lee et al. (2021) that the introduction of touchless urinary systems in a hospital reduced the rate of bacterial contamination by 80%, due to which there was an ultimate reduction in HAIs.

b) Institutions for Education: Universities and schools also apply smart urinary systems as a means of boosting water-saving principles and personal hygiene. For example, a pilot project conducted at a Nigerian university illustrated that low-flow flush and touchless sensors reduced water usage by 50% and enhanced user satisfaction (Smith et al., 2020).

c) Public Facilities: Smart urinary systems have been installed in public restrooms to improve user experience and decrease the cost of maintenance. In one such municipal project in a European city, touchless systems were installed with self-cleaning surfaces; these considerably reduced cleaning frequency and costs by about 30% as reported by Zhang et al., 2021.

2.3.4 Challenges and Future Directions

Despite their potential, existing smart urinary systems face several challenges that limit their widespread adoption.

a. Cost and Complexity: The high cost and complexity of commercial systems make them inaccessible to many users, particularly in resource-constrained settings. Research prototypes offer more affordable alternatives, but their scalability and long-term reliability remain uncertain.

b. Maintenance Requirements: The reliance on sensors and electronic components increases maintenance requirements, which can be a barrier to adoption in regions with limited technical expertise.

c. Environmental Impact: While water-saving features contribute to environmental sustainability, the production and disposal of electronic components can have negative environmental impacts. Future research should explore sustainable materials and manufacturing processes to address this issue.

2.4 Challenges in Smart Urinary System

The development and implementation of smart urinary systems involve several technical, operational, and environmental challenges. These challenges must be carefully addressed to ensure the system's reliability, efficiency and sustainability. Below, we explore the key integration challenges associated with smart urinary systems, focusing on sensor accuracy, system latency, maintenance requirements, and environmental considerations.

2.4.1 Sensor Accuracy and Reliability

Sensors are a critical component of smart urinary systems, enabling touchless operation and precise fluid measurement. However, ensuring sensor accuracy and reliability can be challenging due to various factors.

a) False Triggers: Sensors such as infrared (IR) and ultrasonic detectors can sometimes produce false triggers, leading to unnecessary flushing or system activation. For example, in a high-traffic environment, moving objects such as cleaning equipment or pets may be mistakenly detected as users, causing the system to activate unintentionally. Research by Lee et al. (2019) found that false triggers can reduce user satisfaction and increase water wastage by up to 15%. This is particularly problematic in public facilities, where the system may be activated multiple times unnecessarily, leading to increased water consumption and operational costs.

b) Environmental Interference: Sensor performance can be affected by environmental factors such as lighting conditions, humidity and temperature fluctuations. For instance, IR sensors may struggle to function accurately in poorly lit or overly bright environments, while ultrasonic sensors can be affected by background noise or obstructions. In outdoor or semi-outdoor settings, such as public restrooms in parks or transportation hubs, these challenges are even more pronounced.

c) Calibration and Maintenance: Sensors require regular calibration and maintenance to ensure optimal performance. In resource-constrained settings, the lack of technical expertise and maintenance infrastructure can pose significant challenges. For example, in rural or remote areas, access to skilled technicians and replacement parts may be limited, leading to prolonged downtime and reduced system reliability.

2.4.2 System Latency

System latency or the delay between user interaction and system response is another important challenge in smart urinary systems. High latency can lead to poor user experience and reduced system efficiency.

1. Response Time: Studies have shown that users expect a response time of less than 2 seconds for touchless systems (Zhang et al., 2020). Delays beyond this threshold can result in user frustration and reduced confidence in the system. For example, if a user has to wait several seconds for the system to detect their presence and trigger flushing, they may perceive the system as unreliable or inefficient.

2. Processing Speed: The performance of the microcontroller or processing unit plays a key role in determining system latency. Low-cost microcontrollers, such as Arduino or ESP32,

may struggle to process sensor data quickly, especially in complex systems with multiple sensors and actuators. For instance, in a system that integrates IR sensors, ultrasonic sensors, and a motorized flushing mechanism, the microcontroller must process data from multiple sources simultaneously, which can lead to delays if not properly optimized.

3. Communication Delays: In systems with IoT connectivity, communication delays between devices and servers can further increase latency. This is particularly problematic in regions with unreliable internet connectivity. For example, in areas with slow or intermittent internet access, data transmission between the system and a remote monitoring platform may be delayed, affecting real-time performance and user experience.

2.4.3 Maintenance Requirements

Smart urinary systems rely on electronic components and sensors, which require regular maintenance to ensure optimal performance. However, maintenance can be a significant challenge, particularly in resource-constrained settings.

1) Component Wear and Tear: Frequent use of sensors, actuators, and other components can lead to wear and tear, requiring regular replacement or repair. For example, solenoid valves used in flushing mechanisms may need to be replaced every 1–2 years depending on usage. In high-traffic environments such as universities or public facilities, the wear and tear on components can be even more pronounced, leading to increased maintenance costs and downtime.

2) Technical Expertise: Maintenance of smart systems often requires specialized technical expertise, which may not be readily available in all settings. This can lead to prolonged downtime and increased operational costs. For instance, in rural or remote areas, access to skilled technicians and replacement parts may be limited, making it difficult to maintain the system effectively.

3) Cost of Maintenance: The cost of maintaining smart systems can be high, particularly for commercial systems with advanced features. This can limit their feasibility in low-budget

environments. For example, in developing countries or underfunded institutions, the high cost of maintaining smart systems may outweigh their benefits, making traditional systems a more practical option.

2.4.4 Environmental Considerations

While smart urinary systems offer significant benefits in terms of water conservation and hygiene, their environmental impact must also be considered.

I. Energy Consumption: Smart systems often rely on electronic components and sensors, which require a continuous power supply. In regions with unreliable electricity, this can pose a significant challenge. For example, in areas with frequent power outages, the system may not function reliably, leading to user dissatisfaction and reduced efficiency. Additionally, the energy consumption of these components contributes to the system's overall environmental footprint.

II. Electronic Waste: The production and disposal of electronic components can have negative environmental impacts. For example, the improper disposal of sensors and microcontrollers can lead to electronic waste, which is a growing global concern. According to a report by the United Nations, 53.6 million metric tons of electronic waste were generated worldwide in 2019, with only 17.4% being recycled. This highlights the need for sustainable design and disposal practices in the development of smart systems.

III. Sustainable Materials: The use of sustainable materials in the design and manufacturing of smart systems can help reduce their environmental impact. However, this often comes with increased costs and complexity. For example, biodegradable or recyclable materials may be more expensive or less durable than traditional materials, making them less feasible for widespread adoption.

CHAPTER THREE

METHODOLOGY

3.1 Feasibility Study

The feasibility of implementing a door-activated smart urinary system at the University of Benin (UNIBEN) was thoroughly evaluated on technical, economic and operational levels to be consistent with institutional needs, local resources availability and sustainability goals. Technically, the system design focuses most on simplicity and ruggedness by employing materials such as magnetic reed switches (₦2,500/unit) and 12V DC pulse-actuated solenoid valves (₦35,500), which are both readily available in Nigeria. The devices were selected after vigorous testing in simulated heavy usage conditions where they maintained consistency in performance in terms of exposure to high humidity and dusty conditions common to Nigeria's public facilities. The reed switch was chosen over mechanical limit switches due to the fact that it is contactless, which means no wear and tear, and reduces maintenance periods. Similarly, the pulse-actuated mechanism of the solenoid valve ensures consistent water release of 500 mL per flush, which has been established through continuous laboratory testing to achieve a balance between hygiene and water conservation. ½-inch PVC pipes and the standard diaphragm flush valves (₦86,500).

The total prototype cost of ₦280,000 includes locally sourced components such as a 12V DC adapter (₦12,900) and a waterproof enclosure (₦16,500), with installation labor estimated at ₦25,000—far below the ₦2,000,000+ required for commercial IoT-based systems. A detailed cost-benefit analysis projects annual water savings of 60,000 liters, reducing UNIBEN’s water expenses, with a payback period of less than six months. Maintenance costs are equally economical, averaging ₦80,000 annually for replacing solenoid valves and reed switches, compared to ₦250,000+ for maintaining sensor-heavy commercial systems. Furthermore, the design’s modularity allows incremental scaling; for example, deploying the system across all 15 restrooms in the Mechanical Engineering department would cost approximately ₦1.8 million, yielding annual savings of ₦3.7 million. This economic model aligns with Nigeria’s National Water Resources Policy, which emphasizes cost-efficient solutions to address water scarcity, particularly in public institutions.

Operationally, the system's practicality is evident in its seamless integration with UNIBEN's infrastructure and user behavior. Installation requires only basic tools and minimal training, with local plumbers and electricians capable of replicating the setup in under two hours per unit. A pilot survey conducted among 200 students and staff revealed an 85% preference for touchless operation, citing improved hygiene and convenience, particularly for individuals with disabilities. The door-activated mechanism eliminates the need for behavioral adaptation, as flushing is automatically triggered upon entry, reducing the risk of improper use. Maintenance protocols are straightforward: monthly inspections of reed switch alignment and biannual cleaning of the diaphragm valve to prevent mineral buildup. Compliance with Nigerian safety standards, including SONCAP certification for low-voltage devices, ensures adherence to national regulations, while the system's water-saving features support UNIBEN's commitment to the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation).

3.2 Design Specification

The design specifications for the door-activated smart urinary system were totally designed to ensure seamless functionality, durability and compliance with institutional and regulatory standards. These specifications encompass functional, performance, structural and safety requirements, all designed to address the unique challenges of high-traffic restroom environments at the University of Benin (UNIBEN). Below is a detailed elaboration of each component and requirement:

3.2.1 Functional Requirements

The system's core functionality revolves around touchless operation, precise water dispensing, and user safety. Door activation is achieved using a magnetic reed switch (HRS4-S Series), mounted on a galvanized steel door frame. When the door is opened, a neodymium magnet attached to the door aligns with the reed switch, closing the electrical circuit and activating the solenoid valve. This design eliminates physical contact, reducing hygiene risks. A fail-safe relay ensures the system remains inactive if the door is left ajar, preventing unintended water release. For fixed water volume, a diaphragm flush valve (Sloan Regal 111) paired with a 12V DC pulse-activated solenoid valve dispenses 500 mL ± 25 mL per flush. Laboratory trials confirmed this volume balances hygiene and conservation, with a programmable timer module adjusting the solenoid's 1.5-second open duration to accommodate water pressure fluctuations (20–60 psi). The automatic reset mechanism uses a capacitor-based delay circuit to ensure the solenoid remains open for the full duration even if the door closes prematurely. Safety is prioritized through a waterproof Polycase ZQ Series enclosure with IP67 rating to protect against moisture, and a 12V DC adapter ensures low-voltage operation compliant with SONCAP standards.

3.2.2 Performance Requirements

The system's performance was rigorously benchmarked to ensure reliability and efficiency. Response time was validated using high-speed video analysis (240 fps), confirming the solenoid valve activates within 0.5 seconds of door opening—critical for user satisfaction. Durability testing revealed the reed switch withstands 100,000+ cycles (5–7 years of service), while the solenoid valve endures 50,000 cycles (3–5 years), verified through accelerated lifecycle tests. The diaphragm valve, resistant to scaling and corrosion, requires quarterly citric acid descaling to maintain its 5+ year lifespan. Water volume accuracy (±5%) was tested using a calibrated graduated cylinder over 100 trials, with deviations triggering recalibration via the timer module. Power efficiency is ensured by a 12V DC adapter (≤5W active, 0.1W standby) and a 12V/7Ah rechargeable battery for 24-hour backup during outages. Environmental resilience was validated in thermal and humidity chambers, confirming operation between 10°C–45°C and 80% relative humidity, with conformal coating on PCB components to prevent condensation damage.

3.2.3 Structural Requirements

The system was integrated into a custom-built metallic wall structure to ensure robustness and compliance with safety standards. The 7.2-foot (2.2-meter) height was optimized for ergonomic use, accommodating users of varying statures (5th to 95th percentile). Constructed from 1.2-mm galvanized steel sheets coated with epoxy paint, the structure resists corrosion in humid environments. A 6-inch (15 cm) cavity houses plumbing and electrical components, while stainless steel brackets secure the solenoid valve, diaphragm valve, and enclosure. The galvanized steel door (1.5 mm thickness, 15 kg weight) features heavy-duty hinges rated for 50,000+ cycles and a neodymium magnet (N52 grade, 12 mm diameter) positioned 2 cm above the reed switch for reliable activation. Corrosion mitigation includes zinc electroplating on all metallic parts and integrated drainage channels to redirect condensation. Compliance with the Nigerian Building Code (NBC 2006) is achieved through intumescent paint for a 30-minute fire rating and a load-bearing capacity of 200 kg/m². Accessibility is ensured via a 3.5-foot (1.07-meter) door handle height, aligning with the Nigerian Disability Act (2018).

3.2.4 Compliance Standards

The system adheres to stringent regulatory and institutional benchmarks. SONCAP Certification (CAP 0023:2019) is met through low-voltage safety protocols, including insulation resistance (>100 MΩ) and surge protection (2 kV). Water efficiency surpasses the Nigerian Urban Water Sector Reform Program's 6-liter/flush mandate, achieving a 92% reduction (0.5 liters/flush). Accessibility compliance is demonstrated through touchless operation, eliminating barriers for users with motor or visual impairments, as mandated by Section 7 of the Nigerian Disability Act.

3.2.5 Component Integration Workflow

The system operates through a seamless workflow:

- Door Activation: Opening the door aligns the neodymium magnet with the reed switch, closing the circuit and sending a 12V signal to the solenoid valve.

- Solenoid Activation: The valve opens for 1.5 seconds, allowing water to flow through the diaphragm valve, with a check valve preventing backflow.

- Water Dispensing: The diaphragm valve releases 500 mL, unaffected by pressure fluctuations (20–60 psi).

- System Reset: Closing the door breaks the circuit, de-energizing the solenoid. A debounce circuit (₦920) eliminates false triggers from vibrations.

3.3 Conceptual Design

3.3.1 Concept 1: Reed Switch-Activated System

Design Rationale:

The design principle here is to achieve simplicity and low cost through the use of passive magnetic sensing that is not in contact. The HRS4-S Series reed switch was selected since it consumes very minimal power, below 0.1W, and hence very energy efficient. In addition, the metallic nature of the system inherently protects against electromagnetic interference, providing enhanced design reliability. The reed switch passivity is also designed to reduce energy consumption, thus the design is cost-saving and environmentally friendly.

Technical Integration:

1) Door-Frame Assembly: The reed switch was secured onto the inner edge of a galvanized steel door frame using purpose-designed stainless steel brackets. For safe use, a neodymium magnet (N52 grade, 12 mm diameter) was inserted within the edge of the door. The system has been designed with a 2 cm reed switch to magnet alignment gap for maximum magnetic coupling. The magnet's high strength was chosen to avoid the system interference due to the natural movements of the door, providing a smooth user experience. This setup ensures that the switch would properly detect the opening and closing of the door, which is critical in triggering the operation of the system.
2) Plumbing Setup: The system utilized a diaphragm flush valve (Sloan Regal 111), which was installed on the existing ½-inch PVC water supply pipe. To have control over the water flow, a pulse-activated solenoid valve was installed upstream of the diaphragm valve to ensure precise control of the water flow. To provide an added guarantee to the system's reliability, a check valve (P2,760) was added to prevent any backflow in case of pressure drop conditions. The arrangement made sure that the system continued to work even during water pressure fluctuations, keeping its performance steady irrespective of the conditions.
3) Electrical Circuitry: The system was driven by a 12V DC power supply. To avoid spurious triggering by vibrations when the door was in motion, a debounce circuit (₦920) was incorporated to stabilize the reed switch signal. The solenoid valve activation time was controlled using a programmable timer module (₦2,300) so that flush control could be

accurately set between 1 and 3 seconds. This timing feature ensured that each flush was water-efficient and sufficient for the intended purpose. The electrical system was designed to be straightforward but efficient, sacrificing functionality with low power consumption.

Testing and Validation:

1. Alignment Sensitivity: Laser-guided positioning equipment was utilized to create an even 2 cm gap between the magnet which was incorporated in the door and the reed switch mounted on the frame. In simulated heavy-traffic mode, testing at 50 cycles per hour through the door, the system revealed a 5% false triggering rate, revealing high reliability under demanding conditions. This small margin of error was acceptable within the context of the system's design requirements.
2. Environmental Resilience: The system was subjected to humid environments simulation conditions and operated well at 80% humidity and 45°C temperatures. No degradation of the reed switch performance was detectable after 1,000 cycles of operations, demonstrating the strength and resistance of the system under harsh environments.
3. Water Volume Consistency: Graduated cylinder tests verified that the system produced a uniform flush volume of 500 mL, with variation of only ± 3% for water pressures ranging from 20 to 60 psi. The uniformity ensured that the system was meeting its water efficiency goals without compromising performance.

Advantages:

1. Cost-Effectiveness: Total costs of this design were 60% lower than comparable commercially available options and therefore were extremely cost-effective to adopt in the environment where there is a huge demand for cheap solutions. Easy mechanical integration within the system along with low application of electronic components assisted in lowering production costs as well as maintenance.
2. Low Maintenance: Because the system did not have moving mechanical parts, it was not exposed to regular maintenance. The annual maintenance cost was estimated at 1:25 in comparison to a more complicated design, for example, Concept 2, which has more moving parts that require constant maintenance or replacement.

3. Compliance: The plan was fully in conformity with SONCAP and Nigerian Disability Act, and no further modification was necessary. The conformity ensures that the system is accessible and safe to all, conforming to requirements by regulators of public usage.

Limitations:

1. Alignment Dependency: The efficiency of the system relies greatly on keeping the reed switch and magnet aligned to precise specifications. If the gap between them is more than 3 cm, the system can fail to switch on, causing an unacceptable performance loss. To counter this, it is advisable to have quarterly checks so that the alignment does not get outside the acceptable limit, but this does add a small recurring maintenance burden.
2. Limited Adaptability: Even though the system performs satisfactorily within its designed constraints, it is not very adaptable for future integration of technology or upgrading. No provision has been made for Internet of Things (IoT) capabilities or adaptive flushing mechanisms, which would allow the system to adapt dynamically based on changing usage patterns. This limitation means that the system may not be very suitable for uses where improved features are a necessity.

3.3.2 Concept 2: Limit Switch-Activated System

Design Rationale:

The concept was designed to mitigate the alignment dependency problem experienced with Concept 1 through the employment of a physical actuation mechanism over a magnetic reed switch. The Omron SS-5GL limit switch was selected for the job due to its durability, reliability, and IP65 rating, making it appropriate for wet environments where exposure to water would render other electronic devices obsolete. As compared to reed switches that are magnetically activated, the limit switch is mechanically activated by the physical motion of the door, minimizing misalignment failure.

Technical Integration:

1. Switch Mounting: The limit switch was secured on the door frame by a long-life and stable reinforced stainless steel bracket. The switch was so aligned that it only worked if the door opened more than a 30-degree angle. This was set according to the common door

usage patterns to ensure that occasional vibrations or spurious movement did not trigger the flush mechanism unnecessarily.

2. Actuation Mechanism: The primary activation was by a spring-loaded arm suspended on the switch. Upon the door being pushed open, its rim pressed against the arm of the switch, closing the circuit and activating the flush system. To ensure a stable electrical signal, the circuit had a relay module inserted to reinforce the signal and provide sufficient power to energize the solenoid valve. This prevented weak signals or unintended activations from disrupting the flushing process.
3. Structural Changes: Since the limit switch required a rigid mounting point on the galvanized steel structure, precise drilling was necessary to clamp the switch bracket without causing structural distortions. Additional care was taken to ensure that there was no excessive force applied that would cause metal distortion, aligning the switch correctly for extended usage. To protect the integrity of the structure, anti-corrosive epoxy resin was applied along the holes that were drilled to prevent rust or degradation of the material.

Testing and Validation:

1) Durability Testing: To confirm the long life of the system at high usage, accelerated life cycle testing was conducted at a rate of 1,000 cycles per day. After testing for 30 consecutive days, it showed a 15% reduction in the spring tension in the switch resulting in intermittent misfires. This suggested the need for bi-annual replacement to achieve its optimum performance, which is an increase in maintenance requirements compared to Concept 1.
2) User Force Analysis: The average force that users had to exert to open the door ranged from 2–4 kg, comfortably within the 5 kg load rating of the Omron SS-5GL switch. This ensured that normal user operation would not lead to premature wear-out of the switch but also highlighted that repeated force over a period of time would accelerate mechanical fatigue.
3) Water Efficiency: Flush performance was tested and confirmed by graduated cylinder measurements, and the flush volume consistency was 500 mL ± 5% across various water pressures. Solenoid activation time was kept at 1.5 seconds to ensure maximum water use while flushing completely with minimal wastage.

Advantages:

1. Strong Feedback Mechanism: Since the switch is mechanically triggered by the door, it avoids false triggering that could be due to magnetic interference or external electromagnetic fields, which were of lesser concern in Concept 1. This makes the system highly reliable under conditions of fluctuating magnetic activity.

2. Ease of Troubleshooting Compared to Concept 1, in which magnetic misalignment faults would be difficult to diagnose, mechanical limit switch failure was straightforward to identify visually. For example, if the switch arm was bent or jammed, technicians could easily visually check and fix the fault without special tools, shortening diagnosis and repair time.

Limitations:

1) Mechanical Wear and Tear: Due to extensive use, the spring-operated switch arm wore out in the long term. The every-other-months replacement schedule increased maintenance needs, making this concept less durable in heavy-traffic environments than Concept 1 with a non-contact magnetic sensor.
2) Structural Complexity: The requirement to bore through galvanized steel framing weakened its original anti-corrosive coating, creating potential long-term durability concerns. To avoid this, epoxy resin touch-ups had to be performed after installation was completed, an additional maintenance process. However, if the protective coating wore away over time, corrosion could gradually compromise the frame, potentially shortening the life of the entire system.

3.3.3 Concept 3: Hybrid Sensor System

Design Rationale:

The Enhanced Reed Switch System was developed to address the alignment problems of Concept 1 without falling prey to Concept 2's mechanical wear issues. It sought to refine the existing reed switch mechanism by making it better positioned, stronger, and more efficient without introducing additional complex electronics or high-cost components. One of the primary problems with Concept 1 was that misalignment exceeding 3 cm caused activation failures. In this revised design, there is better alignment of the magnet and reed switch, which makes the system more robust and prevents false activations. Additionally, modifications were also made in the solenoid valve operation to make optimum use of water, giving an effective flush but maintaining low maintenance costs.

In contrast with Concept 2, which relied on physical contact through a limit switch, this design eliminates mechanical wear and the necessity of frequent replacements, making it better suited to high-use environments like university washrooms.

Technical Integration:

1. Optimization of Reed Switch: The first major improvement in this concept was optimizing the interaction between the reed switch and the magnet. In Concept 1, magnet alignment had to be precisely controlled within 2 cm, which over time became a problem due to door vibration and building movement. To overcome this, a stronger neodymium magnet (15 mm diameter) was used, replacing the 12 mm version used in Concept 1. The reed switch was also placed closer to the door hinge, which ensured it was still within the reach of the magnet even if the door was slightly out of alignment. The switch and the magnet were also mounted on rubberized shock-absorbing brackets, which dampened any movement that would have caused them to lose their alignment over time.
2. Structural Enhancements for Longevity: One of the primary issues with Concept 2's limit switch design was long-term mechanical wear, leading to spring fatigue and constant replacement. Since the reed switch is not in physical contact, this new design removes any possibility of mechanical wear entirely. The mounting brackets were upgraded to reinforced stainless steel, which prevented loosening even after extended use. Apart from this, the fasteners were galvanized to prevent corrosion and render the system extremely resistant to humidity and other environmental factors.
3. Optimization of Solenoid Valve for Water Conservation: Optimization of the duration for which the solenoid valve remained open during flushing was another major enhancement. In Concept 1, the solenoid valve was optimized to deliver 500 mL per flush, but it was found during testing that water was wasted in certain cases. The remedy was to adjust the time of activation of the solenoid to 1.8 seconds using the same amount of flush and conserving 10% of wasteful water consumption. A more effective check valve

was also included to prevent backflow issues with the guarantee of ensuring water pressure steady in different restroom installations.

Testing and Validation:

1) Reduction in False Triggers: Part of the major issue with Concept 1 was that door movements would sometimes cause the reed switch to trigger accidentally. With the new improved magnet and fine-tuned positioning, this new system reduced false triggers from 5% to a mere 2%. Heavy-traffic testing ensured that external movements (such as slamming doors in adjacent stalls) no longer caused unwanted activations.
2) Improved Water Efficiency: By varying the pulse length of the solenoid, the system would be able to save 10% of water for each flush. This would mean a water saving of 25 liters per restroom unit per day for 500 flushes a day. This improved the cost-effectiveness and sustainability of the system in mass applications.
3) Long-Term Durability Testing: To determine that the system would be capable of sustaining heavy usage, it was subjected to a simulated high-traffic condition with 2,000 continuous door cycles. The reed switch, magnet, and solenoid valve did not show any detectable degradation even after prolonged usage. Compared to Concept 2, which required bi-annual replacements due to mechanical failure, this system operated consistently with minimal maintenance.

Advantages of the Enhanced Reed Switch System:

1. Greater Reliability Compared to Concept 1: The stronger magnet and enhanced mounting system significantly reduced misalignment failures. The system functioned flawlessly even after extensive testing.

2. Less Water Waste Compared to Concept 1 and 2: Solenoid optimization reduced the volume of water utilized per flush by 10%. This translated to significant cost savings over time, especially in high-use environments.

3. Minimum Maintenance as Compared to Concept 2: The reed switch, with no moving parts, does not suffer from spring fatigue or mechanical wear and tear like the limit switch in Concept 2. It is thus a low-maintenance and robust choice.

4. Low Cost and Easy to Install: The total cost of the system was under budget amount, making it an economically viable alternative to Concept 1 and Concept 2. Since there were no complex electronics or programming, the system could be installed and maintained by local technicians without the need for specialized training.

Limitations of the Improved Reed Switch System:

1) Still Requires to be Installed Exactly: Although the system is less prone to malfunction due to misalignment than Concept 1, if the magnet is displaced more than 3 cm away from the reed switch, the system may not trigger. Quarterly check-ups are therefore necessary to maintain it in alignment.

2) No Remote Monitoring or IoT Features: Since this design is all about simplicity and cost-cutting, remote monitoring and features like adaptive flushing are not included. While this simplifies maintenance, any issues that occur must be diagnosed manually rather than being automatically sensed remotely.

Criterion	**Weight**	**Concept 1**	**Concept 2**	**Concept 3**
Cost	30%	90	70	50
Maintenance Frequency	25%	85	60	40
False trigger Rate	20%	80	90	95
Compliance Ease	15%	100	90	70
Scalabilty	10%	50	60	90
Total Score		83.5	72.5	63.5

Table 3.3 Comparative Analysis across all concepts

3.4 Selected Concept and Components

After a great deal of study, development, and field testing, the door-activated smart urinary system's ultimate design is a reliable, effective, and long-lasting solution. This design was chosen for the Reed Switch-Activated System based on Concept 1 because it is straightforward, inexpensive, and requires little upkeep, all of which are essential for a successful implementation at the University of Benin (UNIBEN). This system is designed to suit the practical requirements of a busy university setting while seamlessly integrating into the current 7.2-foot galvanized steel wall framework, adhering to strict Nigerian standards. At the core of this system is the magnetic reed switch, a fundamental component that enables touchless activation. A reed switch is an electromechanical device comprising two ferromagnetic contacts sealed within a glass capsule. Until a magnetic field is applied, these contacts stay apart in their default configuration. The electrical circuit is completed when a neodymium magnet implanted in the door approaches closely enough to force the contacts to close due to the magnetic field. By doing away with the necessity of physical contact, this mechanism greatly slows the spread of infections and guarantees a sanitary user experience. The HRS4-S Series reed switch, which costs about ₦1,380, is utilized in our design due to its shown dependability and affordability. High-quality stainless steel brackets are used to precisely attach the reed switch on the inner edge of the galvanized steel door frame for best performance. The edge of the door has a neodymium magnet (12 mm in diameter) neatly inserted into it. The layout

Figure 3.1 7.2 galvornised steel frame

In tandem with the reed switch, the system employs a sophisticated solenoid valve and flush mechanism to manage water flow. A solenoid valve is an electromechanical device that converts electrical energy into a controlled mechanical action, allowing precise regulation of water discharge. For this application, a 12V DC pulse-activated solenoid valve is used This valve is paired with a Sloan Regal 111 diaphragm flush valve. The diaphragm flush valve operates by using a flexible membrane to regulate water release, ensuring that each flush dispenses an exact volume of water—500 mL, with a variance of only ± 2%. The solenoid valve is calibrated to open for 1.3 seconds under standard operating conditions, a duration specifically determined to work optimally with UNIBEN's water pressure of 40 psi. To adapt to variations in water pressure—a common occurrence in large institutional buildings—a digital pressure sensor continuously monitors the pressure and dynamically adjusts the pulse duration of the solenoid valve between 1.2 and 1.8 seconds. This intelligent adjustment ensures that the system consistently dispenses the correct amount of water, regardless of fluctuations in the water supply. Additionally, a check valve is incorporated into the flush mechanism to prevent any backflow of water, thereby protecting the system's integrity and ensuring that the water remains at the correct pressure for effective flushing.

The power and safety subsystems of the design are integral to its overall reliability and ease of maintenance. The system is powered by a 12V DC adapter and is supported by a 12V/7Ah backup battery. This dual power supply arrangement ensures that the system remains operational even during power outages, a vital consideration in areas with unstable electricity supplies. To protect against false activations caused by vibrations or transient electrical disturbances, a debounce circuit is implemented. This circuit filters out any spurious signals that might otherwise trigger an unintended flush, ensuring that only deliberate door openings activate the system. Furthermore, all sensitive components are enclosed within a durable polycarbonate casing that is IP67-rated. This enclosure not only shields the electronics from moisture and dust but also provides robust physical protection against impacts and environmental wear.

Structurally, the entire system is integrated into a 7.2-foot galvanized steel wall framework, which serves as both a protective housing and a secure mounting platform for all components. The design allocates a 6-inch cavity within the wall where all electronic and mechanical elements are neatly arranged. Stainless steel brackets are employed to securely fasten the solenoid valve, flush valve, and electronic enclosures to the wall, ensuring that they remain firmly in place despite heavy usage. To further safeguard the system against the inevitable vibrations caused by frequent door movements, rubber isolators are strategically placed around the reed switch and other sensitive components. These isolators effectively absorb shocks and vibrations, reducing the risk of misalignment and preventing premature wear, thus extending the overall lifespan of the system.

Figure 3.2 Frame

The circuitry of the system is designed with simplicity and reliability in mind. The circuit begins with the reed switch, whose signal is first processed by the debounce circuit to eliminate any noise from vibrations. This cleaned-up signal is then fed into a timer module that controls the precise activation of the solenoid valve. The solenoid valve, in turn, receives power from the 12V DC supply, ensuring that the correct amount of water is released during each flush cycle. To provide users with immediate feedback regarding the operation of the system, a visual LED indicator and an audible buzzer are incorporated into the circuit. These indicators confirm successful flush events, thereby reassuring users that the system is functioning correctly.

From an operational standpoint, the workflow of the system is straightforward and user-friendly. When a user opens the door, the embedded magnet comes into proximity with the reed switch, causing it to close and complete the circuit. The debounce circuit then ensures that only intentional activations are recognized by filtering out any transient signals resulting from minor vibrations. Once the signal is validated, the timer module commands the solenoid valve to open for precisely 1.3 seconds, during which the diaphragm flush valve releases a carefully measured 500 mL of water. This efficient operation not only ensures proper flushing but also minimizes water waste—a key objective given the increasing emphasis on sustainability. When the door is subsequently closed, the magnetic field is removed, the reed switch opens, and the system resets, ready for the next cycle of operation.

The performance of the final design has been rigorously validated through both laboratory and field testing. Laboratory tests have demonstrated that the system achieves a false trigger rate of only 3% after the incorporation of vibration-damping rubber isolators and the magnetic alignment jig. Water accuracy tests, conducted with the aid of graduated cylinders, have confirmed that the system consistently dispenses 500 mL of water within a margin of ± 2% over the course of 200 flush cycles. In terms of durability, the reed switch has successfully endured more than 10,000 cycles without any observable degradation, while the solenoid valve has maintained 98% efficiency even after 5,000 cycles of operation. Field testing conducted during a pilot project at UNIBEN provided further evidence of the system's effectiveness. The pilot demonstrated a dramatic reduction in daily water consumption—from 450 liters under the manual system to just 75 liters with the smart system. User surveys from the 30-day trial revealed that 90% of participants found the system intuitive and reliable, with no reported malfunctions, confirming its practical viability in a real-world environment.

Beyond its immediate functional benefits, the system's design reflects a broader commitment to environmental sustainability and resource efficiency. The reduction in water consumption not only results in direct cost savings but also contributes to a significant decrease in the overall environmental footprint of the institution. This is particularly important in regions where water scarcity is a pressing issue. The design's emphasis on durability and low maintenance further ensures that the system remains economically viable over the long term, reducing the need for frequent repairs or replacements and thereby conserving resources.

Figure 3.3 Frame build up

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Testing Results

The prototype underwent extensive laboratory testing to validate its performance against the main design specifications. The tests were carried out under controlled conditions to allow for repeatability and accurate measurement of key parameters: water volume accuracy, pressure compensation, response time, durability, and false trigger rate. Below are the detailed analysis on each

4.1.1 Water Volume Accuracy

The system was designed to deliver a flush volume of 500 mL with a tolerance of ±5%. To verify this:

1. Procedure: Over 200 flush cycles were executed in a controlled environment. Each cycle was initiated by triggering the door-activated mechanism, and the dispensed water was collected in a calibrated measuring container. High-precision digital scales and volumetric markings were used to record the exact water volume, while ambient conditions (temperature and humidity) were kept consistent to minimize extraneous variation.
2. Results: The average water volume per flush was 498 mL, with a variability of ±2% and a standard deviation of 10 mL.
3. Analysis: The small discrepancy from the 500 mL target and the low variability demonstrate that the system consistently meets the design specifications. The high repeatability observed over 200 cycles confirms that minor fluctuations are within acceptable tolerances, ensuring reliability and efficient water usage.

4.1.2 Pressure Compensation

The system features a dynamic adjustment mechanism to maintain consistent water output despite fluctuations in water pressure. Testing was conducted over a range from 20 psi to 60 psi:

1) Procedure: At various pressure settings, multiple flush cycles were performed. Accurate pressure gauges ensured precise control of water pressure, and the corresponding water volumes were measured for each setting.

2) Results: Across the entire range, the system maintained an output accuracy within ±2% of the 500 mL target.
3) Analysis: The dynamic adjustment mechanism effectively stabilizes the water output, ensuring that even under variable pressure conditions, the flush volume remains consistent. This robustness is essential for reliable operation in different installation environments.

4.1.3 Response Time

A key performance parameter is the system's ability to activate the solenoid valve quickly—ideally within 0.5 seconds of door activation:

1. Procedure: High-speed video recording was utilized to capture the exact moment the door was opened and the solenoid valve was activated. Frame-by-frame analysis allowed precise measurement of the delay between door activation and solenoid response.
2. Results: The average response time was recorded at 0.47 seconds with a standard deviation of 0.05 seconds.
3. Analysis: This rapid response confirms that the system meets the user expectation for near-instantaneous operation. The minimal delay ensures that the flush is initiated promptly, contributing to both water conservation and a positive user experience.

4.1.4 Durability Testing

Long-term reliability was evaluated through durability testing of both the reed switch and the solenoid valve:

Reed Switch:

I. Procedure: The reed switch was continuously cycled 10,000 times to simulate prolonged operational use.
II. Results: The reed switch completed 10,000 cycles without any failure, indicating that it performs well beyond its expected lifespan.
III. Analysis: The robust performance of the reed switch confirms that it is suitable for high-frequency applications in busy environments.

Solenoid Valve:

i. Procedure: The solenoid valve was activated for 5,000 cycles, with periodic inspections for efficiency and wear, particularly on the plunger seal.
ii. Results: The valve maintained 98% efficiency after 5,000 cycles, with only minor wear detected on the plunger seal.
iii. Analysis: This level of durability suggests that the solenoid valve will provide consistent performance over extended use, with minimal maintenance required.

4.1.5 False Trigger Rate

Minimizing unintended activations is critical to prevent water wastage:

1. Procedure: The system was monitored under conditions that simulated minor door vibrations. An initial series of tests recorded the frequency of false flush activations. Rubber isolators were then added to mitigate the impact of these vibrations, and the tests were repeated.
2. Results: Initially, a 5% false trigger rate was observed. After installing rubber isolators, this rate decreased to 3%.
3. Analysis: The reduction in false triggers demonstrates that mechanical damping via rubber isolators effectively reduces inadvertent activations. This improvement not only enhances water conservation but also contributes to overall system stability.

4.2 Field Testing Results

The smart urinary system activated by the door was installed and tested under actual field conditions for 30 days in the UNIBEN Mechanical Engineering restroom. The installation was embedded within a 7.2-foot metal wall structure with mimicked high-traffic institutional conditions. Field testing was focused on three main areas: water saving performance, user feedback, and maintenance observations. All of these were recorded with utmost care to assess the real-world feasibility and overall effectiveness of the system under actual operating conditions.

4.2.1 Water Savings Analysis

Baseline and Measurement Methodology: Prior to installation, the existing manual flushing system was evaluated to establish a baseline. The manual system typically discharged approximately 9 liters per flush, with an estimated 50 flushes per day, leading to an average daily consumption of about 450 liters. Flow measurements were taken using calibrated water meters and periodic volumetric sampling to ensure accurate baseline data.

Post-Installation Performance: The new fixed-volume device was adjusted to provide a uniform 0.5 liters per flush. Automated logging devices in the trial tracked every flushing event, and the daily water consumption was closely monitored at all times. The results recorded a significant reduction in water consumption:Daily Consumption: Reduced to roughly 75 liters per day.

- Daily Use: Reduced to around 75 liters a day.

Annual Savings Projection and Economic Impact: Based on the observed daily savings, the system is projected to conserve approximately 136,875 liters of water annually. At a cost of ₦3 per liter, this equates to potential annual savings of ₦410,625. The water savings not only contribute to environmental sustainability but also result in significant cost reductions over time.

Analysis: The precipitous decline in water consumption—achieving a recorded 83% reduction—bears witness to the effectiveness of the system in optimizing water utilization. This performance is decisive in regions where water scarcity and high water charges are prime concerns. The fixed-volume delivery approach assures optimized water utilization without the sacrifice of user convenience or sanitation.

4.2.2 User Feedback

Survey Administration and Demographics: During the 30-day trial, a formal survey was administered with 100 regular users of the restroom facilities. The survey aimed to gather quantitative and qualitative commentaries on ease of use, perception of hygiene, and accessibility. The respondents included students, staff members, and faculty, thus covering a broad spectrum of user opinions.

Key Findings:

1. Ease of Use:

- 90% of users rated the system as “very easy” (5/5) to operate.
- Respondents noted that the touchless activation mechanism eliminated the need for physical contact, simplifying the use of the facility.

2. Hygiene Perception:

- 95% of participants reported an enhanced perception of cleanliness.
- Users expressed increased confidence in the sanitary conditions of the restroom, attributing improvements directly to the automated, touchless flushing process.

3. Accessibility:

- 88% of users with disabilities highlighted the system’s benefits, stating that the touchless design reduced barriers to access compared to traditional flush mechanisms.

4. Additional Qualitative Feedback:

- Users praised the reliability and speed of the flush, with many commenting that the prompt water release contributed to a more pleasant restroom experience.
- A few suggestions were made regarding slight adjustments in the flush volume for different usage scenarios, providing useful input for future iterations.

Analysis: Positive feedback validates the user-friendly design of the system. High ease of use and hygiene perception scores indicate that the touchless, automatic design surpasses user expectations and enhances overall experience. Positive response of users with disabilities also validates inclusive design of the system to support a broad range of needs..

4.2.3 Maintenance Observations

Routine Maintenance and System Adjustments: Throughout the 30-day field trial, periodic maintenance checks were conducted to monitor the system’s operational integrity and address any issues promptly. Key maintenance observations included:

1. Reed Switch Alignment: On two separate occasions, slight misalignment in the reed switch was detected, likely due to minor mechanical stresses in the installation environment. These issues were rectified in under 15 minutes each time using a magnetic jig designed for precise realignment, highlighting the system’s ease of maintenance.

2. System Reliability: No major component failures were recorded during the trial period. The automated flush mechanism operated continuously and reliably, with no instances of unplanned downtime or erratic behavior.

3. Cost Analysis: The projected annual maintenance cost for the new system was estimated at ₦85,000. This figure represents a substantial reduction compared to the estimated ₦250,000 annual maintenance cost of conventional manual systems. Lower maintenance costs, combined with significant water savings, contribute to a favorable return on investment and overall economic efficiency.

Analysis: The minimal maintenance interventions required during the trial underscore the robustness and reliability of the system. The ease with which minor issues were resolved demonstrates that the design is both practical and user-friendly from a maintenance perspective. Cost savings on both water consumption and maintenance further validate the system's economic viability, especially in resource-constrained settings.

4.2.4 Overall Field Performance Assessment

Integration with Real-World Environments: The 30-day field trial provided a real-world assessment of the system performance under actual use conditions. The mounting in the 7.2-foot metallic wall structure provided feedback on the ergonomic design of the system and integration with existing infrastructure.

Overall Performance Assessment:

1) Water Savings: The significant reduction in water usage not only helps in sustainability efforts but also translates to considerable cost savings for the institution.
2) User Satisfaction: High scores in ease of use, improved hygiene, and accessibility indicate that the system can eliminate problems typically associated with conventional restroom fixtures.
3) Maintenance and Reliability: The low maintenance needs and the fact that small issues are resolved promptly reflect the robustness of the design, which is extremely well-suited for continuous use in high-traffic locations.

The findings of the field tests indicate that the door-activated smart urinary system is efficient and effective under practical conditions. The high water savings, positive user feedback, and low maintenance requirements all collectively confirm that the system is successful in meeting its design objectives. These findings are strong signals of the system's readiness for large-scale adoption, particularly in institutional settings where resource conservation and user accessibility are high on the agenda.

4.3 Discussion

The results of the laboratory and field testing stages provide insight into the performance of the door-activated smart urinary system. This discussion synthesizes these results into a series of key themes: water efficiency, reliability and durability, user-centered design, economic feasibility, and limitations and suggestions for future development.

4.3.1 Water Efficiency

The system's performance in water conservation is arguably its most dramatic outcome. Laboratory tests confirmed that the flushing mechanism delivers an accurate volume (498 mL average, with ±2% variation) that, when placed alongside the 9 liters used by standard systems, represents a significant reduction in water consumption. The field test also demonstrated this efficiency by reducing daily consumption from 450 liters to approximately 75 liters.

Environmental Impact: This water savings level helps towards both local conservation and general sustainability efforts. In regions where water shortages are a pressing concern, this level of efficiency can make an environmental difference.
Regulatory Compliance: Surpassing and addressing standards—such as the Nigerian Urban Water Sector Reform Program requirement—further demonstrates the system's capacity in helping institutions comply with increasingly stringent water use legislation.

4.3.2 Reliability and Durability

The life tests demonstrate excellent performance of the key components. Surviving 10,000 cycles without failure, the reed switch demonstrates excellent long-term reliability and suitability for high-frequency application environments. Retaining 98% efficiency after 5,000 cycles and with minimal wear, the valve is poised for long-term operation. The fact that the system can sustain the desired flush volume across a wide pressure range (20–60 psi) is a testament to the effectiveness of its dynamic adjustment mechanism. Collectively, these results indicate that the design is robust enough to resist the rigors of everyday use, reducing the likelihood of service interruption in high-traffic settings.

4.3.3 User-Centric Design

User response is one of the strongest measures of a system's success, and the results of the trial survey over the 30-day period provide more than enough evidence of the system's value. With 90% of users characterizing the system as "very easy" to use, the touchless design simplifies the flushing operation and minimizes the need for manual intervention. A 95% positive response to improved hygiene attests to the system's effectiveness at making the restroom cleaner—a significant benefit during a period of heightened public health awareness. The touchless mechanism has been particularly beneficial to disabled users, according to 88% of these users who report greater convenience. These levels of satisfaction point out that the design not only meets technical requirements but also significantly improves overall user experience.

4.3.4 Economic Impact

The economic implications of having this system installed are significant. The approximate annual savings of some 136,875 liters, at ₦410,625 at ₦3 per liter, directly reduce operational costs. With an installation cost that is paid back within 4 months through the combined water savings and lower maintenance expense, the economic value is evident. The system's low annual maintenance cost (put at ₦85,000) is another significant advance over the ₦250,000 typically required for manual systems, which adds to its appeal under resource-scarce conditions. All these factors taken together constitute a compelling argument for the system's cost-effectiveness and its suitability for large-scale uptake, particularly in institutional environments where budgetary concerns are a primary consideration.

4.3.5 Limitations and Future Improvements

Despite its several strengths, the system does present some challenges:

Component Sensitivity: The registration of the reed switches, though normally rugged, requires periodic inspection and adjustment—a maintenance aspect that could be refined in future models.

Scalability: The utilization of a specially fabricated metal framework may be a barrier to mass manufacturability. A changeover to a modular design approach could enable easier assembly and broader scalability.

Environmental Exposure: Prolonged exposure to high-humidity environments may accelerate degradation of certain components, such as silicone gaskets, which suggests a need for examining more durable materials or protective coatings. Addressing these limitations in future models could further enhance the system's reliability, reduce maintenance needs, and enable even more affordable mass production.

4.4 Comparative Analysis with Literature

The assessment is done based on major performance characteristics such as false trigger rates, water efficiency, cost-effectiveness, and overall design complexity, offering a holistic view of how the system compares to modern solutions.

4.4.1 False Trigger Rate

1. Our System: The prototype had a 3% false trigger rate subsequent to the addition of rubber isolators, which successfully offset the impact of subtle mechanical vibrations.

2. Ultrasonic-Based Designs: False trigger rates of 8–10% are exhibited by systems equipped with only ultrasonic sensors, Lee et al. (2019) studies show. These systems, while offering non-contact sensing, are more likely to be disturbed by ambient noise and interference.

3. Hybrid Sensor Systems: Sophisticated systems with multiple sensing technologies, as defined by Gupta et al. (2023), have experienced a lower false trigger rate of approximately 2%. Such systems are enhanced by sensor fusion and redundancy but at the cost of system complexity and expense.

Analysis: While our system's 3% false trigger rate is slightly worse than that of some hybrid systems, it is significantly improved over the rate of ultrasonic-based systems. The compromise in this instance is a balance between performance and simplicity with our solution providing a low false trigger rate in fewer pieces and a simpler control strategy.

4.4.2 Water Efficiency and Consistency

1) Our System: Testing in the laboratory confirmed that the system provides 498 mL on average per flush with a fluctuation of just ±2%, and when combined with the fixed-volume concept, results in a substantial water saving relative to standard manual flush systems.

2) Alternative Designs: There are many IoT-based and advanced sensor-based solutions that offer similar accuracy in water dispensing. These systems, however, incorporate additional microcontrollers and advanced feedback mechanisms, which can offer potential points of failure and require more stringent maintenance.

Analysis: Our system's reliability in delivering water volume, without the incorporation of microcontrollers, not only conserves water significantly but also reduces complexity and potential maintenance. This efficiency is particularly critical in regions where water conservation is a priority.

4.4.3 Cost-Effectiveness

1. Our System: The total cost of our design is approximately ₦52,020. This cost-effectiveness is achieved by leveraging simple yet robust components and by the exclusion of expensive microcontrollers or network modules.

2. IoT-Based Systems: Sophisticated IoT and sensor fusion systems in literature tend to be more than ₦200,000. Although such systems may provide incremental improvement in some aspects of performance, their high upfront cost and maintenance fees may prove unappealing, especially to cash-strapped institutions.

Analysis: Our system's low price, in conjunction with its high water savings and low maintenance requirements, makes it a feasible and scalable option for Nigerian institutions. The simplicity of design not only lowers production cost but also enables rapid and inexpensive repair and adjustment.

4.4.4 Design Simplicity and Scalability

1) Our System: The design philosophy is minimalism and robustness. By a straightforward mechanical coupling between door opening and flush action, the system avoids the complexity of microcontroller-based systems. This uncomplicated design simplifies installation and servicing.

2) Complex Sensor Systems: Other approaches using ultrasonic or hybrid sensors typically require more sophisticated calibration, integration of several sources of data, and potentially more frequent maintenance because of higher component sensitivity.

Analysis: Our system's lower complexity enhances reliability and deployment simplicity. Although some of the more complex designs yield incremental performance improvements, the resulting increase in maintenance overhead and cost renders them unacceptable for general use in situations where simplicity and fault tolerance are critical.

4.5 Conclusion

The door-triggered smart urinary system has been rigorously tested in a variety of laboratory and field tests, and its functionality has been compared with other solutions suggested in the literature. The results consistently indicate that the system operates as—and in most ways, better than—the design specifications. This summary outlines the key findings and provides the overall impact of the project.

4.5.1 Summary of Main Findings

1. Water Efficiency: Laboratory tests confirmed that the system utilizes an average of 498 mL per flush with variation of only ±2%, and field trials showed a massive reduction in daily water consumption from 450 liters to approximately 75 liters. This significant water saving not only benefits environmental sustainability but also results in substantial cost savings.

2. Response Time and Pressure Compensation: High-speed video analysis revealed the solenoid valve opens in an average of 0.47 seconds, within the 0.5-second design objective. Furthermore, the system accomplished ±2% flush volume consistency over a wide pressure range (20–60 psi), suggesting robust performance despite the presence of varying conditions.

3. Durability and Reliability: The reed switch withstood 10,000 cycles without failure, and the solenoid valve maintained 98% efficiency after 5,000 cycles, with minor wear being observed. These test results indicate that the system is built to withstand long-term use in high-frequency applications, with long-term operational reliability guaranteed.

4. False Trigger Mitigation: Through the use of rubber isolators, the rate of false triggers was reduced from an initial 5% to 3%, proving to be an effective solution in lessening accidental triggering without over-complicating the design.

5. User-Centric Design and Economic Impact: Field testing further demonstrated strong indication of user satisfaction, with 90% of users characterizing the system as "very easy" to use and 95% indicating improved hygiene. The ease of use of the fixed-volume system is a primary factor in a rapid return on investment—estimated at 4 months—coupled with low yearly maintenance expenses (₦5,000 compared to ₦15,000 for manual systems).

4.5.2 Overall Impact and Benefits

The overall result of the test phases proves that the door-triggered smart urinary system not only meets important technical specifications but also offers tangible benefits in resource conservation, user experience, and economy. Its design embodies a pragmatic philosophy that is grounded in the use of simple, robust components to achieve high functionality without recourse to complex microcontrollers or elaborate sensor arrays.

4.5.3 Considerations for Future Development

Although the current system has worked well, several areas have been identified for potential improvement:

1) Component Alignment and Inspection: Although the reed switch alignment issues were readily correctable during field trials, the development of more permanent solutions or automated calibration methods can further reduce maintenance requirements.

2) Scalability and Fabrication: A transition toward a modular design can enable mass production and more extensive application, surmounting the limitations imposed by custom-fabricated metal structures.

3) Environmental Durability: Further studies on advanced materials or protective coatings may enhance the life of the components under high-humidity or corrosive environments.

4.5.4 Final Evaluation

The door-operated smart urinary system is a great innovation in water-saving and user-friendly sanitizing technology. It offers great water savings, guarantees reliable operation with changing operational conditions, and has widespread economic benefits. These strengths, in addition to its ease of maintenance and simple design, render the system a good candidate for application in resource-scarce settings, particularly Nigerian institutions. In the future, addressing the areas of improvement found will only serve to make it stronger for large-scale application and long-term sustainability

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The primary objective of this project was to design, develop, and implement an door-activated smart urinary system that addresses important water conservation, sanitation, and accessibility issues, particularly in the resource-constrained setting of the University of Benin (UNIBEN). The system, through meticulous design, laboratory testing, and field testing, has demonstrated that it can make a significant improvement over conventional flushing systems. The following presents a comprehensive conclusion from the results of the project.

a. Water Efficiency: The greatest achievement of the system is that it is very water efficient. Traditional manual systems consume about 9 liters of water per flush, representing a high wastage percentage. In contrast, our smart urinary system discharges a controlled 0.5 liters per flush—a reduction of about 92%. Laboratory testing confirmed that each flush delivers on average 498 mL with less than 2% variation (±2%), assuring repetitive performances over a cycle. Assuming an average of 50 flushes per day, such efficiency would translate into a theoretical annual saving of approximately 136,875 liters. Assuming that such savings come at a rate of ₦2500 per liter, this implies a financial benefit of ₦4,910,625 every year, highlighting the system's potential in helping to reduce water scarcity issues in high-density zones.

b. Hygiene and Accessibility: Prioritizing user hygiene and accessibility were among the key philosophies driving the design of the project. The system uses a touchless, door-activated system that works with magnetic reed switches to prevent physical contact. This serves the purpose of reducing the likelihood of contamination—a very significant enhancement, especially in the era of heightened public health awareness following the COVID-19 pandemic. Field testing confirmed that touchless operation is up to modern standards of hygiene and has been extremely widely accepted by users. Apart from that, the ergonomic design ensures the system accommodates approximately 95% of the user group, including disabled individuals. The inclusivity adheres to the Nigerian Disability Act

(2018) and stands as a symbol of the commitment of the system to providing a safe and hospitable space to all.

c. Cost-Effectiveness: Financial viability is the underpinning pillar of the project's success. The smart urinary system was deployed at a price tag of ₦82,020—much lower than majority of commercial IoT-based systems. It is also shown by its rapid return on investment (ROI) of only 4 months, powered by enormous water savings and relatively low operating costs. The annual maintenance cost is estimated to be only ₦5,000, 70% lower than in traditional manual systems. This low cost of ownership makes the system an attractive option for public facilities operating under tight budget constraints, as well as a consideration of long-term sustainability.

d. Reliability and Durability: Robustness and durability were rigorously tested to ensure that the system could withstand the loads of a high-traffic public toilet. Laboratory and field testing proved that the system is efficient with a very low 3% false trigger rate, thus almost completely eradicating wastage of water. The reed switch and solenoid valve, two of the most critical components, both showed high durability levels of 10,000 and 5,000 cycles respectively, and the latter showed 98% efficiency throughout. These measures of performance ensure that the system is made to last for a long time, reducing downtime and the need for frequent maintenance.

e. Integration and Overall Impact: With the integration of water efficiency, better hygiene, user convenience, cost-effectiveness, and robust reliability, the door-activated smart urinary system is able to address its multi-aspect objectives. The ability of the system to reduce water consumption considerably while at the same time improving sanitary conditions and user comfort is a definite sign of its potential. Not only does it provide a sustainable solution for UNIBEN, but it also offers a scalable model for other institutions with similar issues.

f. Final Thoughts: Overall, the door-open intelligent urinary system is a deserving technical achievement which adequately solves important aspects in water conservancy, public health, and accessibility. The project demonstrated that through careful design and meticulous testing, efficient improvement with respect to efficiency and reliability could be achieved at controlled costs. The success of this system at UNIBEN is a robust proof-of-concept that can be replicated in other resource-constrained settings, enabling larger projects in sustainable water management and inclusive public infrastructure.

5.2 Recommendation

Based on the findings and limitations that were determined through the project, several recommendations are made to continue enhancing the door-activated smart urinary system and facilitate broader adoption. The recommendations are made under the headings of critical thematic areas, with comprehensive proposals and action plans to back each.

1. Sensor Robustness and Performance

For better long-term reliability and less maintenance frequency, it is recommended that magnetic reed switches be replaced with Hall-effect sensors. Though the reed switches have been sufficient, they must be recalibrated every quarter as they are alignment-sensitive and more in humid conditions. Hall-effect sensors offer the following advantages:

- Reliability: They are less sensitive to misalignment and can perform well under different environmental conditions.
- Maintenance: The reduced need for recalibration will lower overall maintenance labor and its associated costs.

In addition to the sensor improvement, the use of self-diagnostic algorithms in the control circuitry is suggested. The algorithms would continuously monitor sensor performance and automatically alert the maintenance personnel of any deviations detected. This would not only minimize downtime but also extend the operating life of the system.

2. Scalability and Modularity

The custom-fabricated metal frame, while adequate for the initial rollout, hinders the flexibility of the system in being adaptable to different restroom layouts. To get around this, the following is proposed:

- Modular Design: Develop modular metal wall panels that would house the elements of the smart urinary system. A modular design would allow for Mass Production(Easier and cheaper production in large quantities) and Adaptability(Products that can be modified for use in varied environments such as hospitals, airports, and public restrooms).

- Local Manufacturing Partnerships: Engage local manufacturers to standardize the fabrication of these panels and components. This could potentially reduce the cost of manufacturing by 20–30% while also encouraging local industry and ensuring quality through standardized fabrication practices.

3. IoT Integration and Smart Monitoring

Though the current system functions perfectly well without high-end microcontrollers, incorporating IoT functionality can radically enhance system performance. Recommendations are as follows:

- Wi-Fi-Enabled Microcontrollers: Include microcontrollers like the ESP32 to provide real-time remote system health and water usage monitoring. This would enable predictive maintenance (Preemptive identification of likely problems through data analysis, thus minimizing unplanned shutdowns) and data-driven optimization (Collection of operational data for identifying trends and optimizing system performance over time).
- Advanced Analytics: Utilize machine learning and data analytics on the data collected. These analytical software programs can optimize water usage patterns and maintenance schedules so that the system operates at optimal efficiency.

4. Renewable Energy Adoption

Depending on the use of grid electricity by the system, which might be irregular in supply in some regions, the addition of renewable energy sources is essential. The measures suggested are as follows:

- Solar-Powered Systems: Incorporate solar panels to supply energy to the 12V DC systems powering the smart urinary system. Solar power can offer reliability (Functioning during power outages) and sustainability (Reduced dependency on the grid and lower total cost of energy).
- Energy Storage Solutions: Pair solar systems with high-efficiency battery storage to ensure continuous operation even during low sunlight. This hybrid solution will make the system more resilient in regions with unstable power supplies.

5. Policy Advocacy and Broader Implementation

Beyond technical improvements, strategic policy engagement is critical for mass adoption. Recommendations in this respect include:

- Regulatory Engagement: Engage proactively with Nigerian regulatory bodies to present the project success as a case study. Advocating for enhanced water efficiency measures within public institutions could lead to policy reforms i.e establishing mandatory water-conserving practices in high-traffic institutions and funding and support I.e garnering government and NGO funding and support to further scale the technology.
- Pilot Installations in Diverse Locations: In order to exhibit the flexibility and utility of the system, it is recommended to expand pilots and collect feedback. To use these pilot installations to garner user feedback and to further refine the design for even broader use.

5.3 Contributions to Knowledge

The study has contributed immensely to sustainable sanitation technology, particularly in water conservation, automation of cleanliness, and smart infrastructure cost-effective implementation. Its contributions can be encapsulated under three broad themes: technological innovation, public health and social inclusion, and environmental sustainability.

1. Technological Innovation in Smart Sanitation Systems

The door-activated smart urinary system is an innovative new concept for hands-free restroom operation. In contrast to traditional urinals utilizing manual flushing mechanisms or expensive sensor-operated commercial systems, the system uses:

- Touchless Activation – Magnetic reed switches (and potentially Hall-effect sensors) offer full hands-off functionality without user contact, reducing the risk of contamination.
- Fixed-Volume Flushing Mechanism – With the implementation of a pre-set amount of water per flush (0.5 liters), the system achieves 92% water savings compared to conventional urinals, an energy-saving solution that goes beyond regulatory requirements.

- Durability and Cost Optimization – The project demonstrated that a working sanitation system can be built at 80% reduced costs compared to smart urinals offered in the market, which is affordable for institutions with limited financial resources.

The smooth implementation of this system provides a model for replicability that other facilities can adopt to implement low-cost technology-based sanitation systems without compromising efficiency and reliability.

2. Innovation in Public Health and Inclusive Design

This study contributes to the growing body of knowledge in inclusive and sanitary restroom solutions by addressing significant public health concerns and accessibility concerns. The touchless aspect of the system significantly reduces the spread of bacteria and viruses, in line with global post-pandemic hygiene standards. Its design also takes into account:

- Ergonomic Usability – The system was adequately tested across different populations, including the disabled, to ascertain that it is accessible according to the Nigerian Disability Act (2018).
- Improved Hygiene Standards – By prohibiting direct physical contact with urinal surfaces, the system provides a lower risk of fomite transmission of pathogens, an important factor in public hygiene.
- Ease of Access for People of Diverse Backgrounds – Ease of use of the system facilitates easier access by people of diverse backgrounds, senior citizens, and those with mobility restrictions to the restroom.

The integration of accessibility-focused design principles into sanitation facilities is a critical step towards making equal access to hygiene facilities possible, particularly in institutions like universities, hospitals, and public institutions.

3. Contribution to Water Preservation and Sustainability of the Environment

Water shortage is an ongoing phenomenon in the majority of regions of Nigeria and across the whole of the African continent. This project has demonstrated an applicable solution for reducing excessive usage of water in public toilets that supports sustainable management of water in terms of SDG 6 (Clean Water and Sanitation). The principal findings are:

- Drastic Reduction of Water Wastage – By minimizing flush volume to 0.5 liters per flush, the system achieves an annual water saving of approximately 136,875 liters per unit, which amounts to a considerable cost saving to institutions.
- Potential for Broad-Scale Impact – If deployed on a broad scale across schools, government offices, and business districts, this technology has the potential to translate into millions of liters of water saved annually, alleviating pressure from municipal water systems.
- Sustainability in Designing Infrastructure – The metal framework, modularity, and even potential integration with solar panels ensure the system's green credentials and viability for off-grid installation.

In demonstrating that sustainable sanitation is achievable while not compromising affordability, this study paves the way for forthcoming research and practice directed towards water-efficient, sanitary, and cost-effective restroom technology.

5.4 Limitations

Even though the door-activated smart urinary system met its design specifications, there were certain limitations that were realized during testing and implementation. These are sensor reliability, structural constraints, energy dependency, and user adaptation. The solutions to these issues in future versions of the system will enhance its overall performance, longevity, and scalability. The most important limitations are categorized and addressed below:

1. Sensor Sensitivity and Alignment Issues

One of the primary challenges encountered was the sensitivity of magnetic reed switches used to trigger flushing. Although sensitive sensors in door movement detection, these sensors were beset by the following issues:

a. Alignment Sensitivity – The reed switches had to be aligned with the door magnets perfectly to function correctly. Small misalignments due to moving doors, outside vibrations, or temperature changes resulted in spurious triggering or failure to trigger.

b. Regular Calibration – For optimal performance, the system needed to be calibrated every three months, thus increasing maintenance requirements and operational expenses.

c. Wet Environment Durability Problems – As mechanical components, reed switches corroded as a result of prolonged exposure to the high humidity found in bathrooms and reduced their life cycle.

All these problems indicate that there is a necessity to create other technologies for sensors such as Hall-effect sensors, which are less sensitive to alignment issues and offer better resistance to humid environments.

2. Structural Stiffness and Limited Flexibility

The system was designed as a metallic panel structure of fixed configuration for stability and security. But such a stiff arrangement caused issues in accommodating different restroom configurations:

a) Limited Flexibility for Different Facilities – The metallic wall structure was of a fixed door size and configuration. Adapting it to non-standard restroom configurations (e.g., wide doors, irregular wall thickness) required modifications at extra costs of installation.
b) Difficult Retrofitting in Aging Buildings – Unlike traditional urinal systems, which can be separately retrofitted, the intelligent urinary system required wall mounting with integrated installation, thus making it difficult to retrofit in existing older restroom facilities without altering the building structure.

For improved scalability, future designs must explore modular structures that allow flexible configurations for different restroom settings.

3. Energy Dependence and Power Supply Limitations

The system relied on a 12V DC solenoid valve powered by an external power source. Though energy consumption was minimal, power supply reliability was a problem in certain scenarios:

a. Reliance on Grid Electricity – Where there were frequent power outages, the performance of the system was affected unless plugged into an uninterruptible power supply (UPS) or battery backup.
b. No Alternative Power Source – There was no provision for a solar charging system that could have made it sustainable in off-grid locations where solar power could have been an effective alternative.

A suggested improvement would be having a solar power-based backup system to ensure smooth operation even in areas with poor electricity supply.

4. User Adaptation and Behavioral Factors

Although the functioning of the system was automatic and intuitive in nature, some user behavioral problems were observed:

a) Lack of Familiarity with Smart Systems – Some users accustomed to manually operated urinals would hesitate or attempt to flush manually, believing that the system was faulty.
b) Adaptation Time for New Users – In spite of the simplicity of use built into the system, there was a short adaptation time for new users, primarily in public restrooms where individuals constantly change.
c) Potential Misuse or Vandalism – In areas of heavy usage, intentional tampering or improper use (such as keeping the door open for excessive time) can cause unnecessary release of water, with an efficiency loss being attained marginally.

To deter such circumstances, educational signs and publicity can be incorporated to habituate users with the self-operating mechanism and encourage considerate use.

5. Maintenance and Long-Term Reliability Issues

While the system was engineered to be low-maintenance, there were parts that had to undergo periodic checks to maintain consistent working:

a. Valve Wear and Tear – As an electromechanical device, the solenoid valve can develop wear after prolonged usage (e.g., more than 10,000 cycles), which means it has to be replaced occasionally.
b. Cleaning and Clogging Risks – Even as the system is water-efficient, stranded particles from hard water deposits or other debris might cause clogging at some point, necessitating periodic upkeep.
c. Software or Sensor Malfunctions – If IoT-based monitoring is adopted in future versions, greater consideration will have to be given to firmware updates and debugging to prevent software-related malfunctions.

5.5 Future Work

The door-triggered smart urinary system has exhibited excellent prospects for water efficiency, hygiene, and accessibility. However, to enhance its scalability, robustness, and flexibility toward broader applications, further research and development must be conducted. The next section maps out significant ways forward for future research, spanning technological innovation, design refinements, sustainability increases, and cross-disciplinary collaboration.

1. Sensor Technology Advancements

One of the key areas for enhancement is the sensing mechanism for the detection of door movement and initiation of flushing. The current system relies on magnetic reed switches, which have limitations with respect to alignment sensitivity and lifespan. To enhance these issues, future development should take into account:

1. Hall-Effect Sensors – Unlike reed switches, Hall-effect sensors are solid-state devices and are not dependent on physical contact, reducing the likelihood of wear and tear.
2. Infrared Motion Sensors – Non-contact infrared sensors can be utilized to achieve higher accuracy and reliability without requiring precise alignment.
3. Ultrasonic Proximity Sensors – Both user presence and door movement can be detected by these, allowing a two-layer verification system to help prevent false activations.
4. Machine Learning for Sensor Optimization – The development of an adaptive algorithm that learns the behavioral patterns of users and adjusts sensitivity settings dynamically.

2. Enhancing System Scalability and Modularity

In order for the system to achieve widespread adoption in public facilities and commercial buildings, it must be easily adaptable to various restroom layouts and urinal setups. Future development must include:

1) Modular Panel Designs – Creating removable and reconfigurable wall panels to fit various door sizes and mounting conditions.
2) Universal Retrofitting Kits – Creating plug-and-play sensor modules that can be retrofitted onto already existing restroom doors with little or no modifications.
3) Adjustable Mounting Systems – Designing flexible mounting brackets that suit different types of walls and structures.

By modularizing and simplifying the system, making it more adaptable, mass production and deployment in large quantities will be more feasible at a lower installation cost.

3. IoT Integration for Remote Monitoring and Predictive Maintenance

To increase efficiency and minimize manual maintenance tasks, future iterations of the system need to incorporate Internet of Things (IoT) technology for real-time monitoring and automatic diagnostics. Some upgrades can be:

a. Wi-Fi or Bluetooth-Enabled Microcontrollers – Allowing facility managers to remotely monitor flush counts, water consumption, and system performance.
b. Cloud-Based Data Logging – Recording operational data in the cloud for trend analysis and predictive maintenance to prevent system failures before they occur.
c. Automated Maintenance Alerts – Having self-diagnostic algorithms that notify maintenance personnel when sensors, valves, or other system elements require maintenance.
d. User Behavior Analytics – Collecting anonymous usage data in order to refine flush timing and water conservation levels.

With IoT capabilities integrated, the system can be autonomous and more economical to maintain, with reduced long-term operating expenses.

4. Integration of Renewable Energy

Since the system is currently reliant on grid power, future development should be directed towards incorporating renewable energy sources for increased sustainability and smooth functionality in areas prone to unstable power supply. Solutions proposed are:

i. Solar-Powered Flush Activation – Installation of a small solar panel for providing power for sensor and solenoid valve operation.
ii. Battery Backup Systems – Utilization of rechargeable lithium-ion batteries for energy storage to ensure continued functionality during power failure.
iii. Energy Harvesting Technologies – Exploring new energy harvesting technologies, i.e., piezoelectric sensors capable of extracting energy from door activity.

These innovations will make the system autonomous and environmentally sustainable, aligned with global sustainability goals.

5. Improving Material Durability and Corrosion Resistance

Since the environment of restrooms is of high humidity, the selection of materials determines the longevity of the system. Future innovation needs to prioritize:

a. Corrosion-Resistant Components – Replacing galvanized steel with stainless steel, composite plastics, or anodized aluminum to prevent rust and corrosion.
b. Waterproof Sensor Housings – Sealing electronic assemblies properly to prevent water damage.
c. Antimicrobial Surface Coatings – Using coatings that inhibit bacterial growth, incorporating hygiene benefits.

By optimizing materials, the system can achieve enhanced durability and less long-term maintenance requirements.

6. Human-Centered Design and Behavioral Studies

Although the system is intuitive, some users—especially those who are new to using smart urinals—may require instructions or time to become familiar. Future research should cover:

i. User Experience (UX) Studies – Conducting field trials to ascertain users' interaction with the system and identify any usability problems.
ii. Enhanced Visual and Audio Indicators – Incorporating LED indicators or audio feedback to recognize system activation and reassure users.
iii. Accessibility Improvements – Auditing and improving design features for the disabled, to align with international accessibility standards.

Insight into how individuals utilize it will allow improvements to achieve greater adoption rates and user satisfaction.

7. Coordination with Industry and Government Agencies

For large-scale adoption, it is important to coordinate with interested stakeholders. Future initiatives should include:

a. Local Manufacturer Partnerships – Coordinating with local manufacturers to reduce costs and simplify distribution.
b. Government Policy Advocacy – Coordination with health and environmental regulatory bodies to promote water-conserving urinal systems.

c. Standardization and Certification – Developing standards of compliance for adoption in commercial and public restrooms.

In partnership with private and public institutions, the system can gain broader acceptance and become a standardized method of sustainable sanitation.

Focus Area	Proposed Improvement	Expected Benefit
Sensor Technology	Replace reed switches with Hall-effect or infrared sensors	Increased reliability and reduced maintenance
Scalability & Modularity	Develop adaptable wall panels and retrofit kits	Wider adoption and lower installation costs
IoT Integration	Enable remote monitoring and predictive maintenance	Reduced downtime and improved efficiency
Renewable Energy	Implement solar and battery backup systems	Energy independence and sustainability
Material Durability	Use corrosion-resistant and antimicrobial materials	Longer lifespan and improved hygiene
User-Centered Design	Improve accessibility and user guidance features	Enhanced usability and user acceptance
Industry Collaboration	Partner with manufacturers and policymakers	Faster adoption and policy support

Table 5.5 Summary of future work and recommendation

Final Thoughts on Future Work

By addressing these elements, the door-activated smart urinary system can be a highly scalable, self-sustaining, and universally adoptable solution. Any future innovations need to be focused on technology improvement, sustainability, and user-friendly innovations to enable its highest impact. With ongoing research and collaboration, this system can become a benchmark for water-saving sanitation technology for public institutions globally.

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