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IMPROVED DESIGN OF SMART TOILET SYSTEM

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CERTIFICATION

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DEDICATION

This project work is dedicated to God Almighty who granted us courage and patience to perform and carry out this project work, and without His help we would not have achieved what we have done so far.

Also, the project is dedicated to our parents for their great support, guidance, sacrifice and prayers throughout the duration of our course of study.

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ABSTRACT

With increased urbanization and the growing need for better sanitation hygiene practices across several countries, including many developing nations such as Nigeria, there was a great need for better sanitary facilities that would allow for cleaner sanitation. Most conventional latrines have required high manual intervention and constant maintenance, creating an environment that is often dirty, wastes water, and does not have enough cleaning facilities, even in places like restrooms at homes and public places. Despite some innovative restrooms being designed before, the majority of such restrooms either lack feasibility financially or do not contribute effectively to smart hygiene monitoring. The smart toilet design mentioned in this paper seeks to overcome the above challenges.

The proposed system comprises User Detection using Sensors, Automatic Flushing, Optimization of Water Usage, Surface Hygiene monitoring, with Logic implemented using a microprocessor, and Wireless Communication as well. The design employs Infrared and Proximity Sensors for detecting the presence of the user and seat usage. The system utilizes solenoid valves for controlling the amount of water used in flushing. Furthermore, the proposed system will incorporate Adaptive Flushing Logic whereby the amount of water will be optimized to improve its usage and conserve more water. Testing will be done to evaluate the performance and ensure the proper functioning of the sensors and accuracy of the flushing.

After completion of the project, the expected outcome would be a working smart toilet with automatic flush capability. Moreover, after testing it is expected that the system will be capable of reliably detecting users and communicating wirelessly while optimizing water usage as well as ensuring restroom hygiene. Not only is the project useful for home and public usage but also it will go a long way to improving the sanitation level in the ever-growing cities.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Sanitation is a key aspect of public health, yet many conventional toilet systems remain inefficient and unhygienic. In both developed and developing regions, toilets and urinals are often prone to poor maintenance, excessive water usage, and lack in automation. With increasing urbanization and the global growth on smart technologies, there is a growing need for intelligent sanitation solutions that not only improve hygiene but also enhance user convenience and reduce wastage.

Smart toilets, which integrate automation, sensors, and control systems, have gained attention in recent years for their potential to improve user experience and environmental sustainability. By automating processes such as flushing, hand washing, and water usage control, these systems can significantly reduce human contact with contaminated surfaces, thereby lowering the spread of infections.

In recent years, the growing demand for automation and intelligent systems has transformed several aspects of human life, including healthcare, agriculture, transportation, and home automation. Sanitation, however, has not received the same level of attention despite being directly linked to public health, hygiene, and overall quality of life. Traditional toilet facilities often depend on manual operation, which exposes users to germs and bacteria through frequent contact with taps, flush handles, and other surfaces. Studies have shown that public toilets are among the most contaminated environments, contributing to the transmission of communicable diseases. This problem becomes more pronounced in highly populated areas such as schools, hospitals, workplaces, and recreational centers where hygiene practices are not consistently enforced.

1.2 Problem Statement

The conventional approaches for sanitation rely significantly on manual efforts, which leads to poor hygiene, inefficient performance, and wastage of water resources. The issues related to toilet include bad smell, urinals not being flushed, and contamination from surfaces handled by everyone, such as the taps and flush buttons. Despite having some developed approaches for sanitation in certain areas across the globe, it is quite difficult for public restrooms to adopt any of them due to financial constraints.



Fig. 1.1: Manual Hand Wash Basin

1.3 Research Gap

Despite the availability of smart sanitation systems or intelligent systems for restrooms, most are either costly, hard to install and maintain or meant for luxury use. Current solutions often focus on one aspect such as automatic flushing without integrating multiple features into a single system improving simplicity. Therefore, there is a gap in developing a practical, affordable, and user-friendly smart toilet design that integrates automated flushing, smart urinal detection, and automated hand washing, especially for public environments.

1.4 Research Aim and Objectives

The goal of this project is to develop a better version of the smart toilet with respect to increasing hygiene levels or convenience to the users.

The detailed goals are:

- Develop an automatic hand wash system, whereby there is little or no manual interaction needed.
- Develop a smart urinal with the capacity to sense user presence and start flushing automatically upon usage.



Fig. 1.2: Automated Hand Wash and Smart Urinal system

- Install an intelligent toilet-flushing system that operates when the door is opened to ensure cleanliness.
- Utilize the design as a prototype for other public toilet facilities.

1.5 Scope and Significance

The objective of this project is to design and build a smart toilet system which automatically washes hands, flushes urine, and flushes the toilet bowl. The system will target locations like schools, hospitals, public bathrooms, and other places where hygiene and water conservation are critical.

The significance is simply to:

- Reduce human contact with contaminated surfaces, thereby reducing disease transmission.
- Properly controlled and sensor-based flushing mechanisms.
- Enhance user convenience or experience and also encourage hygienic practices.

1.6 Expected Outcome

The anticipated result of this study includes the creation of a working model for a smart toilet system that will be able to do the following:

- Automate handwashing of the users while saving water.
- Automate the process of detecting urine use and then flushes the urinal automatically.

Flush the toilet automatically when the user leaves it for better hygiene practices. This innovation will demonstrate how smart technologies can be adapted to meet sanitation challenges in an affordable, sustainable, and user-friendly manner.

CHAPTER TWO

LITERATURE REVIEW

2.1 Smart Toilet Systems and Sanitation Management

In Nigeria, where there aren't enough toilets and people don't wash their hands often enough, sanitation is still a major public health and environmental issue. This leads to disease outbreaks, groundwater contamination, and a general decline in public health. The World Health Organization (WHO, 2022) says that more than 47 million Nigerians still use open defecation, and many public toilets are not well-kept or don't work at all because there aren't any systems in place to check on them and keep them clean. Many homes and public places in Edo State, especially in Benin City, still use regular toilets that don't have smart features for keeping an eye on hygiene, saving water, and doing maintenance automatically (Okolie & Edewor, 2021). These problems show how important it is to have technology-driven sanitation systems that can improve cleanliness, find problems on their own, and encourage the best use of resources.

Recent research has examined the incorporation of intelligent technologies in sanitation management. For example, Udo et al. (2021) created a prototype of an automated toilet flushing system that uses infrared sensors to find out if someone is using the toilet and start cleaning. This was a step forward in the automation of hygiene, but the design did not include advanced features like detecting odors, optimizing water use, and diagnosing faults. Afolabi et al. (2020) also suggested an Internet of Things (IoT)-based system for keeping an eye on sanitation that lets maintenance workers know when a public restroom needs to be cleaned. But the system didn't have any ways to keep track of health-related data or get feedback from users, which are both very important for making the user experience better and making maintenance more efficient.

Another problem with the present systems is the nonexistence of alerts that notify maintenance personnel about faults within the system. Many toilets are able to function only up until a point where there is some kind of mechanical or plumbing breakdown after which these toilets are in bad condition for quite some time due to faulty maintenance. As pointed out by Eze and Akinola (2021), the need for automated fault-detection systems is important for the avoidance of hygiene problems and overall satisfaction.

Moreover, another important issue that has been overlooked within Nigeria in relation to sanitation system development is water saving and energy efficient technologies. According to research done by Rada et al. (2019), smart toilets capable of adjusting their flushing mechanism and water recycling technologies are able to reduce water waste considerably without lowering levels of hygiene. Nevertheless, at this moment there is not a single reported case of this type of system developed and applied within the state of Edo and across Nigeria.

From the reviewed literature, it is evident that Nigeria and Edo State in particular faces persistent challenges in sanitation and toilet management that cannot be addressed through traditional

approaches alone. While some studies have proposed basic automation solutions, none have fully integrated features such as automated cleaning, fault detection, user health monitoring, odor control, and water optimization into a single system. These represent key gaps that the design of an Improved Smart Toilet System seeks to address. By developing a multifunctional system that enhances hygiene, efficiency, and health insight, this project aims to contribute to sustainable sanitation management and serve as a scalable model for other regions across Nigeria.

2.2 Conceptual Framework

2.2.1 Definition and Concept of Smart Toilet Systems

The term smart toilet system implies the use of automation, sensing, and data science technologies in the development of sanitary technology that will increase hygiene level, comfort and even help with health monitoring. As indicated by the World Health Organization (WHO, 2022), current sanitation systems are supposed not just to run the system properly, but to ensure hygienic conditions as well as water conservation. The smart toilet system goes further, using such technological elements as motion sensors, automatic flushing, optimization of water consumption and cleaning.

The topic of smart toilets relates to intelligent buildings' systems which operate through the Internet of Things (IoT) and sensors. Such systems can detect presence, controlling water flow, triggering actions and managing the system automatically without any manual operation required. In addition, some devices may include health monitoring functions, including sample analysis for early detection of certain health problems (Zhang et al., 2021).

In the Nigerian context, the National Environmental (Sanitation and Wastes Control) Regulations, S.I. No. 28 of 2009, emphasize the importance of sanitary waste management and hygiene in public and private spaces. However, the integration of automation and real-time monitoring into toilet design is still emerging. Smart toilet systems aim to bridge this gap by introducing intelligent waste disposal, water management, and maintenance diagnostics to ensure efficient operation and sustainability.

The foundation of a smart toilet system extends beyond traditional sanitation. It involves a technology-driven approach that enhances cleanliness, reduces maintenance costs, conserves resources, and contributes to improvement of public health. Therefore, a smart toilet system represents the evolution of sanitation from new technology, hygiene management solution that supports both user wellbeing and environmental protection.

2.2.2 Phases of Smart Toilet System Operation

1. **Hand Washing Phase:** After toilet use, the system proceeds to the hand hygiene phase. The automatic hand wash unit uses infrared sensors or motion sensor to detect the user's hands and release water without physical touch. This reduces the spread of germs and conserves water,

as the system dispenses only the required amount for each use. Studies by Afolabi et al. (2020) emphasize that touchless systems significantly improve hygiene in shared facilities and support infection prevention.



Fig. 2.1: User Detection Image



Fig. 2.2: User Washing Hands

2. **Hand Washing Phase:** After toilet use, the system proceeds to the hand hygiene phase. The automatic hand wash unit utilizes infrared sensors to detect the user's hands and release water without physical touch. This reduces the spread of germs and conserves water, as the system dispenses only the required amount for each use. Studies by Afolabi et al. (2020) emphasize that touchless systems significantly improve hygiene in shared facilities and support infection prevention.



Fig. 3.1: User Drying Hands

3. **Flushing and Cleaning Phase:** In addition to the automatic flush generated by the user, the smart toilet design has an auto-flush feature that works in line with the door movements. This ensures the cleanliness of the toilet for the next user after leaving the room or entering it. This phase enhances convenience and ensures that no odor accumulation occurs, which remains the primary challenge facing ordinary toilets.
4. **System Monitoring and Maintenance Phase:** The last phase involves system monitoring and maintenance diagnosis. In case of challenges such as water leakage, lack of soap, or sensor issues, sensors prompt system maintenance. According to Eze and Akinola (2021), it is a prudent decision to integrate self-diagnosis in the system.

2.2.3 Traditional Approaches to Sanitation and Their Limitations

Manual sewage systems, common in Nigerian states including Edo State, include manual toilet systems such as conventional toilet pans, pit latrines, and flush systems that do not involve automation or control functions. These systems commonly suffer from poor hygiene upkeep, waste of water and excessive dependence on manual cleaning activities (Okolie & Edewor, 2021). In many cases, the use of conventional restrooms necessitates manual toilet flushing, hand washing via taps, and manual drying using tissues, thus raising concerns regarding the spread of diseases and poor hygiene maintenance due to lack of systematic cleaning routines.

The limitations of these traditional sanitation methods is increased by rapid urbanization, lack of maintenance schedules, and insufficient investment in modern sanitation technologies. Many public toilets in cities like Benin lack adequate ventilation, cleaning systems, or functional handwashing facilities, creating unhygienic conditions that discourage use (Nwachukwu, 2020). Additionally, manual flushing and tap systems often result in equipment damage, and increased maintenance costs.

Traditional sanitation approaches have shows several downside in addressing the growing need for hygiene, automation, and environmental protection. In several Nigerian facilities, toilets are frequently left unflushed, handwashing stations lack running water, and hand dryers or tissue

supplies are often unavailable. This contributes to poor sanitation and increased risk of disease transmission through contaminated surfaces (Eze & Akinola, 2020).

This brings up the idea of transitioning into a more technology-driven approach like smart toilets that can help minimize or completely avoid physical interaction and guarantee high levels of cleanliness and water savings.

2.2.4 Evolution of Smart Toilet Systems

The evolution of smart toilet system development is characterized by gradual improvement of sanitation technology through automation, sensor integration, and data analysis. Initially, toilet models featured purely mechanical design that involved manual execution of all tasks related to use and maintenance such as flushing, washing, and cleaning. These systems provided satisfactory performance without having hygiene-friendly options that can help in conserving water or reducing physical interactions with unclean toilet surfaces. Gradually, increased concerns about sanitation quality and public health safety triggered the development of new technologies and incorporation of automation and intelligence into existing sanitation solutions (Lee & Park, 2020).

Development of smart toilets in Japan in the late 1980s became an important step towards creation of modern sanitation devices featuring additional functionalities aimed at improving users' comfort. Such technologies included automatic lid opening/closing, electronic bidet function, and temperature adjustment (Zhang et al., 2021). Within decades, they managed to spread over other Asian, European, and North American countries, giving rise to self-cleaning and odor-removal technologies, as well as automatic flushing. Today, smart toilets offer more advanced opportunities for enhancing sanitation such as optimizing water consumption, introducing touchless controls and voice activation, and detecting diseases using urine or stool samples.

Despite being a developing country, Nigeria's use of smart toilets is limited to factors like costs, infrastructural limitations, and lack of knowledge. In the existing toilets, manual methods that put people at risk of infections and wastage of water are applied (Okolie & Edewor, 2021). However, increased interest in automated equipment and the need for infection prevention after the coronavirus disease has led to the development of inexpensive smart toilets.

The enhanced smart toilet system presented by this project reflects a part of the technology advancement process. As it was noted above, there are three key automation features implemented into the new toilet system – an automatic hand wash machine, an automatic flush (activated by opening the door), and an automatic hand dryer. The improved toilet system utilizes sensors that allow its users to avoid any direct contacts and use less water than in standard bathrooms.

Overall, the evolution of smart toilet systems demonstrates a global shift from traditional sanitation toward intelligent, user-centered, and environmentally sustainable solutions. By adopting such technologies in Nigeria, particularly in Edo State, the improved smart toilet system contributes to bridging the gap between modern sanitation practices and public health standards.

2.3 Overview of Smart Toilet Systems

Smart toilet systems represent a significant technological advancement in addressing the persistent sanitation and hygiene challenges in Nigeria, particularly in urban areas such as Edo State. These systems integrate automation, sensors, and the Internet of Things (IoT) to enhance cleanliness, improve user experience, and promote efficient water and energy use. The primary objective of smart toilet technology is to create contactless, self-operating facilities that minimize disease transmission, conserve resources, and ensure sustainable sanitation management (Okolie & Edewor, 2021).

At the core of these systems lies the principle of automation and real-time responsiveness. Sensors are strategically embedded in toilet components to detect user presence, trigger automatic flushing, dispense water for hand washing, and activate hand dryers without the need for physical contact. Such designs not only improve hygiene standards but also reduce the spread of infections caused by shared touch surfaces (Afolabi et al., 2020). Modern smart toilets also incorporate intelligent water control mechanisms that regulate flow rates, ensuring that only the required amount of water is used per session, thereby conserving resources and lowering operational costs.

The major distinguishing factor between the modified version of the smart toilet and the earlier models is the integration of automated systems which have been specifically tailored to address issues arising in Nigeria. These include:

- Automated hand wash station that utilizes infrared sensors to dispense water to a hand that is within the range of the sensors.
- Automated toilet flushing that operates upon the detection of a door sensor, ensuring that the toilet will always be flushed after each use.
- Automated hand dryers that serve as alternatives to the paper towels, which reduce the costs of waste disposal.

As compared to the traditional toilet units in Nigeria, the above-mentioned toilet unit has employed the use of modern technology for operation, unlike the traditional toilets which rely on manual cleaning processes. Such toilets are applicable in urban areas such as Benin City (Nwachukwu, 2020).

Various projects conducted around the world have shown how these technologies may affect the future of the sanitation industry. For example, according to the findings of Lee & Park (2020), the use of automatic hand washing and flushing stations in public bathrooms causes a 60% decrease in bacteria levels. In addition, as per Zhang et al. (2021), touchless stations increase the efficiency of water consumption and customers' satisfaction in such locations as airports and hospitals.

With minor adjustments to accommodate local needs, the advanced toilet facility designed during this project indicates that automated systems can become both accessible and efficient. The emphasis on hygiene automation, sustainable operation, and user comfort allows for further implementation of the proposed solution in the development of advanced toilet facilities at universities, hospitals, and office premises.

Therefore, it can be concluded that automated sanitation facilities offer a productive approach to solving current problems associated with hygiene management and maintenance of traditional facilities in Edo State.

2.3.1 Components of a Smart Toilet System

A smart toilet system refers to a modern form of technology-based sanitation that increases efficiency in terms of hygiene, water conservation, and customer satisfaction due to the integration of automatic control, sensors, and mechanical components. Such systems make use of embedded technologies, for instance, microcontrollers, proximity sensors, and relays among others, to automate activities such as flushing, hand washing, and hand drying. Through the process, it eliminates any need for manual touch which enhances hygiene and efficiency (Afolabi et al., 2021).

There exist various critical components of a smart toilet system.

1. **Proximity sensors:** The proximity sensor forms one of the critical components of the system. This sensor detects whether there is anyone around. Proximity sensors can be used to trigger the hand wash process, flushing of the toilet when the door opens, and the activation of the hand dry process. They function through infrared and ultrasonic technologies that detect distance and motion. Lee and Park (2020) state that incorporating proximity sensors in sanitation systems is highly advantageous in improving hygiene levels.
2. **Solenoid Valves:** The solenoid valves control water flow inside the system. These open or close depending on the signals received from the Arduino microcontroller to enable water flow to the taps or flush valve. The adoption of these valves ensures the proper management of the flow of water in order to prevent wastage and maintain consistency. They play an important role in the regulation of the timing and amount of water for both hand washing and flushing processes (Okolie & Edewor, 2021).
3. **Pumps:** Pumps are necessary in regulating the pressure of water to be delivered. They help in delivering the required pressure needed for water flow in the hand wash and flushing units. They coordinate with the solenoid valves to deliver water at a specified point and intensity. Consistent water flow is necessary in maintaining good performance of the system (Afolabi et al., 2021).
4. **Relay Module:** Relay module refers to an electronic device that acts as an electronic switch and works alongside the Arduino to perform the functions of turning ON and OFF high-power gadgets such as pumps, dryers, and valves. This device serves as a bridge between the control circuit and power circuit, providing efficient electrical switching. It is essential in the smart toilet application because it helps in automating multiple elements through the microcontroller (Adeyemo et al., 2019).
5. **Microcontroller:** It is one of the most vital elements in this intelligent toilet application as it acts as its 'brain' performing the tasks of processing the signals and issuing commands to relays for efficient automation processes. The microcontroller used in this application is the Arduino

since it is flexible in programming and facilitates the communication process among the elements in this sensor-based application (Atayero et al., 2019).

6. **Power Supply:** Power supply is used to provide energy to all electrical devices of the system. For the intelligent toilet system, the source of electricity may either be alternating current or direct current in the form of batteries depending on where the system will be installed. Power supply should be stable for the system to function effectively because of the use of sensors, relays, and the Arduino microcontroller (Afolabi et al., 2021).

2.3.2 How the Components Work Together

In the proposed smart toilet system, the components are designed to work together in an integrated and automated manner to enhance hygiene, water efficiency, and user convenience. Each component plays a specific role in ensuring the seamless operation of the system, while the microcontroller coordinates the entire process to ensure responsiveness and reliability (Adeyemo et al., 2019).

The system operation begins with the proximity sensor, which detects the presence of a user. When motion or proximity is sensed, it sends a signal to the Arduino microcontroller, which serves as the central control unit. The Arduino processes the sensor data and activates the corresponding output devices. For example, the solenoid valve is triggered to release water through the pump for automatic hand washing, while the relay module ensures safe switching between the low-voltage control circuit and the high-power electrical components such as the pump or hand dryer.

2.3.3 Case Studies and Global Implementations

Smart toilet technology applications have gained popularity in many parts of the world for the purposes of enhancing sanitation, ensuring water conservation, and enhancing overall customer experience within public and institutional buildings.

- a **Japan:** This country is one of the pioneers in smart toilet technology applications. These smart toilets incorporate features such as proximity sensors, self-flushing abilities, heated seats, and self-cleaning processes among others. These smart toilets utilize very little amounts of water by ensuring that there are precise amounts controlled using valves. They also ensure touchless functions that minimize the spread of germs (Sato & Nakamura, 2021).
- b **Singapore:** There have been applications of smart toilets in this city-state as part of the national effort towards building a smart nation. Such smart toilets apply sensor technologies and IoT that allow for monitoring of usage data and cleanliness of public toilets in real time. The usage data is sent to a central platform where maintenance work can be scheduled if necessary (Lee et al., 2022).

2.3.4 Relevance to Nigeria

In the country under consideration, the implementation of smart toilet solutions is extremely promising regarding the provision of proper hygiene standards, minimizing the waste of water, and creating effective approaches in public health care. The majority of public toilets in educational institutions, schools, and even cities are in poor condition and lack both water and sanitizing measures because of their manual operations. The application of smart toilet solutions would be an excellent solution to such issues as all of the processes would be automated (Anyaocha et al., 2023).

The integration of proximity sensors, pumps, solenoid valves, and microcontrollers such as Arduino enables contactless operation, which reduces the risk of germ transmission and enhances user convenience. Moreover, automation ensures that water is dispensed only when necessary, supporting Nigeria's efforts toward water conservation especially in regions facing challenges with water supply.

For example, one can apply the same approach to the University of Benin. By means of using local materials, one would demonstrate the effectiveness of the solution proposed and its ability to be implemented to maintain high standards of hygiene in institutional structures.

The incorporation of these technologies into other universities, hospitals, and public buildings in Nigeria would result in better sanitation results, lower maintenance costs, and adherence to national plans for development and environmental sustainability. In all, the introduction of smart toilet technologies is an answer to the sanitation problems in Nigeria.

2.4 Current Sanitation Management in Nigeria

2.4.1 Overview of Sanitation Practices in Nigeria

Sanitation management in Nigeria continues to face significant challenges stemming from rapid population growth, poor infrastructure, and inadequate enforcement of public health regulations. Despite national efforts to promote hygiene and access to improved sanitation, many public and institutional facilities, such as schools, hospitals, and marketplaces, still rely on outdated and poorly maintained toilet systems (Abila & Kantola, 2013). The lack of automation, coupled with inconsistent water supply and inefficient maintenance practices, often results in unhygienic conditions that pose serious health risks.

The use of public toilets in Nigeria typically involves manual flushing systems, handwashing using mechanical taps. These facilities frequently suffer from broken fixtures, water leakages, and poor ventilation, leading to user dissatisfaction and reduced hygiene (Adewole, 2009). In many public restrooms, there is little to no provision for hand dryers or touchless facilities, thereby increasing the likelihood of crosscontamination and the spread of infectious diseases such as cholera and typhoid (Amin et al., 2024).

Inadequate maintenance funding and the absence of smart monitoring systems further aggravate the problem. Cleaning schedules are often irregular and reactive rather than preventive, leading to facility degradation. The lack of automation also results in significant water wastage due to manual flushing and taps left running (Nzeadibe & Ajaero, 2010). These inefficiencies highlight the need for innovative, technology-based approaches to sanitation that prioritize hygiene, water conservation, and operational efficiency.

Health and environmental implications of poor sanitation in Nigeria are severe. Unhygienic toilet facilities contribute to disease transmission, discourage toilet use, and often lead to open defecation in rural and peri-urban areas. The World Health Organization (WHO, 2022) estimates that millions of Nigerians are exposed to sanitation-related health risks each year due to inadequate facilities. This challenge is especially prevalent in educational institutions and public offices, where large populations share limited resources.

Recent government and non-governmental efforts have sought to improve sanitation management. Agencies such as the Federal Ministry of Water Resources and the National Task Group on Sanitation have introduced initiatives like the “Clean Nigeria: Use the Toilet” campaign to eliminate open defecation and promote hygiene awareness (Ogunkan, 2022). However, these initiatives often focus on behavioral change rather than integrating technology-driven solutions.

Smart toilet systems present an opportunity to complement these initiatives through automation and IoT-based design. By incorporating proximity sensors, solenoid valves, pumps, and relay-controlled systems—such as those used in the prototype developed at the University of Benin—smart toilets can ensure automatic flushing, touchless hand washing, and efficient hand drying. This not only promotes hygiene and convenience but also minimizes water wastage and maintenance demands.

The integration of smart sanitation systems into public and institutional facilities across Nigeria could therefore bridge the gap between infrastructure and hygiene. Such systems align with the United Nations Sustainable Development Goal 6 (Clean Water and Sanitation), providing a scalable and sustainable model for improved sanitation management in the country (Amasuomo & Baird, 2016).

2.4.2 Challenges of Sanitation Management in Nigeria

The provision of sanitary, effective, and sustainable public restroom facilities is hampered by the ongoing and complex issues facing Nigeria's sanitation management sector. Government and private sector initiatives to enhance sanitation have been hampered by inadequate infrastructure, sporadic maintenance, and a lack of widespread adoption of new technologies (Okeke et al., 2024).

The majority of public institutions and communities use antiquated toilet systems and inadequate infrastructure, which present a significant challenge. Poor drainage networks, broken taps, and

manual flushing systems are used in many facilities, creating unhygienic conditions and discouraging appropriate toilet use. The issue is exacerbated by limited access to clean running water, which results in unsanitary behaviors like improper handwashing or a total disregard for post-use hygiene (Abbas & Ali, 2024).

Another major obstacle is the lack of finance and investment in contemporary sanitation technology. Public restrooms in colleges, hospitals, and shopping centers frequently have tight budgets and put more emphasis on routine upkeep than on new technology. Consequently, it is uncommon to find features like motion-activated water dispensers, hand dryers, or automatic flushing installed. Financial limitations also affect private contractors in charge of sanitation facilities, which restricts their capacity to implement creative fixes or guarantee regular upkeep and cleaning (Amos et al., 2024).

The lax enforcement of laws pertaining to public health and sanitation is another serious problem. Despite the existence of national regulations like the National Environmental (Sanitation and Wastes Control) Regulations of 2009, their implementation varies. Due to a lack of inspection and maintenance oversight, many public facilities have broken fixtures, lingering odors, and unsanitary conditions.

Nigeria's sanitation problems are also greatly exacerbated by a lack of public awareness and a culture of hygiene. Because handwashing stations are frequently unavailable or broken, many users neglect to follow hygienic habits like washing their hands after using the restroom. Sanitation-related public education initiatives have had a limited impact, and behavioral change is still taking time (Etim, 2024). As a result, there is still a high chance of disease transmission, particularly in crowded places like schools.

Furthermore, the current sanitation infrastructure is still under stress due to the fast urbanization and population growth. As cities grow, so does the demand for public restrooms, but new facilities are rarely built or outfitted with contemporary amenities. Inadequate sanitation facilities, which result in open defecation and environmental contamination, are particularly problematic in rural areas and informal settlements (Okeke et al., 2024).

These issues have serious effects on the environment and human health. Poor toilet maintenance contributes to the spread of waterborne illnesses like cholera, diarrhea, and typhoid by providing a haven for insects and pathogens. Wastewater stagnation, which presents major environmental risks, is also caused by ineffective flushing systems and leaking drainage lines.

A potential remedy for these issues is the use of smart toilet technologies, such as motion-activated handwashing stations, automatic flush systems, proximity sensors, and hand dryers. Such systems have the potential to revolutionize sanitation management in Nigeria by lowering direct contact with surfaces, increasing water use efficiency, and guaranteeing consistent hygiene. To guarantee

sustainability and long-term effects, however, broad adoption necessitates more funding, regional technical know-how, and more robust institutional support.

2.5 Traditional Toilet Systems in Nigeria

2.5.1 Methods of Traditional Toilet Systems

The use of conventional approaches to toilet maintenance in Nigeria is widespread in almost all regions but with minimal success regarding hygienic practice and environmental conservation. The use of manual methods such as manual flushing, bucket hand washing, and direct disposal of waste is rampant in both private and public areas. Such practices contribute to poor sanitization and spread of diseases, as well as degradation of the environment. This situation makes the adoption of innovative toilets imperative since these toilets can be used to automate the sanitization process and waste management process (Jibrilla et al., 2024).

- i. **Manual Flushing and Poor Waste Handling:** Conventional toilet facilities depend entirely on manual flushing after use, something that creates a problem considering human error and faulty flushing mechanisms that may occur. Many people do not flush manually after use, leading to odor, bacterial growth, and unhygienic environments. Also, there is usually poor handling of the flushed waste material. Smart toilets overcome this limitation by automatically flushing upon entering the room or leaving the facility (Ogunrinola and Adepegba, 2012).
- ii. **Manual Washing Techniques:** In conventional public toilets, washing hands usually entails the use of buckets or manually operated faucets. The likelihood of contamination is high due to repeated touching of the same surfaces by different people. Moreover, in some regions where there is no provision for consistent water flow, washing hands becomes a challenge. However, this problem is addressed by the automated hand wash technique used in the smart toilet concept through the application of water dispensing sensors.
- iii. **Poor Waste Management and Maintenance Practice:** Traditionally, the management of toilet waste is through the manual cleaning of septic tanks and soakaways, which poses health risks to the people involved. Besides, improper waste disposal of untreated sewage into the water bodies and other open spaces still poses a risk. This problem can be addressed through the integration of water consumption management and waste tank level management systems with IoT technologies. The primary reason why these systems are still used in contemporary times is because of inadequate technology infrastructures, poor knowledge about alternative approaches, and financial constraints. Traditionally, such sanitation systems were enough, but with increased population growth and the use of public toilets, there arises the need for automation to maintain hygiene and sustainability.
- iv. **Absence of Effective Hand Drying Mechanisms:** In conventional toilets, people resort to drying their hands either through the use of communal towels or by air drying. Some of the public toilet systems do not even have provision for hand drying at all. The addition of hand dryer in this innovative toilet makes it an efficient facility in terms of sanitation, paper conservation, and maintaining hygiene (Njoku et al., 2021).

2.5.2 Dangers of Traditional Toilet Systems

There are several environmental, health, and economic risks that come with conventional toilet systems due to their heavy dependency on manual flushing, manual hand washing, and sanitation systems. Such traditional toilets still remain widely used in many institutions including government agencies, corporate offices, and even universities in Nigeria due to lack of technology and innovation in sanitation practices. Nevertheless, their frequent use brings various negative effects to the health of people as well as leads to improper utilization of natural resources.

i. Environmental Consequences

In most cases, the conventional toilets tend to use more water in flushing processes hence water wastage in places where there is little water in supply. Besides, bad plumbing connections and leakages in the plumbing system also cause damage of resources and environmental pollution. There are no automatic systems to control the volume of water consumed compared to the modern systems that control water volume.

Moreover, there is poor air circulation and drying of the toilet which results in dampness thereby facilitating the growth of molds and foul smell.

ii. Public Health Risks

There are numerous issues associated with the hygiene factor since individuals must be constantly in contact with surfaces, including flush handles, taps, and doorknobs, which could be contaminated with various bacteria. Public bathrooms become perfect places for the proliferation of bacteria that cause diseases, like cholera and typhoid, as well as other kinds of infections.

Manual washing systems, which utilize the same basin or bucket for different people, only add to the problem. The lack of automatic flushers and hand dryers prompts many individuals to neglect hand hygiene and creates favourable conditions for the development of various diseases. Furthermore, poorly cleaned and sanitized bathrooms may produce foul smells and attract flies.

iii. Economic and Social Implications

Maintenance of conventional toilets is expensive. Water wastage and plumbing problems make their operation expensive in terms of costs. Besides, the lack of automation calls for more work to be done to ensure maintenance, hence lowering efficiency.

From a social perspective, the use of an unhygienic toilet facility makes it less usable by people in various social areas like schools, workplaces, and hospitals. This leads to loss of man-hours, inefficiencies at workplaces, and additional government health budget spending. Poor maintenance of facilities sends bad signals about the organization or place.

2.5.3 Case Studies and Statistical Data

Traditional toilet systems are still prevalent in many areas of Nigeria and other developing countries, leading to low sanitation standards, unhygienic conditions, and ineffective water management practices. As per a WHO report from 2022, about 46% of Nigeria's total population does not have access to adequate and sanitary toilet systems, whereas almost 25% share public or communal toilets that are not maintained hygienically. Lack of automation and smart controlling in such toilet systems leads to frequent cases of epidemics and bad smell inside the toilets.

In a study performed in Lagos and Abuja, it was discovered that about 60% of public toilet rooms use manual flush mechanisms and more than 70% have no automated hand washing or hand drying mechanism (Aminu & Eze, 2023). Such situations lead to infections caused by bacteria or germs, like cholera and typhoid infection, in places where many people use the same toilets, such as schools, markets, religious places, and transportation stations.

On an international scale, smart toilets are becoming popular in connection with the rise of smart buildings and smart cities movement.

As an example, Kim et al. (2021) designed a smart toilet system in South Korea through the application of proximity sensors, automated flushing mechanism, and touchless faucets that resulted in saving up to 32% water usage while improving the level of cleanliness by avoiding contact with potentially contaminated surfaces. Another solution for designing the smart toilet may include Jadhav et al.'s (2020) work on implementing a system controlled by means of the Arduino microcontroller with such sensors as motion and flow control.

Patel & Joshi (2022), in their part, proposed designing a public smart sanitation facility in India with the use of technologies of ultrasonic sensors, solenoid valves, and GSM communication system to achieve a 25% reduction in maintenance costs and increase the cleanliness level by enabling remote control.

Nevertheless, current technologies face certain restrictions associated with high cost and complexity of installation and design. Thus, Rahman et al. (2023) developed a concept of smart restroom, which incorporates such functions as toilet flushing, soap dispensation, and drying with the help of the Arduino microcontroller and infrared sensors. Despite effectiveness in terms of minimizing contact and ensuring better hygiene level, this system is rather costly, thereby limiting its use.

It is clear that these findings together point out the importance of having cheap and adaptable smart toilets in countries like Nigeria. Combining features like proximity sensors, pumps, valves, relays, and other Arduino-based devices into one system can be used as a feasible way of increasing sanitation efficiency, reducing water waste, and improving the performance of users. Thus, the current proposal of creating smart toilets is consistent with the development of the industry.

2.6 Smart Toilet System and Monitoring Technologies

Conventional sanitation systems, particularly in public and institutional settings, often suffer from inefficiencies such as irregular maintenance schedules, poor hygiene monitoring, and excessive water consumption. Recent advancements in technology have showed the need for improved, automated sanitation systems that improve hygiene and efficiency. Saha et al. (2017) contend that by incorporating real-time monitoring of usage, cleanliness, and resource consumption, sensor-equipped smart toilet systems mark a substantial advancement. These systems guarantee user comfort and environmental efficiency by detecting occupancy, monitoring water usage, and automatically turning on flushing and cleaning systems. Predictive maintenance and efficient

facility management are made possible by the real-time analysis of data sent to the cloud by these embedded sensors.

Similarly, Zackarias and Sangeetha (2018) highlight the growing relevance of IoT-based sanitation systems that monitor parameters such as toilet usage frequency, odor levels, and handwashing compliance. By transmitting these data points to centralized platforms, facility managers can identify high-usage zones, detect malfunctions early, and optimize cleaning schedules. This level of automation ensures maintenance is performed based on actual usage patterns rather than rigid schedules, significantly reducing operational costs and improving overall hygiene standards.

Azam and Lung (2016) advanced the conversation on smart sanitation by proposing a cloudbased Smart Toilet Management System (CloudSTM) that combines several toilet units with sensors that track important physiological and environmental parameters, including temperature, humidity, and user health metrics (e.g., urine protein or glucose levels). By sending anonymized health data to cloud platforms for analysis, their model shows how smart toilets can be used for purposes other than just keeping bathrooms clean. Stakeholders such as maintenance crews and medical professionals can obtain real-time insights thanks to the cloud infrastructure, which guarantees timely intervention, higher sanitation standards, and better user health outcomes.

Researchers like Caniato et al. (2014) stress the importance of assessing the systemic and human-centered aspects of smart sanitation solutions in addition to the technological dimension. Stakeholder analysis (SA) and social network analysis (SNA) are two analytical frameworks that can be integrated to help stakeholders better understand how users, maintenance staff, and policymakers interact within a sanitation system. This helps identify important areas for resource allocation and hygiene education improvement.

While the main benefits of smart toilet technologies are to improve sanitation efficiency and hygiene monitoring, it is important to balance innovation with social and institutional demand, according to frameworks like the Integrated Sustainable Sanitation Management (ISSM) model. According to Klundert and Anschutz (2001), a sustainable sanitation system should involve institutions and communities in addition to relying on technology. According to Wilson et al. (2013), smart sanitation solutions should be affordable, tailored to the context, and created through participatory methods that guarantee equity and usability for people from a variety of socioeconomic backgrounds.

When implementing smart toilet systems, stakeholder involvement is still essential, particularly in developing nations where infrastructure and public health issues are still present. Lohri et al. (2013) contend that collaboration between government bodies, engineers, and communities enhances long-term sustainability and social acceptance of such systems. Technical and user-centered priorities have been successfully balanced through the use of analytical tools like the Analytical Hierarchy Process (AHP) (De Feo and De Gisi, 2010; Bao et al., 2012). Geographic Information System (GIS) technologies have also been used to select locations for public restrooms, guaranteeing accessibility and fair distribution (Moeinaddini et al., 2010; Tavares et al., 2011).

Furthermore, the energy and material design of smart toilets is sustainable. To lessen reliance on grid electricity and encourage environmental conservation, recent studies highlight the use of solar-

powered systems and eco-friendly, long-lasting materials (Abba and Light, 2020). Longterm maintenance and durability issues are brought up by the fact that many current prototypes still use traditional materials and have little energy optimization. Additionally, variations in environmental conditions such as humidity and temperature may affect sensor accuracy and system performance.

Research on smart toilets has advanced, but there are still a number of shortcomings. With little testing in actual public or rural areas, most studies have concentrated on developing prototypes in controlled settings (Ali et al., 2020). Future studies should focus on integrating health monitoring features, AI-driven analytics, and advanced automation while guaranteeing affordability, robustness, and context-specific adaptability. With these changes, smart toilet systems would develop into data-driven, sustainable solutions that concurrently address environmental, public health, and sanitation objectives.

2.7 Monitoring and Control Mechanisms

Monitoring and control systems are key elements in any smart toilet, since they provide convenience, energy efficiency, and automation of the process of cleaning. Modern technologies are used in this system in the form of implementation of sensing technology, embedded controls, and IoT, which makes the operation of the device fully automated and maintains hygienic conditions (Kalaiselvi et al., 2024; Sohail et al., 2024). Smart toilets have implemented advanced features of sensors, communications, and data analytics aimed at improving hygiene conditions, reducing the amount of water consumption, and ensuring environmental controls. Sensors that are integrated in IoT-based smart toilets monitor real-time information on such parameters as tank level, water flow, occupancy of a toilet, as well as air humidity and quality. Proximity, infrared, and ultrasonic sensors can detect the presence of a user and turn on.

The functioning of smart toilet monitoring systems relies on IoT-enabled sensors, which ensure the process of continuous data collection concerning tank levels, water consumption, user activity, and other environmental factors like humidity and air quality. Contactless sensors monitor the presence of the users in the restroom and enable automatic hand washing, toilet flushing, and hand drying, without requiring any manual interaction from the users. In addition to improving hygiene conditions, such continuous monitoring leads to effective resource management because of energy and water savings. Collected data from several sensors may be transferred to one centralized cloud computing system for further processing (Gribova and Kharitonov, 2024).

Other features in smart toilet control include self-regulation of the toilet system as well as automation where there is action triggered by certain inputs. This could be where the flushing process starts after a person moves away, soap dispenser gets activated in case of hand washing or hand dryer switches on upon sensing any hands. Microcontroller that processes the signal sent by various sensors triggers the right functions. However, if some abnormal sensor signals occur like water pressure issues, system malfunctions and others, then the control device changes its processes or sends notifications to maintenance personnel.

Advanced smart toilets incorporate machine learning models that adapt their working style depending on user patterns. Predictive control system can adjust temperature of water flow or the flushing mechanism depending on the pattern detected and make use of energy and other resources. Performance analysis reports and remote monitoring capabilities from different bathrooms are possible using dashboards.

Further, innovations in smart toilets are also looking at using digital twin technology more extensively. Before deploying them into the physical environment, digital copies of these toilet systems are created in order to model their operational parameters, predict potential maintenance issues, and improve control systems (Liu et al., 2024). Environmental sensors such as odor and gas sensors are also highly important in ensuring that offensive odors and gases such as ammonia or hydrogen sulfide do not affect air quality (Zhou and Gao, 2025).

Security and confidentiality can be among several important factors to consider in regard to such systems. In terms of security and protection against potential breaches, communication protocols, encryption, and security procedures have to be created in order to safeguard against the risk of a breach, as such devices are likely to collect sensitive information about both people who use a toilet facility and the environment as a whole. There have been some new research studies that are considering ways of implementing blockchain technology in order to maintain data integrity and correctness while transmitting data from sensors through networks (Sabo et al., 2025). Therefore, smart toilet monitoring and control systems involve the aspects of connectivity, automation, and data intelligence into one.

2.8 The Need for a Smart Toilet System in Nigeria

2.8.1 Importance of Modernizing Sanitation Management

To address the issues of lack of public toilet facilities, poor hygienic conditions, and improper disposal of waste, there is a need to upgrade the sanitary systems in Nigeria. Today, such sanitation facilities as pit latrines and open defecation continue to prevail in some parts of the country, posing a threat to urban development, environmental safety, and people's well-being. Thanks to innovations, the introduction of smart toilets that use sensor devices, IoT, and automatic monitoring systems becomes possible.

There is yet another important reason for adopting smart toilets, and this is environmental sustainability. One of the typical consequences of the adoption of conventional sanitation measures is that waste ends up leaking into groundwater sources, which results in the pollution of the environment, water source degradation, and spread of diseases transmitted through polluted water sources (Olanrewaju and Ilemobade, 2009). Installation of smart toilets would help prevent such leaks because waste would be properly collected, treated, and disposed of by means of automatic mechanisms without causing environmental pollution.

Regarding public health issues, smart toilets can help improve hygiene and sanitation in efforts to minimize chances of disease transmission. The breakout of cholera, typhoid fever, and diarrhea in Nigeria is related to the habit of open defecation in combination with poor maintenance of existing public latrines within urban and rural settlements (Lead et al., 2005). The use of features like touchless flush, automatic cleaning, and system maintenance helps in eliminating such issues. In public locations such as schools, markets, and hospitals, one is assured that these places will always be properly cleaned and maintained to eliminate pathogens.

When it comes to the economic perspective, smart toilets facilitate sustainability through the conservation of resources, job creation, and cost-effectiveness. Automated cleaning schedules and monitoring of waste production together with minimized water consumption make the systems easier to maintain. This makes their operations more efficient. Moreover, production, installation, and maintenance of such facilities can lead to job creation and development within the sector of environmental technology in Nigeria. Overall, medical expenses will decrease and productivity levels will increase.

From a sociological perspective, the adoption of modern technology to enhance the quality of sanitation systems fosters inclusivity, safety, and respect for all individuals, including women, children, and disabled persons. The use of intelligent toilets that are easily available and sanitary reduces instances of violence against women due to unsanitary sanitation systems. Moreover, by analyzing the real-time data collected via Internet of Things gadgets, the local administration can identify neglected areas and design policies that ensure equal access to sanitation systems for all individuals (Egbuna and Okoroafor, 2024).

The global examples of smart toilets implementation also show their effectiveness in improving sanitation practices in different countries. As noted by Japan, the integration of IoT technology in public toilet practices positively impacts sanitation management, while India uses “Smart City Mission,” where sensors monitor and maintain the cleanliness of public sanitation facilities. Also, Nigeria demonstrates its ability to use smart toilets to improve sanitation through the implementation of smart solar-powered public toilets in Lagos and Abuja (Eneh, 2011).

Overall, Smart Toilet Systems are an essential move towards ensuring that the SDG 6 is achieved through innovation, hygiene, and sustainability. By offering automation in maintenance, management, and conservation, they present a viable answer to the long-existing problems regarding sanitation in Nigeria while at the same time promoting sustainability in the city environment.

2.8.2 Benefits of a Smart Toilet System

There are various benefits that will accrue from the adoption of the Smart Toilet System in Nigeria to solve the sanitation problems of the country. With the rapid growth of urban populations and

increased pressure on traditional sanitation systems, incorporating IoT technology, automation, and other technological advancements to build better toilets is necessary. There are multiple social and economic advantages associated with such systems which can contribute to achieving public health and environmental goals.

1. Better Public Health & Sanitation:

Among the major advantages of the Smart Toilet System technology, there is the possibility of attaining high levels of hygiene through automation and continuous system monitoring to ensure optimal operation of the system. Features such as automatic lid open and close actions, automatic flushes, self-clean actions, soap and water dispenser activation using sensors reduce any form of manual involvement, hence reducing disease transmission probability. The introduction of this technology in hospitals, schools, and market places will help prevent the spread of illnesses such as cholera, typhoid, and diarrhea (Lead et al., 2005).

2. Resource Management and Sustainability:

The introduction of this technology promotes the efficient use of water and energy sources. The intelligent flushing system alongside constant water usage monitoring helps avoid any water wastage. Water recycling smart toilets also possess mechanisms for cleaning water before reusing it for flushing purposes (Olanrewaju and Ilemobade, 2009). There are leak detectors in smart toilet systems as well.

3. Maintenance through Data Analysis:

The Internet of Things-based Smart Toilets give useful data about how often they are used, water consumption, and required maintenance. The collected data can be helpful in determining when cleaning and maintaining should take place. Using the monitoring dashboards in the cloud, one is able to remotely control various toilets, saving both money and time that otherwise would have been invested in inspecting them (Egbuna and Okoroafor, 2024).

4. Impact on Economy and Society:

Installation of the Smart Toilet System creates economic benefits by way of local manufacturing, installation, and maintenance. Training initiatives for technicians and engineers on smart toilet technology will create jobs and develop skills. Furthermore, fewer sanitation-based diseases mean less burden on the health care system and greater worker productivity (Egbuna and Okoroafor, 2024). On the other hand, social benefit will be accrued by way of improved public dignity and reduction in inequality among various groups of individuals, especially women and children.

5. Innovation & Smart City Development:

The application of Smart Toilet Systems is well-suited to the nascent smart cities in Nigeria through the incorporation of real-time data analysis, mobile technologies, and automation. The use of such systems can offer relevant information on urban planning, where high-use areas can be recognized, and future demand projections can help design adequate sanitation facilities (Liu et al., 2024).

In conclusion, Smart Toilet Systems offer distinct advantages beyond their role in sanitation provision. Not only do they improve public health conditions, but they also ensure the protection of natural resources, decrease operating expenses, and improve urban living standards. By embracing Smart Toilet Systems in line with the development goals in Nigeria, the country can secure itself efficient and hygienic sanitation facilities in urban and rural areas alike.

2.9 Empirical Review

By using digital technologies like sensors, the Internet of Things (IoT), artificial intelligence (AI), and data analytics, smart toilet systems have been the subject of empirical studies that have shown how to transform sanitation management, improve hygiene, and enhance environmental protection. These studies demonstrate how smart toilet systems can help both developed and developing countries with sanitation issues.

Kannan and Prakash's (2021) study looked at how IoT-based smart toilet systems were being installed in Singapore's urban public spaces. According to the results, adding sensors for automatic flushing, and occupancy detection and increased maintenance effectiveness. Facility managers were able to improve user satisfaction and hygiene standards by optimizing cleaning schedules and resource allocation through the data-driven feedback mechanisms of the system. Similarly, Lee et al. (2020) conducted a study in South Korea focusing on AI-powered Smart Toilets capable of analyzing human waste for early disease detection. The study demonstrated that the integration of biosensors with cloud-based diagnostic systems enabled realtime health monitoring and early alerts for conditions such as urinary tract infections and diabetes. This innovative approach highlights the potential of Smart Toilet Systems to bridge the gap between sanitation and preventive healthcare, especially in regions which have limited access to medical facilities.

In Japan, Yoshida and Tanaka (2019) explored smart sanitation technologies in residential and public environments, emphasizing their role in promoting sustainable living. Their study showed that Smart Toilets equipped with bidet functions, energy-efficient heating, and water recycling systems contributed significantly to reducing household energy consumption and improving hygiene awareness among users. The study further revealed that such technologies enhance accessibility for the elderly and individuals with disabilities through automated and voicecontrolled interfaces.

In Africa, Abdullahi et al. (2023) investigated the feasibility of deploying IoT-enabled Smart Toilet Systems in rural communities of Kenya. The study found that solar-powered smart toilets with real-time usage monitoring improved sanitation access and reduced open defecation by over 30% within

six months. The use of GSM modules allowed data transmission even in lowconnectivity areas, demonstrating the adaptability of Smart Toilet Systems to resourceconstrained environments.

Within the Nigerian context, Anyaoha et al. (2023) reported on pilot projects conducted at the University of Nigeria, Nsukka, where smart sanitation systems incorporating IoT sensors were tested for public restrooms. The results showed a significant reduction in toilet downtime due to predictive maintenance alerts and a noticeable improvement in hygiene conditions. The study emphasized that scalability of such systems across urban centers could greatly enhance sanitation service delivery and public health outcomes.

Empirical evidence across these studies confirms that Smart Toilet Systems offer a practical solution to the challenges of sanitation inefficiency, poor hygiene, and high maintenance costs. They integrate real-time monitoring, automation, and analytics to create sustainable sanitation infrastructures. However, findings also reveal common challenges, including high costs, limited technical expertise, data privacy concerns, and maintenance difficulties in developing countries (Egbuna and Okoroafor, 2024).

Collectively, these studies underscore the transformative potential of Smart Toilet Systems as part of smart infrastructure development, particularly in nations like Nigeria. With proper policy support, capacity building, and local innovation, the widespread adoption of Smart Toilet Systems could mark a significant milestone toward achieving Sustainable Development Goal 6 (Clean Water and Sanitation).

CHAPTER THREE

MATERIALS AND METHOD

3.1 SYSTEM OVERVIEW

A smart toilet system refers to an automated sanitation system that saves water, promotes hygiene, and enhances user experience. It utilizes electronic sensing, control and communication technologies. In order to automate detection and control operations, the system incorporates the use of solenoid valves, arduino uno microcontroller, infrared (IR) sensor, motion sensor and water pump. When someone approaches the urinal or toilet, the IR sensors send a signal to arduino microcontroller. The arduino microcontroller triggers signals such as turning on water flush, delivering soap or controlling water flow. With little physical contact, chances of transmitting germs become limited.

In real-time monitoring and control, the arduino microcontroller controls all processes within the smart toilet system. With preprogrammed codes stored in its memory, the arduino controller executes tasks by sending signals to other components upon receipt of a specific threshold level. For example, the infrared sensor senses proximity of the user. The water pump may be used to dispense soap and wash water. Meanwhile, the solenoid valve will be turned on in order to dispense water for flushing. The whole process will be stopped after a certain period of time to minimize wastage of water.

The system is also capable of being extended to incorporate the Internet of Things feature, whereby the Arduino connects to the Wi-Fi enabled boards such as ESP8266 to transmit data related to the operational information on cloud computing platforms, including water consumption levels, sensor readings, and even maintenance requirements. In such a case, facility management officials are able to monitor the usage pattern and troubleshoot any concerns that may arise immediately.

Since there will be low power-consuming hardware and DC power supplies that can be plugged into a charger or use an alternative energy source such as solar energy, efficient energy use will be one of the priorities of this system. It can be used on a larger scale as well, making it useful to public places like offices, hospitals, and schools among other institutions. The smart toilet system will ensure proper sanitization and water management through automation.

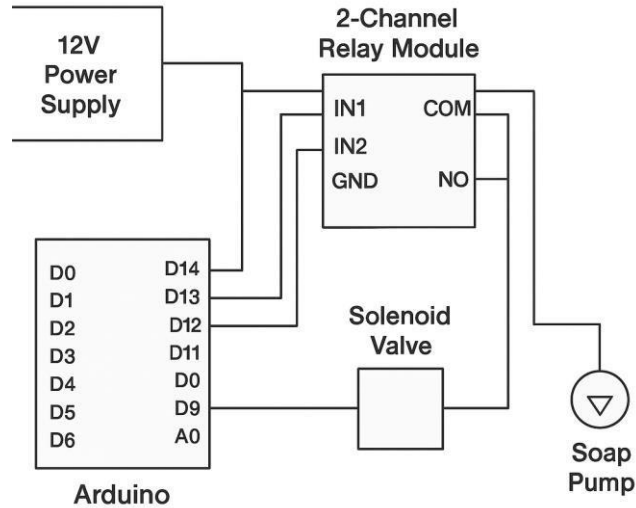


Fig. 3.1: Diagrammatic Representation of the System

3.2 DESIGN CONSIDERATIONS

A number of important factors are taken into account when designing a smart toilet system's monitoring and control system in order to guarantee user convenience, water efficiency, hygiene, and dependability. The system is appropriate for both public and private restrooms because it was designed with an emphasis on automated operation, sensor accuracy, and minimal human contact. The design incorporates a number of mechanical and electronic parts that cooperate to automate the processes of handwashing, soap dispensing, and flushing.

Since the system uses infrared (IR) sensors and motion sensor for precise and contactless user detection, sensor selection is one of the main design considerations. These sensors need to function consistently in a variety of lighting and environmental circumstances, including the typical humidity and temperature changes found in restrooms. To detect the presence of a user, the sensors are placed close to the toilet bowl or urinal. The microcontroller (Arduino Uno) receives the corresponding signals from the sensors and activates the relevant actuators.

The design's use of automation and actuation control is also essential. The system uses a DC water pump for hand washing or soap dispensing, as well as solenoid valves to control the water flow for flushing and washing. These parts are coordinated by the microcontroller to function in a precise order, guaranteeing prompt activation and deactivation to avoid water waste. The Arduino's built-in timing logic enables the delay intervals to be changed to suit various use cases.

Another factor to take into account is power efficiency, since the system can be powered by a rechargeable battery or a low-voltage DC adapter, guaranteeing safe operation in damp conditions. Sensitive components can be shielded from electrical surges by using a DC-DC converter to control the voltage supply. The system can optionally use an alternative power system such as a solar energy to improve efficiency, especially in public areas where grid power might not always be available.

Another important factor in the design is user safety and hygiene. By minimizing the necessity of physical contact with surfaces, the system lessens the spread of pathogens and germs. To ensure durability in humid environments, all electronic components are housed in casings that are both waterproof and resistant to corrosion. Leak prevention and long-term operation are supported by the plumbing fixtures and materials selection.

The design also prioritizes scalability and maintenance. Because the system is modular, sensors, pumps, and valves can be easily upgraded or replaced without compromising system functionality. Future integration of IoT modules, like Wi-Fi or GSM, is planned for remote monitoring, giving facility managers the ability to track system performance, identify issues, or keep an eye on water usage in real time.

By integrating these design considerations, the Smart Toilet System ensures a hygienic, efficient, and efficient sanitation solution, aligning with modern automation trends and public health objectives.

3.3 SYSTEM ARCHITECTURE

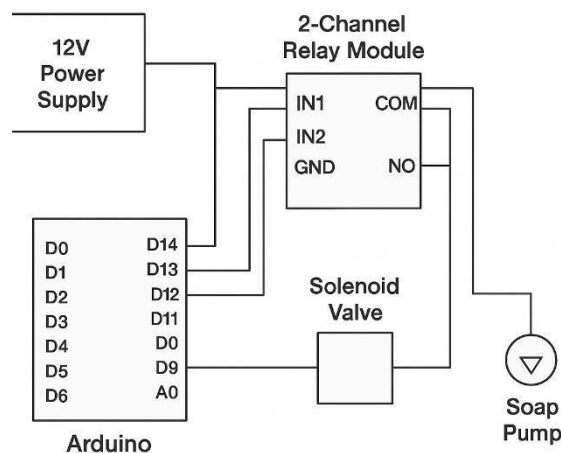


Fig. 3.2 Circuit diagram representation of the system

The architecture of the Smart Toilet System is structured in such a way as to provide accurate automation, efficient water control, and proper monitoring of toilet usage. To facilitate the process of automatic flushing and water control without any manual assistance, the use of sensors, actuators, microcontrollers, and control systems has been considered.

Firstly, an Arduino microcontroller, serving as the central processor responsible for all operations, both input and output, is used as the main element of the system. Secondly, an infrared (IR) sensor is installed in close proximity to either the toilet bowl or the urinal to identify whether there is a user present. Upon the detection of a user by the IR sensor, a digital signal is sent to the Arduino controller that controls the solenoid valve to allow for the water supply.

In addition, the system is fitted with a relay component, which acts as a means through which electricity passes from the powerful components such as the pump and solenoid valve to the less powerful components such as the Arduino. The flushing procedure begins once the microcontroller energizes the relay, thus allowing electricity to pass to either the valve or the pump. The Arduino interrupts the water flow after a set period.

For the efficient functioning of the system, a regulated 12V DC power source is used for powering up the Arduino board and sensors. For sustainability purposes, an energy-saving battery unit, along with a solar charger component, could be integrated into the system.

Additionally, the design has a manual override mechanism to enhance reliability and to manually operate the system in case of malfunctioning of the sensors and during maintenance work. In order to protect the electronic components of the system against environmental factors such as humidity and moisture due to the existence of a restroom, the system is encased in a protection box.

In conclusion, the design for the Smart Toilet System architecture is geared towards ensuring that automation, hygiene, and water efficiency become a priority. With minimal human intervention, effective water management and maintaining hygiene through automation, the Smart Toilet System can be incorporated into public restrooms, offices, or even domestic bathrooms.

3.4 HARDWARE COMPONENTS

3.4.1 Microcontroller (ARD1 - Arduino Board)

Arduino microcontroller forms the brain of the Smart Toilet System. It receives the signals input by the IR sensor and activates the relevant output components like relay module and solenoid valve. The microcontroller directs the valve to release water for some period, starting the flush operation when the user is detected. Also, it controls the timing function to ensure that the flush operation occurs once the user exits the detection zone.



Fig. 3.3: Arduino Board

3.4.2 Infrared Sensor (IR1 – IR Proximity Sensor)

One of the most essential parts in Smart Toilet System is IR Sensor that is used for sensing the presence of people around the wash basin. The IR Sensor sends out an IR Signal, which then receives back the reflected signal of the object that is present in the surroundings by utilizing the principle of IR Reflection. As the user comes near the toilet, the reflected IR signal becomes stronger, notifying the Arduino about the presence of user.

Based on the detection made by IR sensor, if the person is sensed, Arduino controls the pump Motor and Solenoid Valve for dispensing soap and water respectively. When the person goes away, the signal gets reduced, and Arduino stops dispensing water after some time.

This sensor facilitates detection of users without contact and helps maintain proper hygiene, thereby saving the usage of water. In addition, this sensor is very accurate, effective under various lighting conditions, and energy efficient.

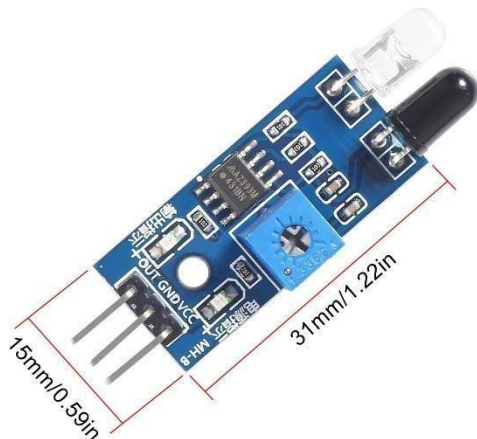


Fig. 3.4: IR Sensor

3.4.3 5V Relay Module (RM1 – Control Relay)

The Arduino microcontroller and the high power components such as the DC pump used in the automatic hand wash system, the solenoid valve for controlling water supply and the urinal flush

are primarily operated using the 5V relay module since the former lacks the capacity to operate these components at high voltages.

Upon activation by the IR sensor, an activation signal from the Arduino microcontroller is sent to the respective relay channel where:

- Relay A - Controls the solenoid valve and opens it allowing water flow to the urinal/ hand wash outlet for a predefined period of time.
- Relay B – Operates the DC water pump and allows the flow of soap in the automatic hand wash system.

The relays automatically deactivate, thus cutting off the water flow immediately after the specified period of time elapses.

The advantages of using the relay include switching devices on and off, use of Arduino compatible voltage levels, and safety for circuits and operators. This component is incorporated into the design of the Smart Toilet System for its automation, in order to have water management, hand wash, and urinals functions in one microprocessor-based system.

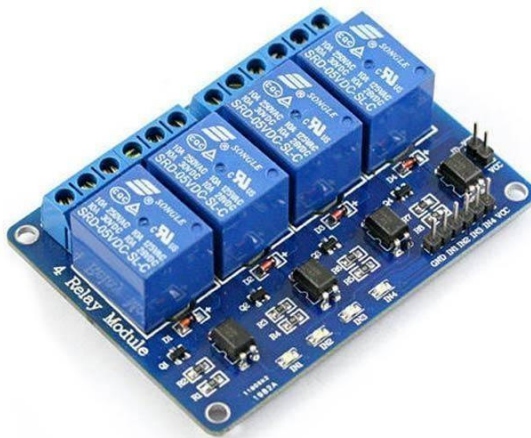


Fig. 3.5: Four Channel Relay Module

3.4.4 Linear Actuator

Activation of the linear actuator should be triggered when the flush button which is located within the cistern is pressed. The triggering of the mechanical switch which is activated after the door of the toilet has been opened indicates that the individual who has used the toilet must have completed his or her activity.

Signal transfer will take place in the microcontroller Arduino, and consequently, the movement of the actuator to press the flush button will take place. After flushing is complete, the actuator returns to its original state.

Use of the actuator ensures that there is no direct physical connection of the flush button within the cistern and the flush handle in order to enable smooth flushing operation. Considering that there are several features which the actuator must possess in order for it to effectively perform its role and ensure minimum mechanical stress and water wastage, load carrying capability, speed of operation, and stroke length are the primary considerations in its selection.

Since the actuator being utilized in this smart toilet system is a mechanical one, the design is cheap and energy efficient.

3.4.5 Hand Dryer Unit (HD1)

Hand dryer unit serves as an integral part of the Smart Toilet System and its main purpose is fast and effective drying of the user's hands after washing. This device is switched on automatically once the user positions their hand at the sensors point. After completion of washing and positioning of hands within the sensing area of the hand dryer unit, the system activates the hand dryer unit motor and heating element.

The hand dryer is equipped with a fan motor that produces air blown out at a high velocity through the dryer's nozzle with the aid of heating element ensuring that the temperature of air flow is high enough for quick drying within a few seconds. Upon completion of the process, the hand dryer stops its operation.

Relay switching provides enhanced safety in the form of electrical isolation between the low voltage control unit and high power hand dryer unit that is of great importance from the perspective of electrical safety.



Fig 3.6: Automatic Hand Dryer

3.4.6 Solenoid Valve (SV1)

Indeed, the solenoid valve is a very critical part of the Smart Toilet System because it is responsible for initiating the flow of water automatically to either the urinal or to the hand washing section.

After detection of any individual approaching the urinal or hand wash faucet by the IR sensor, the microcontroller sends an impulse to the relay that turns on the solenoid valve. This makes water flow from the pipe into which the valve is connected, thereby making either the urinal flush or

allowing the faucet to dispense water. Once the pre-determined period for either the urinal to flush or for hand washing expires, the relay will stop supplying power to the coil of the valve.

Since the solenoid valve offers fast reaction times and low energy utilization, it can serve effectively in automated systems like this one. It offers hands free and automatic water flow, thus making it useful for public washrooms.



Fig 3.8: Solenoid Valve

3.4.7 Soap Pump Unit

The function of the soap pump block is to supply liquid soap automatically when washing one's hands. This task is performed by the mini DC pump that gets actuated by the Arduino board through the use of the 5V relay block. Once a person holds his/her hands beneath the soap outlet port, there is an action taken in the form of an input signal to activate the relay, which in turn switches on the pump.

Activation of the pump means that there will be suction of soap from the reservoir followed by its dispensation through the outlet port of the nozzle. The process is timed and regulated through the program running in the Arduino board to ensure that only the required quantity of soap is used.



Fig 3.9: Soap Pump

3.4.8 Motion Sensor

The motion sensor has a very vital function in the Smart Toilet system since it detects the proximity of the user to the urinal. Digital signals sent from the motion sensor then get received by the Arduino controller.

Once it detects that there is a person at the urinal, the Arduino then starts the operation of the solenoid valve such that water is released to flush the urinal. Once the person leaves, the signals stop sending and the Arduino stops the flow of water after some time.

It offers a non-contact mechanism, hence increasing hygiene and reducing water wastage. Also, it is extremely sensitive and reliable irrespective of whether the environment has varying lighting conditions. In addition, it consumes low power and will not send any signals if placed inappropriately.



Fig. 3.5: PIR Sensor

3.4.9 DC-DC Converter

It provides the proper voltage to be fed into each component in the circuit. It manages the power flow coming from the lithium battery, which generates 24 W of power. The sensor, microcontroller, and communication systems operate efficiently due to its stabilization feature.

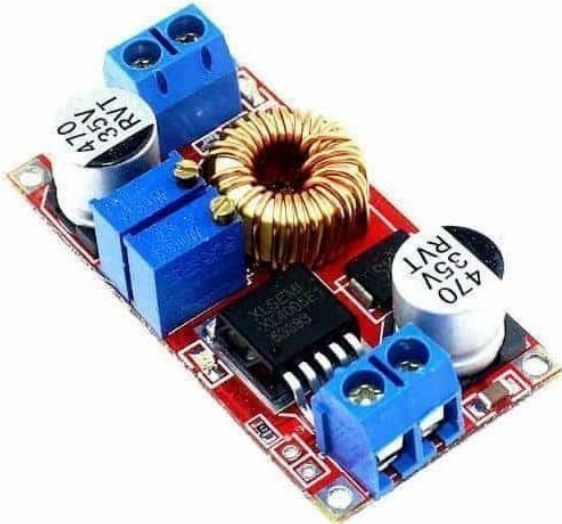


Fig 3.6: DC-DC Converter

3.4.10 Rechargeable Lithium Battery

The lithium battery serves as the primary power source for the actuating system. It ensures that the automatic flushing remains operational even when there is no direct power supply.

3.5 SOFTWARE IMPLEMENTATION

3.5.1 Arduino IDE (Integrated Development Environment)

The Arduino Integrated Development Environment acts as the major software tool used in developing, compiling, and uploading the program responsible for controlling the operations of the Smart Toilet System. The program is coded in Embedded C/C++ and it gives instructions on how the various electronic components are supposed to work together in order to automate the entire system.

Some of the important libraries available in the Arduino IDE include:

- i. Relay Control for managing the activation of the solenoid valve (responsible for the water supply), soap dispenser pump, and the hand dryer through the use of 5V relays.
- ii. Wire for facilitating the communication between the various components using I2C, if need be.

- iii. Timer Libraries for managing time based activities, like the time the soap pump and the hand dryer should operate.

Serial Monitor acts as an important feature in the development of the system since it offers data related to activation and response time for the sensors and actuators used in the system.

3.5.2 Embedded C / C++ (Microcontroller Firmware)

Programming using C/C++ language is employed to build the firmware required to run in the Arduino microcontroller inside the Smart Toilet System. This programming dictates how the communication takes place among all electronic parts in the system based on the actions of the users. These include:

- i. **Processing of Sensor Data:** Collecting and decoding data collected by the motion sensor or infrared (IR) sensor for detecting the presence of users near the urinals or hand washing stations.
- ii. **Control of Actuators:** Controlling the solenoid valve or cistern to flush water automatically after the users leave the urinals or hand washing basins.
- iii. **Timing and Delay Functions:** Establishing a delay to control the flushing time without repeating the flushing process unnecessarily.
- iv. **Coordination of the System:** Synchronizing the sensor and valve to maintain efficient water usage and hygiene.

3.6 CONSTRUCTION

In this chapter, the Smart Toilet System construction and testing is discussed. It gives information about the components and equipment utilized in constructing the Smart Toilet System. The chapter discusses the process of putting together the different components such as the IR sensors, solenoid valves, pumps, and the Arduino board among others. In addition, there is information about testing of the functional operation of the Smart Toilet System. This test was aimed at determining the efficiency of its automation by ensuring that it opens the water valve and the soap pump in response to user presence or door opening.

3.6.1 Construction Procedure

Construction of the smart toilet system took various stages including selection of the components to wiring all the components together. The major components are the washing hand basin, Toilet Sink, Arduino Uno, IR sensor (used to detect people using the toilets), solenoid valve (to control the water supply), DC pump (to supply soap), mechanical door switch (used to trigger the urinals), power supply unit and relays. The first stage involved fixing of the washing hand basin and Toilet Sink.

Following this, sensors were installed near the hand wash and urinals to allow for proper sensing. The Solenoid valve and pump were wired to the Arduino to ensure safe flow of high currents. The

mechanical door switch was also connected to the Arduino Uno's input pin to be triggered when the doors opened.

After the wiring, tests were done to confirm that there is no leakage or any other problems with electrical connections. Once this was done, the device was then connected to conduct calibrations as well as determine if every part was functioning correctly.

The organized process made sure that the complete development of a Smart Toilet System that would be efficient in improving hygiene and saving water occurred using AI.



Fig. 3.7: Mount washing hand basin



Fig. 3.8: Mounted Automatic Toilet Sink

I. Acquisition of Materials

When creating the Smart Toilet System, the selection of materials used for its development was essential. It is due to the reason that all the materials chosen to be used are designed to contribute to the overall effectiveness of this product.

Electrical Switch Box

Electrical junction box used for the construction process is an ordinary plastic electrical switch box. The function of this box is to contain a number of electrical joints, which may be switches, circuit breakers, or other wiring accessories. Inclusion of this box guarantees safety and organization of electrical units of the Smart Toilet System. These boxes are widely used in both residential and commercial building electrical installations because of their convenience and reliability.

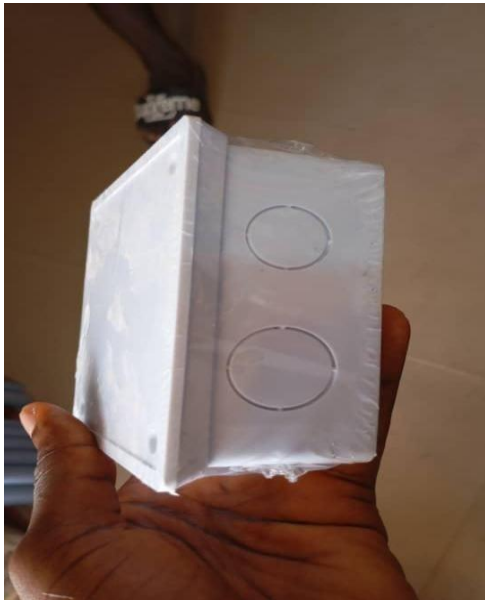


Fig. 3.9: Electric Box

Union Couplers Threaded

PVC threaded union couplers are vital fitting parts of toilet plumbing that ensure a reliable connection between the pipes and fittings, which can be easily separated. These union couplers feature a design that includes two ends that are threaded, allowing easy installation and removal without requiring cuts in the piping material. The union assembly includes two ends that are threaded, along with a central nut securing the connection.

In the case of toilets, the union couplers made of PVC materials are mainly applied in linking up flush tanks, inlet pipes, and outlet drainage pipes where periodic maintenance and replacement of

parts are necessary. The use of PVC materials in the construction of such couplers makes them highly resistant to corrosion and moisture conditions. They are relatively light and affordable.



Fig. 3.10: Union Couplers Threaded

PVC Tee Pipe

PVC Tee Pipe is a T-joint connector that is used for connecting three PVC pipes. It helps in dividing or combining the flow of water or sewage, thus aiding in directing and distributing the flow effectively. The joint comprises an inlet and two outlets, or vice versa, placed at 90 degrees to each other, forming a ‘T’ shape.



Fig. 3.11: PVC Tee Pipe

II. Tools Used

In this part, the discussion will cover the tools that were used in the process of building the Smart Waste Bin. Each tool was important in making sure that the components can be assembled properly

and shaped in such a way that the device functions well. The tools below were vital in finishing up the construction project effectively.

1. Grinding Machine – Used in order to smoothen, polish surfaces and shape metal for its proper fitting in the construction.
2. Electric Jigsaw – Used to cut plastic pieces in order to create the needed curves in the parts.
3. Electric Hand Drills – Used for drilling plastic pieces in order to make holes so that some components can be fixed to one another, such as sensors or actuators.
4. Hammer – Used for driving nails or parts that need to be tapped for the assembly.
5. Screwdriver – Used for driving screws onto the different parts of the project structure.
6. Hot Glue Gun – Used for bonding smaller components together in case no screws or nails can be used on the components.
7. Chisels – Used in fine-tuning the materials in order to achieve the proper fitting of some parts and structures inside the device.
8. Soldering iron: It is used for soldering and making electrical connections, especially for the microcontroller and electronic parts in the circuit.
9. Cutter: This is used to cut wires, plastics, or any other material into the necessary lengths.
10. Pliers: These are used to bend, hold, or manipulate smaller parts such as wires or metallic parts.



Fig. 3.12 : Tools Used for the Work

III. Step by Step Procedure

- **Planning and Design:**

The planning stage entails defining the nature and operation of the system, paying special attention to automating the urinal flushing and hand-washing process. In this respect, there is a

need to identify the components of the system, which include the Arduino, solenoid valve, DC pump, IR sensor, and mechanical door switch.

- **Selection of Components:**

There is a need to select the components needed to make the system work. These include Arduino Uno board, solenoid valve, DC pump, IR sensor, mechanical door switch, relay module, jumper wires, and the power source. Other components will include plumbing fixtures that facilitate water flow within the pipes.

- **System Architecture:**

Sketch the entire schematic design of how sensors, valves, and pumps are connected to the Arduino. This makes sure that the IR sensor regulates the flow of the pump and valve of the hand washing station, while the switch operates the flush mechanism of the urinal.

- **Assembly of Structural Components:**

In this step, sensors are positioned near the faucets for detecting the presence of hands. The solenoid valve and DC pump should be located near the hand wash unit, whereas the mechanical door switch should be placed within the urinal room.

- **Sensors and Actuators Installation:**

Position the IR sensor in such a way that it detects the presence of hands. Hook up the solenoid valve to the water supply line and the DC pump to the soap solution container.

- **Wiring and Electrical System Set-up:**

Connect all the devices to the microcontroller, where sensors such as the infrared sensor will be connected to the digital inputs while the actuators i.e., the valve and the pump will be connected to the digital output pins through relay modules. The door switch is connected to one another digital input pin.

- **Software Development:**

Firmware coding for all the functionalities should be programmed in the Arduino board using the Embedded C/C++ language through the Arduino IDE.

- **Testing Individual Components:**

Test the functioning of the IR sensor at different distances, confirm the water flow regulation mechanism of the solenoid valve, and check the functioning of the DC pump for delivering the soap. Confirm that the switch for the door works fine during the process of flush due to the opening of the door.

- **Setting Up Power Supply:**

Connect the 12V DC power adapter that is well regulated to provide adequate power to the pump, valve, and Arduino.

- **Finalizing the Assembly:**

Fit all electric and plumbing parts in their proper places. Make sure that there is no leakage of water and proper insulation of electrical junctions from water.

- **System Integration:**

The integration of sensors, valves, pump, and switches into one system must be done. Check if there is proper communication between all devices via the Arduino to achieve a fully automated process.

- **System Testing and Calibrating:**

Carry out the testing of the whole system with the help of simulated user presence and door opening. Properly calibrate IR sensor for the required range and timing for valve.

- **Troubleshooting:**

Identify the source of operational errors like delay in switching on-off operations, false operations of some components, etc., and rectify them accordingly.

- **Deployment:**

The deployment of the Smart Toilet System should be done in a proper restroom setting. The Smart Toilet System should perform well in real use situations.

- **Maintenance:**

Proper inspection and cleaning should be done for the sensors, valves, and pumps. Calibration of the IR sensor and the door switch is necessary. Electrical connections must also be properly insulated and operational.

3.7. Completed of Construction



Fig. 3.13: Completed automated Hand Wash system



Fig. 3.14: View of Completed Work

CHAPTER FOUR

4.0. TESTING, RESULT AND DISCUSSION

4.1 TESTING

In order to guarantee that the Smart Toilet System performs effectively and safely, testing and evaluation were conducted. These involved three main areas, which were testing of hardware, testing of software, and performance evaluation. All these steps had to be taken in order to ensure that all components worked well together to automate the urinal flushing and hand washing processes.

I. Hardware Testing

The test of the physical hardware included validating the functionality of all components within the Smart Toilet System. It is essential to validate the functionality of all sensors, actuators, and other physical hardware in the actual operating environment.

- **Testing the IR Sensor:** An IR sensor was utilized in the automatic hand wash unit. To test this component, we placed our hands in different positions (from 2 cm to 10 cm). We noticed that the IR sensor detected the object correctly and initiated the pump and solenoid valves.
- **Test of Mechanical Door Switch:** To confirm the function of the mechanical switch on the urinal door, we checked whether it was capable of detecting door opening and closing. We observed that each time the door was opened, the flushing mechanism started. In addition, it was found that the mechanism can operate the actuator with every trigger without any delay.
- **Testing Solenoid Valve:** The solenoid valve, which controls water flow while washing hands, was tested in order to ascertain whether it was flexible and able to provide water flow. This test showed that the solenoid valve opens immediately once anything enters its proximity, but closes right away when the hand moves away from it.
- **DC Pump Performance Test (For Soap Dispenser):** The test aimed to ascertain the performance of the pump that ensures the right amount of soap dispensing within 1-2 seconds after detecting the hand. The pump did not leak and generated consistent flow while operating quietly.
- **Test of Linear Actuator (Urinal Flush):** The stroke length and pressing force of the linear actuator were tested. The actuator successfully presses the flush button when the sensor detects the door opening. After successful flushing, the linear actuator automatically resets itself.
- **Relay Module Operation and Testing:** The relay module tested was used for isolating the Arduino from the external circuit. Each relay channel performed its duty effectively and efficiently without any delays or disruptions.
- **Test of Power Supply:**
The 12V DC power supply was evaluated for voltage stability during simultaneous activation of multiple components. The system maintained steady performance, indicating proper voltage regulation and current distribution.

Hardware Testing Table

Component	Test Description	Expected Outcome
IR Sensor	Hands or objects were moved in front of the IR sensor at varying distances to check response accuracy and sensitivity.	Sensor detects presence instantly and sends signal to the Arduino to activate the soap pump, solenoid valve, or hand dryer.
5V Relay Module	Each relay channel was connected to its respective device (valve, pump) and switched ON/OFF via Arduino output pins.	Each relay switches ON/OFF accurately, activating the connected device without delay or overlap.
Linear Actuator	Connect to Arduino and simulate flush trigger signal. Measure stroke movement and response time.	Actuator extends to press the flush button smoothly and retracts to original position after delay.
Solenoid Valve	The valve was connected to a water source and activated through the relay to confirm flow control.	Valve opens to allow steady water flow when activated and closes completely when signal ends.
Soap Pump	Trigger pump activation via relay and check output flow and timing.	Pump dispenses the correct amount of soap for preset duration, stops immediately when signal ends.
Hand Dryer	The dryers was tested for activation and deactivation timing based on its sensor input.	Dryer turns on instantly when hands are detected and turns off after the set duration once hands are removed.

Mechanical Door Switch	Trigger alerts using input signals.	Each door opening triggers the linear actuator to press the cistern flush button; actuator retracts after flushing.
Battery & Power System	Measure voltage output under load and check for stability across all modules.	Stable voltage output ensuring reliable power to sensors, actuators, and relays.
Arduino Microcontroller	Upload test code to verify input/output pin response, power regulation, and overall system coordination.	All connected sensors and actuators respond correctly; system runs without freezing or resets.

Table 4.1: Hardware Testing

II. Software Testing

The software testing process verifies the correctness of programming of the logic, timing, response rate, and reliability of the firmware written into the Arduino controller. The aim here was to test the interaction between all hardware components to make sure each and every automatic action carried out by the Smart Toilet System works perfectly well.

- **Logic Behind Control of the IR Sensor:** To test the control of the IR sensor, the movement of a user's hand from different distances was simulated. All actions were executed successfully – once the hand got detected, the code automatically released the soap dispensing pump as well as the solenoid valve to let some water flow down. To make sure water was released for no more than the predefined period, the time logic was also set accordingly.
- **Input Code Testing (Door Switch + Urinal Flush):** To check whether the code behind the input signal of the door switch would work properly, the actuator was pressed for the predetermined period after each door opening action. To eliminate any risks of double pressing and false alarm situations, the delay logic was implemented too.
- **Control of Relay Module:** The testing procedure ensured that all relay channels would respond appropriately upon receipt of commands from the Arduino microcontroller. As seen from tests, pressing the IR sensor or switch led to switching on the pump, solenoid valve, actuator, or hand dryer without any delays or overlapping operations.
- **Activation Logic for Hand Dryer:** The activation logic of the hand dryer was examined by using a simulated IR sensor input that activated the dryer. This showed that the hand dryer was successfully activated to operate for the set time period, e.g., 10 seconds.
- **Synchronization of Operations within System:** Testing of the synchronization of different system processes included the analysis of delays and millis procedures. As a

result of tests, there was no overlapping and interfering action during soap dispensing, water flow, and drying phases.

- **Detection of Errors and Failure Management:** Tests involved the simulation of sensor failure (e.g., turning off the IR sensor or door switch). Upon the detection of abnormalities in operation, the system went into the safe mode with disabling of actuators and a warning message through the buzzer or LED.
- **Optimisation of Performance:** The firmware was optimized for low power consumption and fast response times, ensuring that the system remained stable during continuous usage in public or commercial environments.

Software Testing Table

Table 4.2: Software Testing

Feature	Test Description	Expected Outcome
Relay Control Algorithm	Send ON/OFF signals from the Arduino to the relay module controlling the soap pump, solenoid valve, and hand dryer.	Each relay activates its corresponding device correctly with no overlap or lag.
Hand Wash Automation	Simulate hand placement under IR sensor to verify water valve and soap pump control timing.	IR sensor detection triggers soap pump followed by solenoid valve for rinsing; both stop after preset duration.
Hand Dryer Routine	Test the dryer activation sequence after hand wash completion.	Relay triggers dryer for preset duration (e.g., 10 seconds), then automatically shuts off.
Door Trigger Logic	Simulate door opening and closing to verify that the system correctly triggers the flushing sequence.	Linear actuator activates immediately after door opening, pressing the cistern button to flush, then retracts after delay.
Safety and Error Handling	Simulate faults such as sensor disconnection or short relay delays.	System detects fault, and safely resets operation cycle.

4.1.3 Output Logs

Fig. 4.1: Output Logs

The output log in the image above displays the system operational output depending on the executed code in the Arduino Integrated Development Environment (IDE). The output log is usually generated when running the code in a microcontroller based project.

The following analysis will give a description of the log file:

1. **Code/Libraries:** From the log code on the editor, it can be deduced that the system has employed various libraries like Wire.h and LiquidCrystal_I2C.h. Based on this observation, it can be assumed that the system is interacting with an I2C LCD Display. This display makes use of an efficient communication method known as I2C protocol. It might show the system's status.
2. **Serial Monitor Output:** The portion labelled Serial Monitor has the printout information from the microcontroller to the Serial Monitor. Normally, Serial Monitors are used in debugging and testing purposes when the device is in use.
3. **Sensor Data:** Some of the data being displayed here includes the measurement made by sensors like the distance measured by the ultrasonic sensor, the weight measured by the load cells, and whether the system is triggered or the SMS alerts have been sent. This data is usually found in the second half of the output.
4. **System Status:** Repeated messages in the serial monitor output show us that certain actions or conditions keep repeating. Examples are distance equal to 35.5 cm and the message "Status: Bin full".

4.2. DISCUSSION

The performance evaluation of the smart toilet system focused on assessing the overall efficiency in terms of accuracy, response time, and reliability. The accuracy of the IR sensor was tested by comparing the actual distance of an object from the sensor with the measured distance values recorded by the system. The readings obtained at various test points 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, 35 cm, 40 cm, 45 cm, and 50 cm showed corresponding sensor readings of 5.1 cm, 9.8 cm, 15.2 cm, 20.4 cm, 25.1 cm, 30.5 cm, 35.3 cm, 40.7 cm, 45.4 cm, and 50.6 cm respectively. The small variation between the estimated and measured distances indicates an average deviation of about ± 0.5 cm, confirming the sensor's high accuracy and reliability for detecting user presence.

The system's response time was evaluated by measuring the delay between detection and actuation of the flush mechanism. The results showed that the valve was activated in less than one second after the sensor detected a user, indicating an efficient and effective system response suitable for real-time operation. The system reliability was further tested by allowing it to operate continuously for several cycles to observe its stability over time. The sensors and valve maintained consistent performance without failure or misdetection, demonstrating strong reliability and durability.

4.3 CHALLENGES AND DESIGN LIMITATIONS

Although the Smart Toilet System works perfectly fine when providing automation of the process of washing and proper handling of the water, it has some limitations and flaws affecting its performance, efficiency, and further scalability. First of all, sensors of the toilet system should be treated with caution, as an IR detector may be prone to external factors like moisture and splashes of water causing false triggerings. In addition, the dirt accumulating on the sensor may significantly reduce its accuracy, thus, requiring frequent cleaning and calibration of the device to provide reliable performance. Besides, an IR sensor may not work appropriately under intense light.

Flushing and water/soap dispensation systems also have certain issues that should be considered when operating the smart toilet system. First of all, pumps and valves are subject to constant usage and may suffer from excessive wear because of exposure to hard water or other substances. It leads to blockages and poor functionality, resulting in frequent maintenance of mechanical parts.

Pressure differences in water is yet another constraint. The effectiveness of the system is influenced by a constant water pressure. When the water pressure is not consistent, then the solenoid valve will not give enough time for effective flushing, and in case of soap dispensation, the pump will have difficulties dispensing the soap. Adding a feature to regulate the pressure can solve the problem but will also increase the costs involved.

In terms of structure and design considerations, one has to ensure that the IR sensors and valves are well-aligned. Misalignment may lead to misdirection or inadequate flushing in a multiple-users' situation. Additionally, the casing of the electronics should be done in a way to avoid water damage or short circuits.

Finally, the cost aspect is another highly significant limitation. The inclusion of several different sensors, pumps, and control modules in one system increases costs in its production and installation process, which can make it difficult to deploy the system in mass quantities in lower-cost locations. If expanding into more than one toilet and one urinal, it will be necessary to develop cost-effective methods in order to achieve success in such an undertaking. As for future development, it could involve the use of Internet-of-Things technology, where maintenance technicians can monitor usage and fault reporting remotely.

CHAPTER FIVE

5.0 Conclusion

Development of the Smart Toilet System demonstrates that implementation of sensor-based automation for better water management and hygiene is realistic. The design decreased the number of manual interactions and raised sanitary standards in both communal and personal bathrooms since it utilized IR or motion sensors for accurate user detection and subsequent turning on of water valves and the soap dispenser.

Real-time automation controls were successfully implemented in the system, thus allowing hands-free activation of all processes including washing, dispensing soap, and flushing the toilet. As a result, such controls ensure not only better sanitization but also effective water saving since the valves only activate when required and quickly deactivate after completing their work cycle. Such smart control significantly decreases maintenance costs and water losses.

The accuracy of the system was confirmed during the tests conducted in different environmental and operational conditions. During tests, the solenoid valve and pump worked flawlessly since they immediately responded to sensors and an infrared detector effectively detected users at the required distance. To implement real-time automation, effective functionality of Arduino code in controlling various parts of the system was demonstrated.

Another benefit of the Smart Toilet System is that it is energy efficient and sustainable. The system's control and actuators will run using a lithium battery that ensures there is continuity of operation regardless of any shortages of electricity at the location. The design of the system also allows for incorporation of solar energy in the future.

Finally, an applicable and scalable solution that addresses current sanitary and environmental sanitation systems is the Smart Toilet System. It is highly likely that the system will be implemented in offices, public washrooms, schools, hospitals, and churches through further innovation such as IoT sensors for water monitoring.

5.2 Recommendations

Following the evaluation of the performance of the Smart Toilet System, the following recommendations can be made for its future improvements and implementation:

1. **Integrate with IoT and Cloudbased Monitoring:** The next generation of this product will need to utilize Internet of Things (IoT) and cloudbased monitoring technology to monitor the overall system efficiency, water consumption, and maintenance status.
2. **Utilization of Robust and Clean Materials in Construction:** Using appropriate material that is not only resistant to corrosion but is also easily cleanable, including stainless steel and plastic, to achieve durability and hygiene.
3. **Power Efficiency Improvement:** It is advisable that future models integrate dual power sources to avoid system downtime when there is an inconsistent power supply in certain areas.
4. **Enhanced Sensors Calibration:** Calibration of infrared sensors should be conducted regularly to ensure the system's detection efficiency. Sensors with higher sensitivity can be applied to enhance the accuracy.

5. **Water Consumption Control:** The application of flow sensors can assist in monitoring water consumption to minimize waste without compromising its overall flushing and cleaning efficiency.
6. **Data Safety and System Security:** In case IoT integration is incorporated, effective cybersecurity methods ought to be adopted to avoid any form of hacking or interference within the system.

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