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IMPROVED SMART URINAL SYSTEM

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG),

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CERTIFICATION

This is to certify that this research project titled: **Improved Smart Urinal System**, was carried out by the students listed above under the supervision of Engr. P.O. Olagbegi

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DEDICATION

We dedicate this report to God Almighty, whose grace has granted us the strength to accomplish all that was necessary for the success of this project. To our families, whose unwavering support and encouragement have been the foundation of our academic journey. To the Department of Mechanical Engineering, whose guidance and commitment to equipping us through extensive training and lectures have been pivotal in shaping us into who we are today. This work is also dedicated to all who have inspired and supported us along the way. Your faith in our potential has ignited our passion for learning and striving for excellence.

ACKNOWLEDGEMENT

We wish to express our profound gratitude, first and foremost, to God Almighty, who makes everything beautiful in His perfect timing. His boundless grace, unwavering strength, and divine wisdom have illuminated our path and sustained us throughout the course of this project. Our heartfelt thanks go to our families for their constant love, support, and patience. Their encouragement and wise counsel have been a source of strength during the challenges we faced along the way.

We are deeply appreciative of our supervisor, Engr. P.O. Olagbegi, for his exceptional mentorship, consistent support, and insightful feedback. His dedication played a pivotal role in making this project both educational and rewarding. We also extend our gratitude to the Department of Mechanical Engineering, University of Benin, for granting us the platform to carry out this project. The department's commitment to excellence has equipped us with the skills and knowledge necessary to undertake such an endeavor.

Likewise, we are thankful to the Faculty of Engineering for cultivating a learning atmosphere that encourages innovation, critical thinking, and professional growth. Finally, we sincerely thank all those who, in one way or another, contributed to the success of this project.

We would especially like to recognize Engr. God’spower Ojariefe, our project coordinator, whose guidance, dedication, and encouragement were invaluable throughout the project journey.

ABSTRACT

The increasing demand for sustainable sanitation solutions underscores the need for innovative systems that conserve water, improve hygiene, and enhance user experience. This project has focused on the design and development of a Smart Urinal System—an automated facility that integrates a motion-switch with a microcontroller-based control unit to regulate flushing mechanisms. By eliminating manual operation, the system has reduced the risk of cross-contamination while optimizing flush cycles based on actual usage to conserve water. The methodology combines hardware design, circuit integration, and microcontroller programming to synchronize the switch inputs with actuator responses. Experimental results have shown that the system reduces water consumption by approximately 30–40% compared to conventional urinals while maintaining high hygiene standards. The study demonstrated that automation in sanitation not only promotes efficient water management but also offers a practical, user-friendly solution to modern hygiene challenges, particularly in regions where access to clean water remains limited.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUNG OF STUDY

In today's world, technology is changing the way we live, work, and interact with our environment. From smartphones to smart homes, innovation is helping to make everyday life easier, more efficient, and more sustainable. One area that often gets less attention, but is just as important, is sanitation. Clean and efficient sanitation systems are essential for public health, comfort, and environmental protection, especially in places with high population density such as schools, offices, and public facilities.

Traditional urinals, though widely used, have several limitations. They usually depend on manual flushing or outdated mechanisms that waste water, spread germs, and require frequent maintenance. In many cases, these issues result in unhygienic conditions, higher water bills, and extra workload for facility managers. As cities grow and resources become more strained, it has become clear that conventional sanitation methods are no longer.

Figure 1.1, Traditional urinals

This is where **smart urinals** come in. A smart urinal system uses sensors, automation, and Internet of Things (IoT) technology to improve hygiene, reduce water waste, and make maintenance easier. For example, sensors can trigger automatic flushing, detect leaks or faults, and even provide real-time data on water usage. Some advanced systems go further by offering health-related insights through urine analysis or by helping managers keep track of when cleaning is needed.

The idea of smart urinals fits perfectly into the bigger picture of **smart cities** and the global push toward sustainability. It supports the United Nations' Sustainable Development Goal 6 (Clean Water and Sanitation), which emphasizes the importance of efficient water use and improved sanitation facilities. On university campuses, introducing a smart urinal system can serve as a practical step toward modern, eco-friendly infrastructure while also giving students opportunities to engage in real-life innovation and research.

This project is therefore aimed at **designing and testing a smart urinal system** that is practical, affordable, and user-friendly, just solving hygiene and water wastage problems. The project seeks to show how technology can transform even the simplest facilities into smarter, cleaner, and more sustainable solutions for the future.

1.2 PROBLEM STATEMENT

In many public spaces, particularly in schools, universities, offices, and transport terminals, urinals are an essential part of sanitation facilities. However, most of these urinals remain traditional and outdated, with little or no technological integration. They often rely on manual flushing or basic timed flush systems, which can result in several recurring problems.

Poor hygiene is a common issue. Manual flushing means users must touch surfaces, increasing the spread of germs. In some cases, users may neglect flushing altogether, leaving the facilities in unpleasant conditions.

Issues of excessive water usage. Traditional urinals consume a significant amount of water regardless of the frequency of use. For example, some flushing systems operate on a fixed schedule, even when the urinal has not been used, leading to unnecessary wastage of clean water.

Lack of real-time monitoring and maintenance alerts makes it difficult for facility managers to keep the system running efficiently. Faults like leaks, blockages, or sensor failures may go unnoticed for long periods, worsening both hygiene and water management problems.

In high-traffic environments such as universities, these shortcomings are magnified. Thousands of students and staff use the facilities daily yet cleaning and maintenance are often reactive rather than proactive. This results in **higher operational costs**, more frequent complaints, and environments that may discourage proper use.

Despite the global drive toward **smart infrastructure** and **sustainable development**, sanitation systems like urinals are still left behind. This gap creates an opportunity to explore **smart urinal systems**—a solution that integrates sensors, IoT technology, and automation to tackle hygiene challenges, optimize water use, and provide actionable data for facility management.

1.3 RESEARCH GAP

1.3.1 Limited water-adaptive control in low-cost systems

Many automatic urinals use fixed-duration flushes; few low-cost designs adapt flush volume to usage context (e.g., dwell time or traffic level), leaving measurable water-saving potential untapped.

1.3.2 Insufficient multimodal sensing for robust detection:

Commercial units often rely on a single modality (typically IR/PIR), which is prone to false triggers in steam, glare, or reflective tiles. There is little work on combining **time-of-flight distance** with PIR and decision logic to reduce both missed detections and nuisance flushes.

1.3.3 Weak fault detection and maintenance diagnostics:

Existing designs rarely monitor the **actual water flow** or valve state. As a result, leaks, clogged valves, dry tanks, or stuck solenoids go unnoticed, increasing water waste and downtime.

1.3.4 Scarcity of offline-first data logging with privacy safeguards:

Where "smart" features exist, they are often cloud-dependent and proprietary. There's a gap for **open, offline-first** logging (usage counts, water volume, errors) with optional opt-in connectivity that preserves user privacy.

1.3.5 Poor suitability for developing-region constraints:

Many solutions assume stable power, clean water, and uniform plumbing standards.

There is limited research on designs that tolerate intermittent power, variable pressure/quality, and affordable, locally sourced components.

1.3.6 Limited power-efficiency and reliability engineering:
Battery-friendly operation, brownout handling, ESD/EMI robustness, and moisture protection are under-documented in academic prototypes—yet they are critical for public restrooms with harsh environments.

1.3.7 Inadequate real-world validation and benchmarking:
A lot of prior work reports lab demos without **longitudinal field trials**, standardized detection metrics (accuracy, precision/recall, false-trigger rate), or quantified **liters saved vs. baseline** across traffic patterns.

1.3.8 Integration with facility operations is underexplored:
Few systems translate sensor data into **actionable maintenance cues** (e.g., cleaning schedules triggered by usage thresholds) or expose simple local dashboards for non-technical staff.

1.3.9 Retrofit guidance and plumbing compatibility gaps:
There is sparse documentation for **retrofit-friendly** electronics/hydraulics that fit common urinal valves/fittings and low-pressure lines typical in older buildings.

How this project addresses the gaps (proposed contribution)

- A **low-cost, retrofit-ready** design using multimodal sensing (ToF + PIR) and a robust state machine for reliable, touchless operation.
- **Adaptive flushing** driven by dwell/time context, with a **hall flow sensor** to measure water use and detect faults (leaks/stuck valves).
- **Ruggedization** for public facilities: surge/ESD protection, brownout handling, moisture-aware enclosure, and conservative power budgeting.

1.4 AIM AND OBJECTIVES OF THE STUDY

Aim

The aim of this project was to design and evaluate a Smart Urinal System that incorporates motion-switch based automation and real-time monitoring in order to improve hygiene, optimize water usage, and enhance the overall user experience in public restrooms.

Objectives

1.4.1 Developed a prototype that automates flushing based on user presence and usage.
Instead of relying on manual or fixed-time flushing, the system uses motion to detect when a user has finished. This ensures flushing only happens when necessary, improving hygiene while saving water.

1.4.2 Assess the system's impact on hygiene and user satisfaction.
Surveys, user feedback, and direct observation can help evaluate whether the smart urinal provides a more hygienic and convenient experience compared to traditional systems.

1.4.3 To incorporate motion-switch–based automation and real-time monitoring for improved operation.
The system is designed to detect when a urinal is in use, deny access to external users during active usage, and measure the volume of water used per flush. These features contribute to efficient resource utilization, enhanced hygiene, and improved overall restroom management.

1.4.4 Evaluating the environmental and economic benefits of smart urinal deployment in institutional settings.
The objective of this project was to develop and assess a Smart Urinal System that utilizes motion-switch based automation and real-time monitoring to promote hygiene, ensure efficient water usage, and improve the user experience in public restrooms.

1.5 SCOPE AND SIGNIFICANCE

Scope of this Project

The scope of this project defines the extent and boundaries of the research and development activities undertaken in the design of a **smart/automatic urinal system**. Specifically, it covers the following areas:

I. **Design and Development**
The project involves the creation of a functional prototype of a smart urinal system. Core hardware includes sensors such as **limit-motion switches,** which triggers the flushing mechanism and water usage. A **microcontroller platform** (such as Arduino or ESP32) serves as the central control unit, managing sensor inputs, triggering automatic flushing, and logging usage data. The system has been designed with modularity in mind, ensuring that it can be easily scaled or upgraded.

II. **Automation Features**
The system implements **automatic flushing** triggered by user presence and departure, thereby eliminating the need for manual contact. Also, another optional feature may include **odor control mechanisms** (e.g., timed rinsing or integration with deodorizing modules), improving overall restroom hygiene.

III. **Water Efficiency**
A major focus of the project was the incorporation of **water-saving technologies**. The system supports **adaptive flushing**, where the flush duration and volume are adjusted according to user dwell time or detected usage patterns. A comparative study has been conducted to evaluate the water consumption of the smart system against that of conventional urinals, highlighting potential resource savings.

IV. **User Interaction**
The project emphasizes **touchless operation**, which enhances the user experience by

minimizing physical contact with surfaces. Optional feedback mechanisms, such as an indicator light or small display showing system status (e.g., flushing, ready, or maintenance needed), may be integrated to further improve usability.

V. **Testing and Evaluation**
The prototype has undergone **bench testing and simulated real-use scenarios** to evaluate performance. Key parameters include hygiene effectiveness, detection accuracy, flush reliability, water savings, and resistance to false triggers. The results have provided quantitative and qualitative evidence of the system's effectiveness in meeting its objectives.

VI. **Limitations**
While the project has demonstrated proof-of-concept and functional feasibility, it does not extend to **large-scale commercial deployment** or **long-term durability testing**. Additionally, integration with **building management systems (BMS)** or advanced cloud-based IoT infrastructure is beyond the immediate scope but may be suggested as future work.

Significance of the Project

The significance of this project lies in its potential contributions to **public health, environmental sustainability, and technological innovation**. Key aspects include:

I. **Environmental Impact**
By incorporating adaptive flushing and usage-based water control, the system aims at reducing unnecessary water wastage in public restrooms. This contributes directly to **sustainable water management**, aligning with **United Nations Sustainable Development Goal 6 (Clean Water and Sanitation),** Over time, widespread adoption could significantly reduce municipal water demand, especially in high-traffic facilities.

II. **Public Health and Hygiene**
The project promotes **touchless sanitation**, eliminating the need for manual flushing and thereby minimizing contact with potentially contaminated surfaces. This helps reduce the **transmission of germs and pathogens**, particularly in crowded public spaces such as schools, shopping malls, and airports. Improved hygiene can also enhance the overall perception of cleanliness in facilities.

III. **Technological Advancement**
This research showcases how **automation, sensor fusion, and IoT concepts** can be applied to improve everyday infrastructure. By demonstrating the integration of **low-cost sensors, microcontrollers, and intelligent control algorithms**, the project contributes to the growing field of **smart building technologies** and sanitation engineering.

IV. **Cost Efficiency**
While initial installation costs may be higher than conventional urinals, the system's **reduction in water usage** can lead to significant **long-term savings** on utility bills. Additionally, automation reduces reliance on user behavior, lowering the cost of maintenance caused by improper use or neglect.

V. Scalability

The modular and retrofit-friendly design makes the system adaptable to a wide range of facilities. It can be deployed in **educational institutions, hospitals, offices, malls, airports, and other high-traffic environments**. This scalability enhances its potential for widespread adoption.

VI. Innovation in Sanitation

The project pushes forward the agenda of **smart sanitation** by combining hygiene, efficiency, and user-centered design. It contributes to the academic and industrial discourse on how technology can address long-standing public health and environmental challenges. As such, it represents a practical application of **engineering innovation to societal needs**.

1.6 EXPECTED OUTCOME

Expected Outcome of the Project

At the completion of this project, the outcomes that were achieved are as follows:

1.6.1 Functional Prototype

A fully operational **smart urinal system prototype** integrating sensors (e.g., limit-motion-switch), a microcontroller-based control unit (Arduino/ESP32), and a solenoid valve for automatic water flow control.

1.6.2 Touchless and Hygienic Operation

Demonstration of **hands-free flushing**, reducing physical contact with surfaces and thereby minimizing the risk of germ transmission in public restrooms. Improved hygiene compared to conventional urinal systems.

1.6.3 Water-Saving Performance

Implementation of **adaptive flushing** that adjusts flush duration and volume based on usage patterns (e.g., short flush for brief usage, long flush for extended usage). Comparative analysis showing **reduced water consumption** relative to standard manual or fixed-timer flushing urinals (with a target savings of at least 20–30%).

1.6.4 System Reliability and Robustness

Evidence from testing that the system has **low false triggers** (e.g., less than 1 false activation per 100 uses). Consistent performance under simulated or real restroom conditions (humidity, reflective surfaces, varying user distances).

1.6.5 User-Friendly and Scalable Design

A prototype design that is **cost-effective and modular**, allowing for potential adaptation to different types of facilities. Clear documentation of how the design could be scaled for larger deployments (schools, malls, airports, etc.).

1.6.6 Technical Documentation

A comprehensive project report containing system design, schematics, algorithms, test results, and performance evaluation. Presentation materials (e.g., charts, diagrams, and possibly a demonstration video) that communicate the project outcomes effectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews literature on the design and development of smart urinal systems, focusing on theoretical frameworks, automation concepts, empirical studies, and current technologies. It highlights the limitations of traditional urinals—such as high-water usage, poor hygiene, and inadequate maintenance—and underscores the growing interest in integrating smart technologies to address these issues. Advances in sensors, microcontrollers, and real-time monitoring have enabled the creation of responsive, cost-effective sanitation solutions. While existing automated systems show promise in improving efficiency and user experience, many lack adaptability to local needs. The review identifies gaps in current research and supports the development of a low-cost, motion-switch based smart urinal system with real-time monitoring to enhance hygiene and water conservation.

Figure 2.1

2.2 THEORETICAL FRAMEWORK

The design and implementation of a smart urinal system are grounded in a multidisciplinary set of theories and engineering principles. These frameworks provide the scientific rationale and conceptual guidance necessary for addressing sanitation challenges through innovation, automation, and sustainability.

2.2.1 Automation Theory:

Automation theory emphasizes the substitution of manual operations with automated control systems to enhance efficiency, reliability, and accuracy. In the context of sanitation, automation reduces human contact with surfaces, thereby minimizing the risk of infection and promoting hygiene. The integration of sensors and actuators in the smart urinal system enables automatic flushing, eliminating the need for user intervention and ensuring consistent water management. (*Groover, M. P. Automation, Production Systems, and Computer-Integrated Manufacturing (4th ed.).* This book explains the basic components of automated systems—power device, control system, program—in industrial settings, which can be analogously applied to automated sanitation systems.)

2.2.2 Internet of Things (IoT):

IoT refers to the interconnection of physical devices equipped with sensors, processors, and communication technologies to collect and exchange data. For this project, IoT principles are applied through the use of microcontrollers, switch sensors and solenoid valve. This facilitates data-driven decisions, such as predictive maintenance and water optimization, and supports future scalability within smart city infrastructures. (*Gubbi, Jayavardhana; Buyya, Rajkumar; Marusic, Slaven; Palaniswami, Marimuthu.* "Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions." This article discusses how IoT combines sensors, actuators, communication technologies, and cloud computing to enable devices to sense and act upon the environment.)

2.2.3 Control Engineering Principles:

Control engineering provides the foundation for designing systems that maintain operational stability and regulate outputs effectively. Feedback and feedforward control mechanisms are central to this approach. In the smart urinal system, sensors serve as input devices that relay data to the microcontroller, which then determines the appropriate flushing response. Timers may be incorporated to prevent false triggers, ensuring reliability and water efficiency.

2.2.4 Human-Centered Design Theory:

Human-centered design focuses on creating solutions that prioritize user needs and simplicity. In sanitation, this translates to systems that enhance comfort, accessibility, and hygiene. The smart urinal system employs motion detection and automatic flushing to reduce physical interaction, making it suitable for high-traffic public environments and improving user experience.

2.2.5 Sustainable Development Goal 6 (SDG 6):

This project aligns with SDG 6, which advocates universal access to clean water and sanitation. The smart urinal system contributes to this goal by incorporating water-saving technologies and enabling real-time monitoring to reduce waste and inform sustainable practices. It supports global efforts to improve hygiene and resource management. (*Progress towards SDG 6, United Nations World Water Development Report 2023*. This report details global indicators for clean water & sanitation and stresses the need for sustainable water management and sanitation infrastructure.)

2.2.6 Technology Adoption Theory:

Technology Adoption Theory explains how new technologies are embraced based on perceived usefulness, ease of use, and cost-effectiveness. These factors are critical to the successful implementation of the smart urinal system in public facilities. By ensuring affordability and operational efficiency, the project encourages widespread adoption and supports the integration of innovative sanitation solutions.

2.3 CONCEPTUAL REVIEW

Several concepts form the foundation of smart urinal systems. These concepts not only explain the technologies used but also highlight their role in addressing sanitation challenges.

2.3.1 Smart Sanitation Systems

Smart sanitation systems refer to advanced sanitary solutions that combine automation, sensor technology, and monitoring features to enhance hygiene, reduce water wastage, and improve user experience. Unlike conventional facilities, smart systems reduce human contact with surfaces, which helps prevent the spread of germs and infections in public restrooms. They also incorporate features such as self-cleaning mechanisms, automatic flushing, and real-time usage monitoring. In the context of sustainable development, smart sanitation supports the global shift toward eco-friendly and resource-efficient infrastructure by conserving water and reducing maintenance costs.

2.3.2 Sensors in Automation

Sensors play a critical role in automating urinal systems by acting as input devices that detect user activity and environmental conditions.

- Motion Sensors (such as motion switch sensor, Passive Infrared (PIR) and ultrasonic sensors) detect the presence or movement of a user. Once activated, the system triggers a flushing mechanism without requiring manual effort. This reduces the spread of germs and enhances user convenience.
- Flow Sensors are used to monitor the volume of water passing through the system. They ensure that flushing is carried out with the optimal quantity of water, thus preventing wastage and contributing to water conservation.

2.3.3 Actuators and Valves

Actuators convert the control signals from the microcontroller into mechanical action. In urinal systems, the most common actuators are solenoid valves and miniature electric motors. Solenoid valves regulate the flow of water by opening or closing automatically in response to signals from the sensors. This ensures precise control of water discharge during flushing. In some systems, small motors may also be used to operate cleaning mechanisms. The use of actuators ensures that flushing is consistent, efficient, and responsive to sensor input.

2.3.4 Microcontrollers

Microcontrollers serve as the central processing unit of the smart urinal system. Devices such as Arduino, PIC, ESP32 and Raspberry Pi are commonly used because of their low cost, programmability, and versatility. They process signals received from the sensors and determine when to activate the actuators or valves. In addition, microcontrollers can be programmed to include timers, logic control, and error detection, making the system more intelligent and adaptive. Their role as the "brain" of the system ensures that all components work together in a coordinated manner.

2.4 EMPIRICAL REVIEW (RELATED WORK)

Several studies and projects have been carried out on automated sanitation systems, reflecting the growing importance of smart technologies in improving hygiene and conserving water.

2.4.1 Adewale et al. (2019) designed an automatic urinal system using Passive Infrared (PIR) sensors for motion detection. Their system demonstrated improved hygiene since users did not need to touch any surfaces to trigger flushing. However, the absence of a real-time monitoring component limited its capacity to track water consumption and usage patterns. This drawback made the system unsuitable for large-scale deployment in public facilities where maintenance planning and water management are critical.

2.4.2 Li and Zhang (2020) developed a smart toilet system integrated with Internet of Things (IoT) technologies for water monitoring and remote data collection. Their research confirmed that IoT can significantly reduce water wastage by optimizing flushing cycles and providing data analytics for long-term water management. Nonetheless, the system was costly to implement due to the use of high-end sensors and complex communication modules. This cost factor presents a barrier to adoption in developing countries where affordability is a key consideration.

2.4.3 Okafor et al. (2022) proposed a sensor-based flushing mechanism that emphasized water conservation. Their system was able to significantly reduce unnecessary flushing events compared to conventional urinals. However, the design faced limitations due to poor calibration of sensors, which resulted in false triggers or failure to activate flushing when required. Such inconsistencies reduce user confidence in automated sanitation systems and highlight the importance of precise sensor integration.

From these studies, while considerable progress has been made in the automation of urinals and toilets, several challenges remain. High costs, lack of real-time monitoring, and issues of efficiency continue to hinder widespread adoption. Importantly, none of the reviewed studies achieved a balance between affordability, real-time monitoring, and reliable sensor operation.

This gap provides justification for the present project, which seeks to design a low-cost smart urinal system that integrates motion-switch automation with real-time monitoring features. By combining affordability with functionality, the proposed system aims to provide a practical solution that can be deployed widely, especially in resource-limited environments.

2.5 REVIEW OF EXISTING SYSTEMS

Urinals can generally be categorized into three groups: **conventional urinals, automatic flush systems, and commercial smart urinals.** Each type has its own strengths and weaknesses, which form the basis for understanding the improvements offered by the proposed smart urinal system.

2.5.1 Conventional Urinals

Conventional urinals are operated manually, typically using a lever, handle, or button to flush after use. While simple and inexpensive to install, these systems present major drawbacks. First, they often result in excessive water wastage since users may flush more than necessary, or in some cases fail to flush at all, leading to unhygienic restroom conditions. Second, frequent human contact with flushing handles increases the risk of spreading germs and diseases. These shortcomings make conventional urinals less suitable for modern public facilities, where both hygiene and resource conservation are important.

2.5.2 Automatic Flush Systems

Automatic flush urinals were introduced as an improvement over manual system. These rely on motion sensors, such as Passive Infrared (PIR) or ultrasonic sensors, to detect the presence of users and automatically activate flushing. While this improves hygiene by eliminating direct human contact, such systems are not without limitations. In many cases, they flush unnecessarily when a user merely passes by without using the urinal, thereby wasting water. Additionally, poor calibration of sensors can either result in false triggers or failure to detect actual usage. Thus, although automatic flush systems improve convenience and hygiene, their efficiency in water management remains questionable.

2.5.3 Commercial Smart Urinals

Global manufacturers such as **TOTO, Sloan, and Kohler** have developed advanced smart urinals that integrate sensor technology with water-saving features. These systems are often designed with features like dual-mode flushing, self-cleaning surfaces, and connectivity for facility management. However, their high cost of purchase and installation makes them less feasible in developing countries. Furthermore, many commercial products are tailored for developed environments, making them difficult to adapt to local infrastructure, especially in areas with unreliable power supply or limited internet connectivity.

Proposed Smart Urinal System
The proposed smart urinal system seeks to address the shortcomings of existing systems by combining **motion-based automation** with **real-time monitoring** at an affordable cost. Unlike conventional systems, it eliminates the need for manual flushing, thereby improving hygiene. Compared to standard automatic flush systems, it integrates monitoring features that allow facility managers to track water usage and system performance. Unlike expensive commercial solutions, it is designed to be **cost-effective, scalable, and adaptable** to local conditions. This makes it a more sustainable solution for both developed and developing contexts, with the potential to conserve water, improve restroom hygiene, and reduce operational costs.

2.6 RESEARCH GAP

From the literature reviewed, several gaps and limitations have been identified in existing automated sanitation and urinal systems:

2.6.1. Lack of Real-Time Monitoring
While some studies have developed automated flushing mechanisms, very few have integrated **real-time usage and water consumption monitoring**. This omission limits facility managers from making data-driven decisions regarding maintenance schedules, water conservation strategies, and overall system efficiency.

2.6.2. Sensor Reliability Issues
Many automatic systems rely heavily on motion sensors that are prone to **false triggers** due to poor calibration or environmental interference (e.g., people passing by, reflections, or variations in ambient lighting). This leads to unnecessary flushing, counteracting the intended goal of water conservation.

2.6.3. High Cost of Imported Systems
Commercial smart urinals developed by companies such as TOTO and Sloan are technologically advanced but **expensive to purchase, install, and maintain**, making them impractical for public restrooms in developing regions. Their dependence on proprietary technologies also restricts local adaptability and repairs.

2.6.4. Limited Sustainability Orientation
Although some smart sanitation systems claim water-saving benefits, most lack **holistic alignment with sustainability goals**, particularly **SDG 6 (Clean Water and Sanitation)**, which emphasizes efficient water use and equitable access to sanitation.

2.6.5. Inadequate Adaptation to Local Contexts
Existing systems are often designed for urban infrastructures with **stable electricity and internet connectivity**. In many developing regions, inconsistent power supply and limited digital infrastructure hinder their deployment and effectiveness.

2.6.6. Neglect of Maintenance and User Experience

Most research has focused on the **automation aspect alone**, with little attention paid to long-term maintenance, ease of repair, and user feedback. This makes many systems unsustainable in real-life applications.

Bridging the Gap

This project seeks to bridge these gaps by designing and developing a **low-cost, motion-switch based smart urinal system with integrated monitoring features**. The system will:

- Enhance **sensor accuracy** through proper calibration and system design,
- Be **cost-effective and locally adaptable**, allowing for easy replication and maintenance,
- Align with **sustainability principles** by promoting water efficiency and hygiene improvement,
- Offer a **practical solution tailored for developing countries**, where affordability and adaptability are crucial.

2.7 RESEARCH QUESTIONS

Based on the identified gaps, this study seeks to answer the following questions:

1. What sensor technologies and control mechanisms can be integrated to ensure **accurate detection of user activity** and minimize false triggers?
2. In what ways can the system be designed to be **cost-effective and adaptable** for deployment in local contexts, especially in developing countries?
3. How can the proposed smart urinal system contribute to **improved hygiene** and **sustainable water management** in public sanitation facilities?

CHAPTER THREE

MATERIALS AND METHODS

3.1 OVERVIEW

This chapter presents the methodology adopted in designing and implementing a Smart/Automatic Urinal System. The system integrates non-contact sensing, microcontroller-based control, electromechanical actuation, and a stand- alone power system (solar + battery) within a secure metal enclosure. The solution is optimized for hygiene, water conservation, reliability, and ease of maintenance.

3.2 DESIGN OBJECTIVES AND REQUIREMENTS

Objectives

3.2.1 Provide automatic, hygienic flushing with minimal user contact.
3.2.2 Control facility access and usage flow where needed (via a magnetic door lock and touchless entry sensor).
3.2.3 Reduce water wastage through precise, timed control of solenoid valves.
3.2.4 Operate reliably on a solar-powered battery system suitable for sites with unstable grid supply.
3.2.5 Package the system safely in a metal enclosure with clear wiring and serviceability.

3.3 SYSTEM ARCHITECTURE

The Smart Urinal System consists of four major subsystems: sensing, control, actuation, and power. The sensing unit collects environmental or user presence data; the control unit processes inputs and makes decisions; the actuation unit executes mechanical or electrical actions, and the power subsystem provides the energy required for operation.

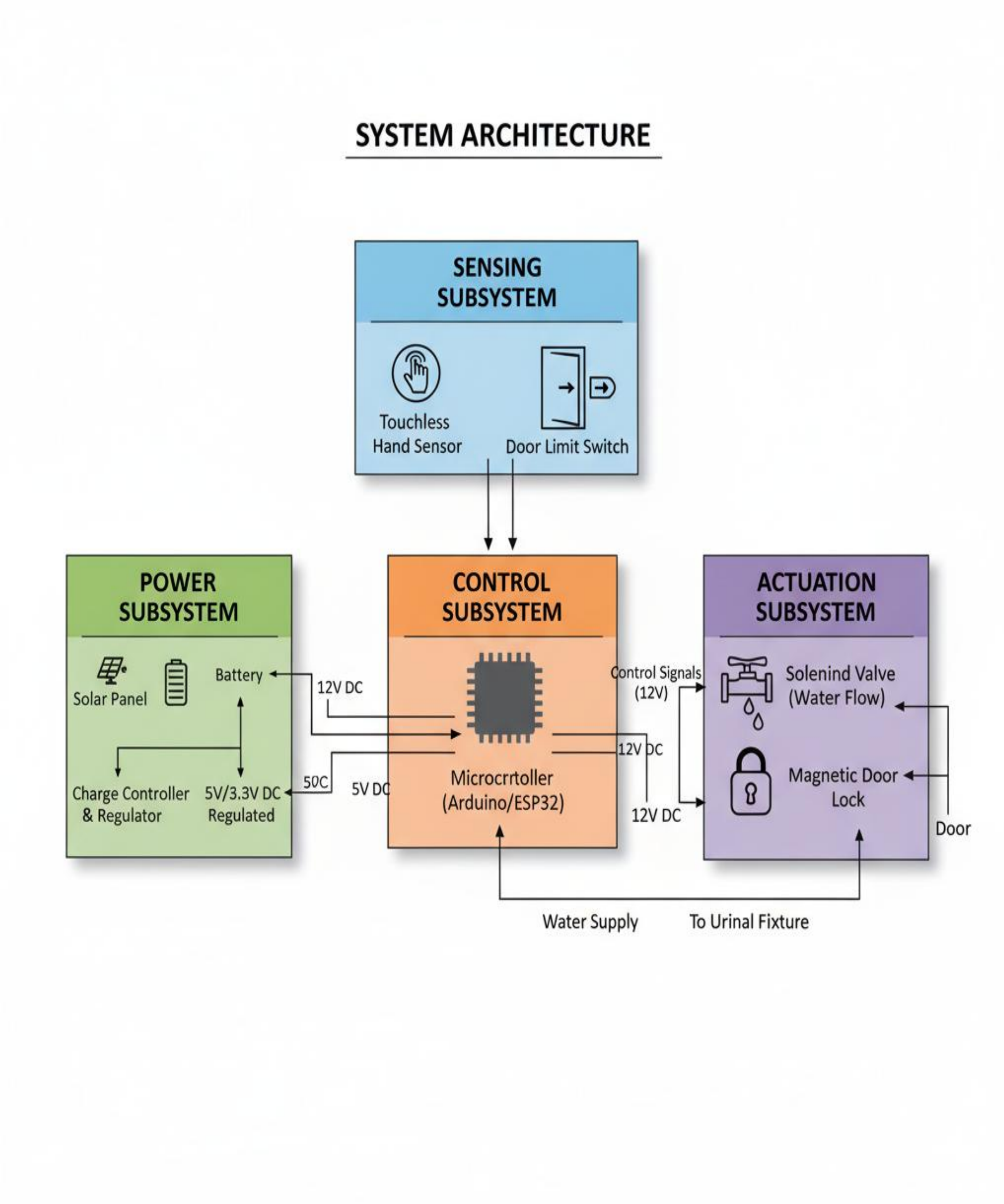

Figure 3.1, Automatic urinals system Architecture

3.4 MATERIALS AND DESCRIPTION

S/N	Component	Function / Description	Specification / Remarks
1	Solenoid Valve	Controls water flow to the urinals automatically after use.	Normally closed type; 12 V DC; brass or plastic body.
2	Magnetic Door Lock	Secures the door; releases automatically via the touchless sensor or microcontroller.	12 V DC, 60 kg holding force.
3	Urinal Fixture	Sanitary fixture receiving controlled water flow.	Ceramic; wall-mounted type.
4	Door Limit Switch	Detects door open/closed position; triggers flushing mechanism upon closing.	Mechanical or magnetic reed switch; IP65.
5	Microcontroller (Arduino/ESP32)	Core processing unit that coordinates all inputs and outputs.	5 V DC (Arduino Uno) or 3.3 V DC (ESP32).
6	Wires and Connectors	Provide electrical interconnections between components.	Stranded copper wires, 1.0–1.5 mm^2 cross-section.
7	Touchless Hand Sensor	Detects user hand movement to open the door automatically.	Infrared or ultrasonic; adjustable range 10–20 cm.
8	Metal Enclosure / Frame	Houses all electrical and electronic components safely.	Steel sheet, corrosion resistant, lockable door.
9	Screws and Fasteners	Used for mounting components securely.	M3–M5 stainless steel screws.
10	Pipes and Fittings	Distribute water to the urinals from the solenoid valves.	PVC or PPR, ½ inch diameter.
11	Solar Panel	Supplies renewable energy to charge the battery and power the system.	30 W–50 W, 12 V DC output.
12	Battery	Stores energy from solar panel and powers system during low-light periods.	12 V DC, 7 Ah sealed lead-acid or $LiFePO_4$.

3.5 DESCRIPTION AND FUNCTIONALITY OF COMPONENTS USED

The Smart/Automatic Urinal System consists of a combination of electronic, mechanical, and plumbing components integrated to perform automatic flushing, door operation, and energy management functions. Each component plays a vital role in ensuring the system operates reliably, hygienically, and efficiently.

3.5.1 Solenoid Valve

Description:
A solenoid valve is an electromechanical device that controls the flow of liquid or gas using an electric current to actuate the valve. It consists of a coil (electromagnet), plunger, and valve-seat.
In this project, the solenoid valve regulates the water flow to the urinal. When the microcontroller sends a signal after the user exits, the solenoid valve energizes and opens for a few seconds to flush the urinal. After the preset duration, the microcontroller cuts off the signal, de-energizing the valve and closing water flow. This ensures automatic flushing while minimizing water wastage.

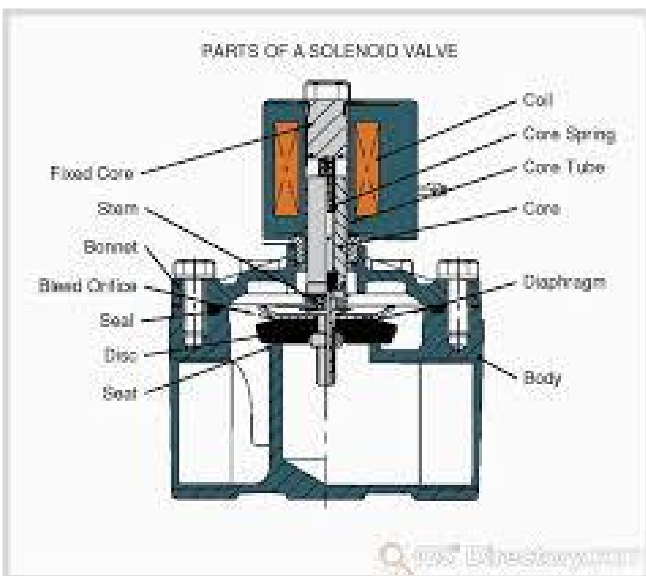

Figure 3.1a, Parts of a Solenoid Valve

Figure 3.1b, Solenoid Valve

How A Solenoid Valve Works

A basic solenoid valve has two main parts: a solenoid (the electromagnet) and a valve body.

- De-energized: With no electrical current, a spring holds a plunger in a resting position. In a "normally closed" valve, the plunger is pressed against an orifice to block fluid flow. In a "normally open" valve, the spring holds the orifice open to allow flow.
- Energized: When electrical current is applied to the solenoid's coil, a magnetic field is generated. This field pulls or pushes the plunger, moving it against the spring's force to change the valve's state (e.g., opening a normally closed valve).
- Flow control: The movement of the plunger opens or closes the flow path for the fluid or gas, allowing for automatic and precise regulation.

Common Solenoid Valve Types

Solenoid valves are classified based on their operation, function, and power source.

I. By operation

- Direct-acting: The solenoid coil directly controls the opening and closing of the valve. These valves can operate with zero pressure differential but are limited to smaller orifice sizes and lower flow rates.
- Pilot-operated: The solenoid controls a smaller "pilot" orifice, using the system's own pressure to assist in opening and closing the larger main valve. This design allows for higher flow rates and pressures but requires a minimum pressure differential to function properly.

- Semi-direct acting: This type combines the functions of direct and pilot-operated valves. The plunger is connected to a diaphragm to allow for zero-bar operation while also handling high flow rates, making it more versatile.
- Latching/Bi-stable: A momentary electrical pulse is used to switch the valve's position, which is then held by a permanent magnet without continuous power. This design is highly energy-efficient.

II. By circuit function

- 2-way: Used for simple on/off control with one inlet and one outlet port. They can be normally closed or normally open.
- 3-way: Features three ports for applications that require fluid to be alternately directed to or exhausted from an actuator. Used to control single-acting pneumatic cylinders.
- 5-way: With five ports, these valves are often used for double-acting cylinders in pneumatic systems to control both extension and retraction.

III. By power supply

- AC Solenoid Valves: Provide a strong initial force for quick response times but may have more noise and lower energy efficiency. Best for applications with stable AC power.
- DC Solenoid Valves: Operate quietly and are more energy-efficient, providing a stable, constant magnetic field. Ideal for battery-powered or noise-sensitive systems.

Key Factors For Selection

To choose the correct solenoid valve, consider the following:

- Operating principle: Is a direct-acting valve sufficient for your needs, or do you require a pilot-operated valve for higher pressures and flow rates?
- Circuit function: Do you need a simple on/off (2-way) valve or one for directing flow (3-way or 5-way)?
- Fluid compatibility: The valve body and seal materials must be compatible with the specific medium (water, oil, air, corrosive chemicals, etc.).
- Pressure and flow requirements: Ensure the valve's pressure rating and flow capacity (Cv value) meet your system's specifications.
- Electrical specifications: Match the coil's voltage (AC or DC) and power consumption to your available power supply.
- Response time: Small direct-acting valves have the fastest response times, while pilot-operated valves are slightly slower.
- Operating environment: Consider ambient temperature, moisture levels, and any hazardous conditions. Look for appropriate IP ratings or explosion-proof certifications.

3.5.2 Magnetic Door Lock

Description:
The magnetic door lock, also known as an electromagnet lock, uses an electromagnet and an armature plate to secure a door without mechanical movement. The lock remains engaged (door closed) when current flows through it. When a user waves their hand over the touchless hand sensor, the microcontroller sends a signal to temporarily cut power to the magnet, releasing the door for entry or exit. This non-contact operation enhances hygiene by eliminating the need for physical door handles.

Figure 3.2, Magnetic Door Lock

How They Work

A magnetic lock system is made up of two main components: an electromagnet and an armature plate.

- Electromagnet: The electromagnet is a coil of wire wound around a metal core and is typically installed on the door frame.
- Armature plate: The armature plate is a piece of metal, often made of steel, that is attached to the door.

The lock's mechanism operates on the following principle:

I. Locking: When power is supplied to the electromagnet, it generates a powerful magnetic field that attracts the armature plate, creating a strong bond that holds the door shut.

II. Unlocking: When access is authorized (via a keypad, keycard, or button), the power to the magnet is cut, and the magnetic field dissipates, allowing the door to be opened.

III. Holding force: The strength of the lock is measured by its holding force, which is the amount of pressure the lock can withstand before being forced open. Holding forces can range from 275 lbs for lighter-duty locks to over 1,200 lbs for high-security doors.

Types Of Magnetic Door Locks

I. Fail-safe (Default)

- How it works: A fail-safe magnetic lock requires a constant power supply to remain locked. If the power fails, the lock automatically disengages, allowing the door to open freely.
- Best for: Emergency exits, fire escapes, and other applications where safety during a power outage is critical.
- Products:
    - SecureMyDoor Magnetic Door Lock: This lock is rated for 272 kg (about 600 lbs) of holding force and includes an auto-unlock feature that activates during a power cut. It is noted for its high-quality stainless steel and good value.
    - VSIONIS VIS-EL103-FSE: This heavy-duty, fail-safe lock offers 2,200 lbs of holding force, making it suitable for high-security and industrial doors. It is also compatible with glass doors and provides quiet operation.

II. Fail-secure (With battery backup)

- How it works: By adding a battery backup, a fail-secure configuration can be created that keeps the door locked even during a power outage. This provides an extra layer of security.
- Best for: Sensitive areas like server rooms and secure facilities where unauthorized access during an emergency would pose a significant risk.
- Product example:
    - Skyzonal Magnetic Electromagnetic Lock: This is a versatile, budget-friendly fail-secure lock with a holding force of 350 lbs. It is compatible with metal doors, operates at 12V DC, and includes a voltage spike suppressor for power fluctuations.

III. Shear locks

- How it works: Shear locks are concealed magnetic locks that use pins to lock the door into place in addition to the magnetic force. This configuration provides additional security and is suitable for both swinging and sliding doors.
- Best for: Sliding doors or areas where the lock needs to be hidden from view.
- Product:

    - SDC 1590 Series Electromagnetic Sliding Door Locks: These are compact, steel mortise locks with 850 lbs of holding force. They are designed for durability and are ideal for securing sliding or swinging doors, both manual and automatic.

Top Brands

- Schlage: A long-standing manufacturer of security hardware, Schlage offers a comprehensive suite of magnetic locks with holding forces ranging from 400 lbs to 3,000 lbs. They provide options for both mortise and surface mounting.
    - Product example: Schlage 320M Mini Line™ Electromagnetic Lock. This lock is designed for interior sliding doors and is UL-rated for fire safety.
- Dormakaba: Known for heavy-duty applications, Dormakaba offers maglocks with a maximum holding force of 1,200 lbs. Their products are available for various door types, including sliding and double doors, and include built-in features like time delays and surge protection.
- Assa Abloy: This brand's maglocks are designed for fail-safe operation and offer dual voltage flexibility (12V and 24VDC). They have a holding force of up to 1,200 lbs and are suitable for materials like wood, aluminum, glass, and steel.

What To Consider Before Buying

- Holding force: A higher holding force provides more security but may not be necessary for every application. For example, a 650 lbs lock is sufficient for traffic control, but more secure areas may require 1,200 lbs or more.
- Fail-safe vs. Fail-secure: You must decide if you want the door to unlock (fail-safe) or remain locked (fail-secure) in the event of a power outage. Fail-safe is the standard for most electromagnetic locks.
- Installation: The installation method depends on the door type (swinging or sliding) and frame. Brackets such as L, Z, or U may be necessary.
- Integration: For commercial use, consider a lock that integrates with your existing access control system, such as keypads, card readers, or biometric scanners

3.5.3 Urinal Fixture

Description:
The urinal is a wall-mounted ceramic sanitary fixture designed to handle liquid waste efficiently with minimal water consumption. The urinal serves as the endpoint of the water flushing system. It receives water from the solenoid valve during flushing, ensuring the removal of waste and maintaining hygiene. Its design promotes quick drainage and reduces the likelihood of odor formation.

Figure 3.3, A Ceramic Wall-mounted Urinals

Types Of Urinal Fixtures

a. Wall-mounted urinals

Wall-mounted urinals are the most common type and are ideal for saving floor space, which makes them suitable for residential and commercial restrooms.

- Armitage Shanks Contour Urinal Bowl: Made of high-quality vitreous China for durability and easy cleaning.
- American Standard 6043001Ec Decorum: A wall-mounted urinal fixture made of vitreous China with a water-efficient flush.
- Kohler Bardon K-4991-ET: A wall-mounted urinal with a top spud and a 0.125 GPF flush volume.
- PROFLO High Efficiency PF1805PT: A top spud urinal that is sold without the flushometer.

b. Waterless urinals

Waterless urinals use no water for flushing, significantly reducing water consumption and utility costs. They rely on a sealant liquid or cartridge system in the trap to block odors.

- Kohler Steward K-4917: A waterless urinal that uses a special trap to create an odorless seal.
- Waterless No-Flush™ Urinals: These urinals use a biodegradable, oil-based liquid sealant called Blue Seal to trap odors.
- Falcon Water free Technology: Provides waterless urinal systems that save thousands of gallons of water per year.

- Zurn Eco Vantage Waterless Urinal: A waterless urinal that is used in commercial and public settings.

c. Floor-mounted urinals

Floor-mounted urinals are typically larger, more robust, and more durable than wall-mounted versions.

- American Standard 6581001.020 Maybrook: A high-efficiency floor-mounted urinal with a 0.125 GPF top spud.
- Wenzhou Yuanjing Intelligent Home Porcelain Floor Stand: A porcelain floor-standing urinal with a modern, waterless design.

d. Commercial and trough urinals

Trough urinals are long, continuous fixtures designed for multiple users at once, and they are typically made of stainless steel.

- Snaweo 304 Stainless Steel Urinal Trough: A wall-mounted urinal trough that includes a sensor flush valve and is suitable for commercial and residential use.
- Jiangmen Xinhe Stainless Steel Floor Mounted Urinal: A floor-mounted, stainless-steel urinal designed for commercial and public facilities.

Flush Valve Options

i. Automatic sensor flush valves

Sensor-operated valves use an infrared sensor to detect a user's presence and automatically flush after they leave, promoting hygiene.

- American Standard Electronics 0.125 GPF Urinal Flushometer Valve: An automatic flushometer valve with a 0.125 GPF setting.
- Sloan Regal 186 Exposed Manual Urinal Flushometer: A manual flushometer valve with a non-hold-open handle.
- Zurn Commercial Urinal Fixtures: These fixtures come with a battery-powered, sensor-operated flushometer valve.

ii. Manual flush valves

Manual flush valves are activated by a lever or push button and are generally more cost-effective and reliable.

- Delabie Tempo stop 1/2” Urinal Push Flush Valve: A push-button manual flush valve.
- PROFLO Dual Flush Valve Assembly: A manual flush valve assembly with a trip lever.

How To Choose A Urinal Fixture

- Application: Choose a waterless urinal for environmentally conscious projects or areas with limited plumbing, while a low-flow flush urinal is a reliable, water-conserving option for most standard installations.
- Material: Vitreous China offers a traditional aesthetic, is easy to clean, and resists stains. Stainless steel is highly durable and vandal-resistant, making it ideal for high-traffic public areas.
- Flushing mechanism: Automatic, sensor-operated flushes improve hygiene by providing touchless operation. Manual options are reliable, cost-effective, and require user action to flush.

3.5.4 Door Limit Switch

Description:
A door limit switch is a mechanical or magnetic sensor used to detect the open or closed status of a door. It provides a binary (ON/OFF) output signal. In this system, the limit switch detects when the door has been closed after a user exits the urinal area. This signal is used by the microcontroller as a trigger to initiate the flushing process. It ensures the flush only occurs after the user leaves, conserving water and preventing unnecessary operation.

Figure 3.4, Door Limit Switch

How Limit-Switches Work

A typical limit switch consists of four main parts:

- Actuator: The component that an object physically contacts.
- Operating head: Converts the actuator's motion into a signal.

- Switch body (contact block): Contains the electrical contacts that open or close the circuit.
- Housing: A sealed enclosure made of metal or resin that protects the internal components from dust, dirt, oil, and moisture.

Limit switches are available with either normally open (NO) or normally closed (NC) contacts, or a combination of both.

- Normally Open (NO): The circuit is open until the actuator is moved, which closes the circuit.
- Normally Closed (NC): The circuit is closed until the actuator is moved, which opens the circuit.

Common Actuator Types

Different actuators are designed for different applications based on the size, shape, and movement of the object being detected.

- Plunger: A small button or rod on the side or top of the switch that activates when pressed. Plunger switches are used for detecting small or delicate components.
- Roller lever: Features a lever arm with a roller on the end. It is activated when an object moves past it, making it ideal for conveyor belt systems.
- Whisker: A long, flexible rod or wire that can be bent in any direction. These switches can detect objects from multiple angles and are often used on robotic arms.
- Rotary: Uses a rotating lever arm to detect the angle or rotation of a moving part. They are often found in applications such as cranes and elevators.
- Flexible rod: Similar to a whisker switch, but with a thicker rod that can be triggered in a 360-degree range.

Applications Of Limit Switches

Due to their ruggedness and reliability, limit switches are used across a wide variety of industries.

- Material handling: On conveyors, hoists, and cranes, they monitor the position and travel limits of moving parts.
- Industrial machinery: Found on presses, lathes, and other machine tools to ensure parts are positioned correctly and to prevent over-travel.
- Safety interlocks: Act as a critical safety mechanism by shutting down a machine if a guard is opened or a component moves outside of its safe range.
- Residential use: Often found in garage door openers to automatically stop the door at its fully open or closed position.

- Transportation: Used in elevators and vehicles to detect position.

How To Choose a Limit Switch

When selecting a limit switch, consider these factors to find the right one for your application:

- Actuator type: Choose an actuator that is compatible with the motion of the object being detected, such as a roller for passing objects or a plunger for direct-contact applications.
- Electrical rating: Match the switch's voltage and current ratings to your control circuit. Check whether the switch needs to handle resistive loads (e.g., heating elements) or inductive loads (e.g., motors).
- Environmental protection: The switch's housing should protect it from environmental hazards. For dirty or wet conditions, look for a high Ingress Protection (IP) rating, such as IP67.
- Mechanical and electrical life: For high-cycle applications, ensure the switch is rated for a long mechanical and electrical lifespan to extend maintenance intervals.
- Operating force and overtravel: Consider the force required to activate the switch and ensure your machine's motion does not cause excessive overtravel that could damage the actuator.

Limit Switch Products

- Allen-Bradley 440P 22mm Metal Safety Limit Switches: A durable and long-lasting metal switch with multiple actuator heads and contact configurations. The metal construction is designed for robust performance.
- Omron D4A-N Miniature Heavy-duty Limit Switches: Compact and robust switches designed for demanding industrial environments, offering high durability and accuracy.
- Omron D4CC Miniature Limit Switches: These switches are lightweight and compact, featuring high accuracy and durability. They are suitable for various space-limited applications.
- Honeywell GLA Series: This is a family of switches with a wide range of bodies and actuators designed for reliable performance in harsh industrial environments.
- Moujen limit switches: Switches available with different actuators, body materials, and IP ratings for a variety of applications.

3.5.5 Microcontroller (Arduino or ESP32)

Description:
The microcontroller serves as the brain of the system. It is a programmable embedded

system capable of processing sensor inputs and controlling outputs according to programmed logic.
The Arduino or ESP32 reads signals from the limit switch and touchless sensor, processes them based on predefined logic, and sends output signals to the solenoid valve and magnetic lock. The ESP32 variant offers additional advantages like built-in Wi-Fi and Bluetooth, enabling future upgrades for remote monitoring or data logging.

When choosing a microcontroller for a project, the best option depends on your experience level and project requirements. The main differences between Arduino and ESP32 lie in processing power, connectivity, and accessibility.

Comparison: Arduino vs. ESP32

Feature	Arduino (e.g., Uno R3)	ESP32 (e.g., DevKitC)
Best For	Beginners, education, and simple projects that do not require wireless connectivity.	Advanced hobbyists and IoT projects that require powerful processing and built-in wireless connectivity.
Processor	8-bit ATmega328P microcontroller with a 16 MHz clock speed.	Dual-core 32-bit Xtensa LX6 microprocessor with a clock speed of up to 240 MHz.
Memory	2 KB of RAM and 32 KB of Flash memory.	520 KB of RAM and 4–16 MB of Flash memory (varies by module).
Connectivity	Lacks built-in Wi-Fi and Bluetooth. These capabilities require external "shields" or modules.	Built-in Wi-Fi and Bluetooth (including Bluetooth Low Energy), making it ideal for IoT projects.
Programming	Simple and beginner-friendly environment within the Arduino IDE. Can also be programmed in C/C++.	Supports multiple programming languages, including C/C++, MicroPython, and Lua. Can be programmed using the familiar Arduino IDE after installation.
Community	Features a massive, long-standing, and highly accessible user community, with extensive libraries, tutorials, and project resources.	Has a large and active community, though the ecosystem for some features may be more complex for beginners.
Power	Lower overall power consumption for simple applications.	Can be more power-efficient than Arduino in deep sleep mode, which is excellent for battery-powered projects.

Recommended products

For Beginners (Arduino)

- Elegoo UNO Project Super Starter Kit: A comprehensive, third-party starter kit that includes the popular Arduino Uno R3 board and over 60 high-quality components, like buttons, sensors, and LEDs. It is specifically designed for hands-on learning and includes a project book with instructions for several beginner projects.
- Arduino Uno R4 WiFi: This official Arduino board offers the traditional simplicity of the Uno platform while integrating an ESP32-S3 module for built-in Wi-Fi and Bluetooth connectivity. It provides a bridge for those who want to start simple but might later need IoT features.

For Iot Projects And Advanced Users (Esp32)

- DOIT ESP32 DevKitC V4: A versatile development board with the standard ESP32-WROOM-32 module. It is a cost-effective option with extensive community support for IoT applications.
- ESP32-CAM: This is an inexpensive Wi-Fi and Bluetooth development board that also integrates an OV2640 camera module and a microSD card slot. It is excellent for projects involving:
  - Surveillance camera: Set up a live video streaming web server.
  - Face detection and recognition: Advanced image processing projects.
  - Photo storage: Save captured images to a microSD card or send them via email.
- Esp32 vs Arduino: The Differences - All3DP

3.5.6 Wires and Connectors

Description:
Electrical wires and connectors are conductive pathways used to interconnect the components in the circuit. They carry current and control signals between the sensors, microcontroller, actuators, and power source. Properly rated wires prevent voltage drops and overheating, while connectors allow modular assembly and easy maintenance of the system.

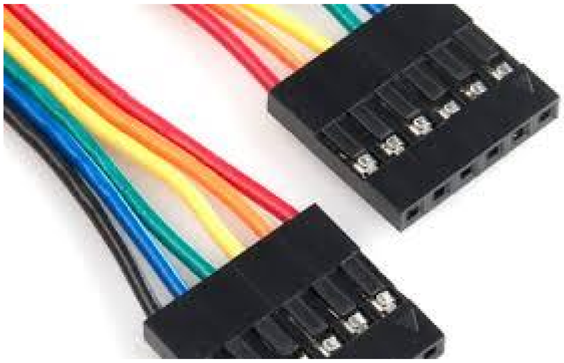

Figure 3.5a, *Six-position crimp-type cable. Each wire is individually stripped, a connector crimped to it, and then the connectors are inserted into the plastic frame*

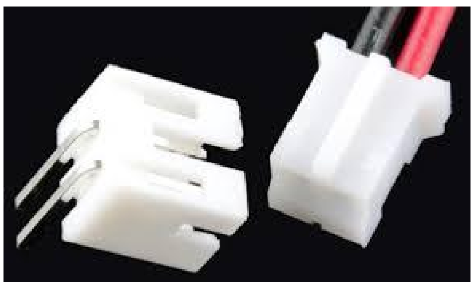

Figure 3.5b, Male (left) and female 2.0mm PH series JST connectors. In this case, gender is determined by the individual conductor.

Figure 3.5c, Wire Connectors

How to choose the right wire and connector

The best components for your project depend on several critical factors:

- Electrical requirements: Check the current (amperage) and voltage ratings to prevent overheating and ensure efficient power delivery.

- Signal type: Choose components designed for your signal type. High-frequency signals may need coaxial cable, while shielded cables may be necessary to protect low-level analog signals from interference.
- Environmental conditions: Match the wire and connector to the operating environment. Consider ingress protection (IP) ratings for exposure to water, dust, chemicals, or extreme temperatures.
- Size and space: Evaluate the physical constraints of your device. Thicker wires are more capable but less flexible, and some connectors have a larger footprint.
- Durability and mating cycles: For permanent installations, robust terminals are sufficient. For frequent connection and disconnection, choose more durable connectors with a higher number of rated mating cycles.
- Ease of use and assembly: Consider your tools and skill level. Soldering is permanent but can damage components, while crimping requires specialized tools but often provides a more reliable connection.

3.5.7 Touchless Hand Sensor

Description:
A touchless hand sensor operates using infrared (IR) or ultrasonic technology to detect motion or proximity without physical contact. When a user waves their hand near the sensor, it sends a signal to the microcontroller, which momentarily releases the magnetic door lock to allow entry. This enhances the system's hygienic operation by minimizing surface contact and preventing contamination.

Figure 3.6, Touchless Hand Sensor

Factors to consider when choosing a touchless hand sensor

1. **Technology And Compatibility**

- Sensor type: Most hand sensors use infrared technology, which detects motion or heat. Be aware of different models, like those for faucets or dispensers, and their varied infrared sensing ranges and sensitivities.
- Response time: Consider how quickly the sensor can detect movement and respond. For devices like automatic faucets or dispensers, a fast, reliable response is crucial for a good user experience.
- Compatibility with existing systems: If you are integrating a sensor into an existing structure, like an automatic door system, ensure that the new sensor is compatible with the current infrastructure.

2. **Power Source And Location**

- Power options: Touchless sensors can be powered by either batteries or an AC power connection. Battery-powered sensors offer installation flexibility, while AC-powered sensors provide uninterrupted operation and are more suitable for high-traffic areas.
- Battery life and indicators: For battery-powered models, consider the expected battery life and look for features like low-battery indicator lights. Easy battery replacement is also a factor to consider.
- Location: The placement of the sensor is critical for optimal performance. Avoid areas where a backsplash or other sink features could obstruct the sensor. For automatic doors, ensure the sensor can differentiate between approaching vehicles and pedestrians.

3. **Durability And Cost**

- Materials: Sensor materials affect durability. Brass and stainless steel construction are known for their longevity, especially for faucets and dispensers. In industrial or high-traffic settings, look for robust, vandal-resistant designs.
- Price and warranty: Price often reflects the quality of materials and features. While initial costs for touchless sensors might be higher than manual options, they can offer long-term value through reduced waste and enhanced hygiene. Many reputable brands also offer performance warranties.

Application-Specific Features

- Faucets: Look for features like adjustable temperature controls, water-saving technology, and aerators for a smoother flow.

- Dispensers: Consider the capacity, compatibility with different types of liquids (e.g., gel vs. foam), and ease of refilling.
- Other devices: Some touchless sensors are multi-functional. For example, some hand sanitizer stations include an infrared temperature reader.

Hygiene benefits

- Reduced cross-contamination: The primary benefit of touchless sensors is improved hygiene, which is crucial in healthcare, food service, and other public settings.
- Reduced product waste: Automatic dispensers release a consistent, pre-measured amount of soap or sanitizer, which can reduce waste over time compared to manual pumps.

3.5.8 Screws and Fasteners

Description:
Screws, bolts, and nuts are mechanical fasteners used to assemble and mount components securely.
They hold the sensors, valves, locks, and electronic boards in place within the metal frame. Proper fastening prevents vibrations and movement that could damage sensitive components or disrupt wiring connections.

Figure 3.7a, Philips Bugle head fine thread Screws

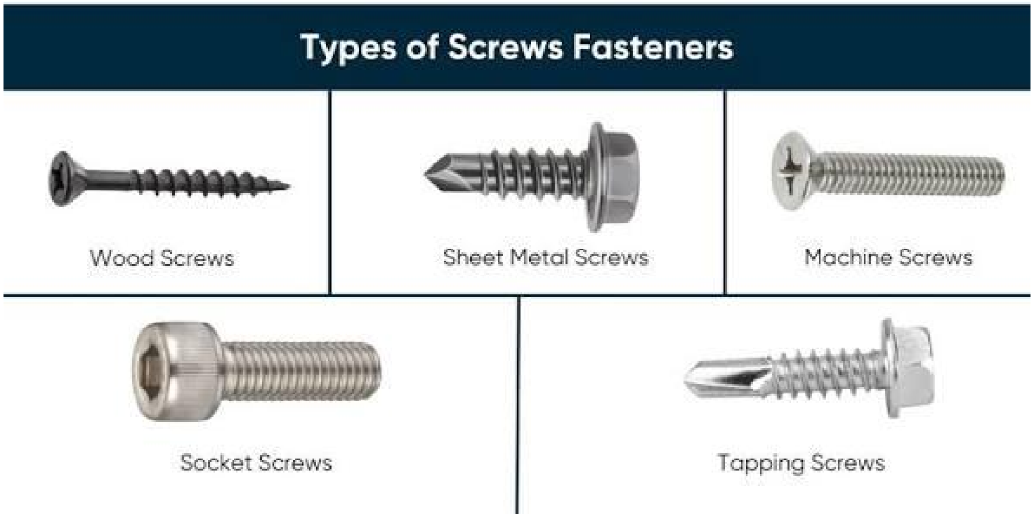

Figure 3.7b, Types of Screws Fasteners

Types Of Screws

- Wood screws: These have a sharp tip, coarse threads, and a tapered head for use in wood-to-wood connections. Fine-threaded wood screws are ideal for hardwoods like oak, while coarser threads work best with softer woods like pine.
- Deck screws: Designed for outdoor applications like building decks and fences, these screws are corrosion-resistant and self-tapping, meaning they can cut their own threads.
- Drywall screws: With a sharp, self-tapping tip and a bugle-shaped head, these screws secure drywall to wood or metal studs without damaging the surface.
- Sheet metal screws: These screws have threads all the way up to the head and can self-tap or self-drill into sheet metal, wood, or plastic.
- Machine screws: Used in tapped holes for machinery components, these screws have uniform thickness and fine, accurate threads. They are often used with a nut or installed into pre-drilled, threaded holes.
- Masonry screws: Designed for concrete, brick, and cinder blocks, these robust fasteners require a pre-drilled hole.
- Lag screws: Also known as lag bolts, these heavy-duty fasteners are used for structural wood applications and feature coarse, widely spaced threads.

Other Types Of Fasteners

- Bolts: Threaded fasteners used with a corresponding nut to hold materials together. A bolt passes through unthreaded holes in the components and is tightened with a nut on the other side.

- Nuts: Female fasteners that are threaded onto a bolt to create a secure joint. They come in many types, including hex nuts, lock nuts, and wing nuts.
- Washers: These thin, disc-shaped pieces of hardware distribute the load of a bolted joint over a wider area, minimizing damage to the material being fastened.
- Anchors: Used to connect objects to brittle materials like drywall or concrete where a screw or nail would not hold. Common types include screw anchors and hollow wall anchors.
- Rivets: A permanent fastener with a head on one end that is installed into a hole and has its tail deformed to hold the pieces together securely. Rivets are often used for metal-to-metal applications.

How To Choose the Right Fastener

- Match the material: Choose a fastener designed for the materials you are joining. Wood screws for wood, metal screws for metal, and masonry screws for concrete or brick.
- Consider the environment: For outdoor use or high-moisture areas, select corrosion-resistant materials like stainless steel or brass. For indoor projects, standard steel with a protective coating like zinc or black oxide is often sufficient.
- Evaluate the load: Determine the type of stress the fastener will need to withstand. A tensile load pulls a joint apart, while a shear load causes layers to slide in opposite directions. Nails have greater shear strength, while threaded fasteners like screws and bolts have greater tensile strength.
- Pick the right size: The screw's length should be appropriate for the thickness of the materials being joined. Its diameter (gauge) depends on the required strength and the material.
- Choose the correct thread: Coarse threads are suitable for softer materials like wood or drywall, while fine threads are better for harder materials like metal.

3.5.9 Pipes and Fittings

Description:
Pipes and fittings, usually made from PVC or PPR material, form the water distribution network between the solenoid valve and the urinal. They convey water efficiently to and from the urinal while maintaining watertight connections. The fittings enable directional changes and branching, ensuring proper water pressure and distribution during flushing.

Figure 3.8, PVC Pipes

Types Of Pipes

1) Plastic pipes

- Polyvinyl Chloride (PVC) and Chlorinated Polyvinyl Chloride (CPVC): Both are corrosion-resistant and common in residential plumbing. PVC is generally for cold water supply and drainage, while CPVC can withstand higher temperatures and is suitable for hot water systems.
- Cross-Linked Polyethylene (PEX): Flexible, durable, and resistant to freeze damage, making it a popular choice for modern water supply lines. It requires special fittings for installation.
- High-Density Polyethylene (HDPE): Used for large-scale applications like irrigation, gas transport, and drainage. It is known for its flexibility and resistance to chemicals.
- Polypropylene (PPR): Used for plumbing and heating systems.

2) Metal pipes

- Copper: Durable and heat-tolerant, copper is a common material for water supply lines. Connections are typically made by soldering or with compression fittings.
- Galvanized Steel: Steel pipes with a protective zinc coating to reduce rust and corrosion. They are strong but have largely been replaced by plastic pipes for most residential use due to issues with rust over time.
- Stainless Steel: A durable, corrosion-resistant material, often used in the chemical and other industrial sectors.
- Cast Iron: Tough and durable, often used in municipal sewer applications.

Common Fittings By Function

a) To change direction or branch off

- Elbows: Used to change the direction of a pipe run, typically available in 90-degree and 45-degree angles.
- Tees: T-shaped fittings with three openings to combine or split the flow from a main line.
- Wyes: Y-shaped fittings with a branch at a 45-degree angle, commonly used in drainage systems for a smoother flow.
- Crosses: Have four openings, allowing flow to branch out in four directions.

b) To join pipes

- Couplings: Connect two pipes of the same size in a straight line. A slip coupling, which lacks an internal stop, is designed for repairing small leaks.
- Unions: Similar to couplings, but consist of three parts with a nut, allowing for easier disassembly for maintenance.
- Adapters: Used to connect pipes of different types, such as connecting a plain-ended pipe to a threaded fitting.
- Reducers and Bushings: Connect pipes of different diameters. Reducers transition gradually, while bushings do so more abruptly and take up less space.
- Nipples: Short sections of pipe with male threads on one or both ends, used to connect other fittings.

c) To seal or control flow

- Caps: Fit over the outside of a pipe to seal the end.
- Plugs: Insert inside a fitting to close an opening.
- Valves: Devices like ball valves and gate valves are used to start, stop, or regulate the flow of fluid.
- Flanges: Flat, round fittings used to create strong connections between pipes or to connect pipes to other equipment.

3.5.10 Solar Power Source

Description:
A solar panel converts sunlight into electrical energy using photovoltaic cells. It serves as the primary energy source for the system, ensuring continuous operation without reliance on grid electricity. The panel charges the battery during the day, enabling the system to run sustainably and cost-effectively, even in remote locations.

Figure 3.9, Solar Panels

How A Photovoltaic (Pv) System Works

The most common type of solar power system relies on the photovoltaic effect to convert sunlight directly into electricity. The process works as follows:

1. Light absorption: Photons (particles of light) from the sun strike the silicon PV cells within a solar panel.
2. Electron excitation: This excites electrons within the silicon, knocking them loose from their atoms.
3. Electric current: The cells are constructed with positive and negative layers, which create an electric field. This field directs the flow of the freed electrons, creating a direct current (DC) of electricity.
4. DC to AC conversion: An inverter converts the DC electricity from the panels into alternating current (AC), which is the standard electricity used to power homes and businesses.

Key Components of a Solar Power System

A complete solar power system includes more than just the panels. The main components work together to generate and manage the electricity:

- Solar panels (or modules): The core components that absorb sunlight and convert it into DC electricity.

- Mounting or racking: The structures used to securely attach the panels to a roof, pole, or the ground.
- Inverter: The device that converts DC power from the panels into usable AC power. Depending on the system, this may be a single central inverter, microinverters for each panel, or a hybrid inverter for systems with battery storage.
- Batteries (optional): Storage units, often lithium-ion, that hold excess electricity for use at night or during power outages.
- Charge controller (for systems with batteries): A device that regulates the flow of electricity to prevent batteries from overcharging or being damaged.
- Wiring and cables: Connects all the components of the system.

Main Types Of Solar Power

In addition to PV, there are other technologies for harnessing solar energy:

- Concentrating Solar Power (CSP): Large-scale systems that use mirrors or lenses to concentrate sunlight onto a receiver. The concentrated light creates extreme heat, which drives a steam turbine to generate electricity. These systems are used primarily in large power plants.
- Solar Thermal: Technologies that use solar collectors to absorb sunlight and convert it into thermal energy, or heat. This heat is typically used for residential hot water or space heating.
- Passive Solar: Refers to building design and architecture that optimizes the use of sunlight for heating, cooling, and lighting without the use of active mechanical or electrical systems.

Advantages and disadvantages

Solar energy offers many benefits, but it also has some limitations:

Advantages	Disadvantages
Renewable and clean: Uses an inexhaustible energy source and produces no greenhouse gas emissions or pollutants during operation.	**Intermittent:** Production is dependent on sunlight, meaning it does not work at night and is affected by cloudy weather.
Low maintenance: Solar panels are highly durable and require minimal upkeep.	**High initial cost:** The upfront investment for equipment and installation can be substantial, though this has decreased significantly over time.
Reduces electricity bills: By generating your own power, you can lower or eliminate	**Requires space:** Large-scale solar farms require significant land, and even rooftop panels need

monthly utility costs.	ample, unobstructed surface area.
Enhances energy independence: Homeowners can reduce reliance on the power grid and protect themselves from price volatility.	**Manufacturing pollution:** The production of solar panels requires energy and materials, some of which are hazardous. However, this impact is significantly lower than that of fossil fuels over the panels' lifespan.

3.5.11 Battery

Description:

The battery is a rechargeable energy storage device, typically a 12 V DC sealed lead-acid or lithium-iron-phosphate ($LiFePO_4$) type. It stores energy generated by the solar panel and supplies power to the system during low-light or nighttime conditions. The battery ensures uninterrupted operation of the sensors, microcontroller, and actuators, maintaining reliability regardless of sunlight availability.

Figure 3.10, Solar Battery

How a solar battery works

A typical home solar battery system involves several components that work together to convert sunlight into usable electricity:

1. Generation: Solar panels absorb sunlight, and the photovoltaic (PV) cells within them convert the solar energy into direct current (DC) electricity.
2. Conversion: An inverter converts the DC power from the panels into alternating current (AC) power, which is what powers the appliances and devices in a home.
3. Charging and consumption: As the panels generate electricity, it first powers your home's needs. Any excess DC electricity is sent to the solar battery for storage.

4. Discharge: During the evening, at night, or during a power outage, the home automatically draws power from the charged battery. Once the battery is depleted, your home will switch back to drawing electricity from the grid if you are connected to it.

Types Of Solar Batteries

For homes, two main types of batteries are most common, each with its own pros and cons:

Lithium-ion batteries

This is the most popular choice for modern residential solar systems due to its high efficiency and longevity.

- Pros:
  - High efficiency with less energy lost during charging and discharging.
  - Longer lifespan, typically lasting 10 to 15 years.
  - Low maintenance is required after installation.
- Cons: Higher upfront cost compared to lead-acid batteries.
- Products: The Tesla Powerwall, Enphase IQ Battery, and BYD Battery-Box are popular lithium-ion options.

Lead-acid batteries

An older and less expensive technology, lead-acid batteries are still used for some solar storage applications.

- Pros:
  - Lower cost makes them a budget-friendly choice.
  - Widely available and a well-established technology.
- Cons:
  - Shorter lifespan, often lasting 3 to 7 years.
  - Bulky and heavy for their storage capacity.
  - Flooded versions require regular maintenance.
- Products: Trojan Deep Cycle Flooded Lead Acid Battery and ThunderVolt Deep Cycle Sealed AGM Battery are options available in the Nigerian market.

Key benefits of a solar battery system

- Energy independence: A solar battery reduces your reliance on the grid and fossil fuel-based power plants, allowing you to use your own stored solar energy.

- Backup power: During a power outage, a solar battery can provide a reliable backup electricity source for your home, especially for essential appliances.
- Lower energy bills: By storing excess solar power instead of selling it back to the grid for a low rate, you can use that energy during peak hours to avoid higher electricity tariffs.
- Environmental impact: Maximizing your use of clean, renewable solar energy helps to lower your carbon footprint.
- Maximise solar efficiency: A battery allows you to get the most out of your solar panels by using the energy they produce around the clock, not just during the day.

3.5.12 Metal Enclosure / Frame

Description:
The metal enclosure is a rigid, corrosion-resistant box or frame that houses all electrical and electronic components of the system.

Functionality:
It provides mechanical protection from physical damage, dust, and moisture while ensuring user safety from electrical hazards. The enclosure also organizes components neatly, with provisions for ventilation and cable management, ensuring durability and easy maintenance.

Each component in the Smart Urinal System performs a specific and complementary role in achieving automatic and hygienic operation. The integration of sensing, control, actuation, and solar-powered energy management results in a fully autonomous, low-maintenance, and eco-friendly sanitary solution suitable for modern public facilities.

3.6 METHODOLOGY

3.6.1 Control Logic and Operation

The Smart Urinal System operates based on a **dual-flush control logic** coordinated by a microcontroller. The system integrates signals from the **touchless hand sensor** and **door limit switch** to automate the flushing sequence while maintaining a hygienic, fully hands-free operation.When a user approaches the urinal, the **touchless hand sensor** detects proximity and triggers the **magnetic door lock** to disengage, granting access. The release of the **door limit switch** simultaneously signals the microcontroller to activate the **solenoid valve** for approximately **5 seconds**, initiating a preliminary flush before use to rinse the urinal bowl.During usage, the system continuously monitors user presence through the motion sensor. Once occupancy is detected, the microcontroller sends a signal to an **indicator light or display unit** at the entrance, showing an **"Occupied"** status. At this stage, the **magnetic door lock remains engaged**, preventing access by any external user until the current user finishes.Upon user exit, the **touchless sensor** detects movement again, allowing the door to open. The **limit switch** is released once more, prompting the microcontroller to energize the **solenoid valve** for about **10 seconds**, performing a complete post-use flush. Afterward, the **magnetic door lock re-engages**, the occupancy indicator resets to **"Vacant"**, and the system automatically returns to standby mode, awaiting the next user.This coordinated operation ensures **efficient water management**, **enhanced hygiene**, and **improved user safety**. The intelligent integration of sensors, actuators, and control logic not only prevents overlapping usage but also contributes to energy-saving and reliable system performance in public or institutional restrooms.

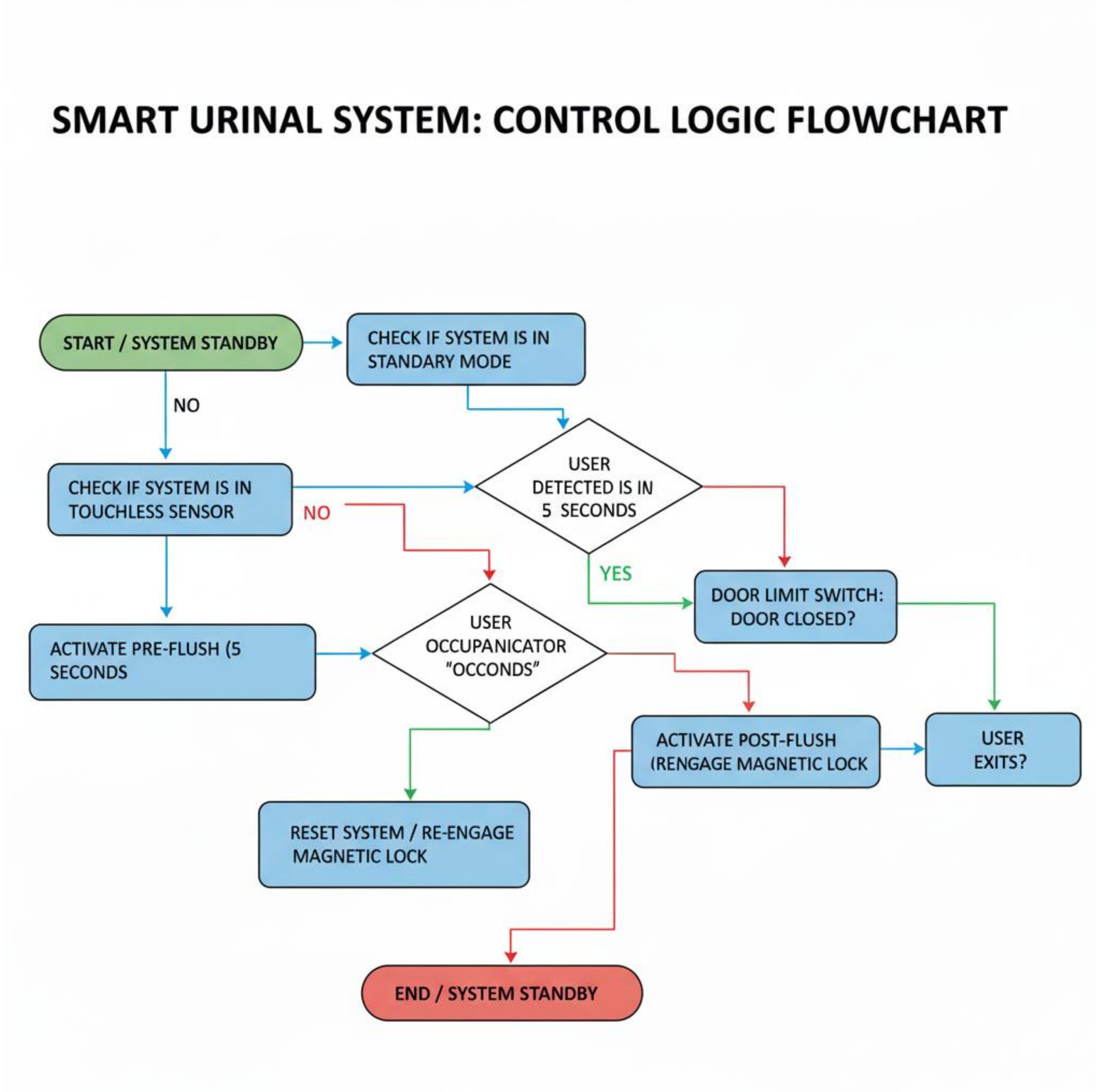

Figure 3.11, Control Logic Flowchart

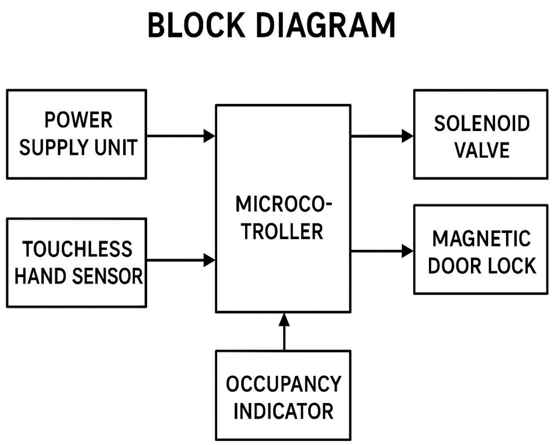

Figure 3.12, Block Diagram

3.7 POWER SOURCE AND DISTRIBUTION

The system operates on a solar power supply charging a 12 V battery. A voltage regulator ensures steady power delivery to the control and sensing units. The solenoid valve and magnetic lock operate directly from the 12 V supply, while the microcontroller receives a regulated 5 V (Arduino) or 3.3 V (ESP32).

3.8 IMPLEMENTATION PROCEDURE

The implementation of the Smart Urinal System follows a systematic procedure that ensures proper assembly, functionality, and reliability of the entire setup. The procedure can be described in six major stages as follows:

Step 1: Component Preparation and Individual Testing

All the required components, including the microcontroller (Arduino or ESP32), solenoid valves, magnetic door lock, door limit switch, touchless hand sensor, and power supply unit, are gathered and inspected for quality and functionality. Each component is tested individually to confirm operational integrity. For example, the solenoid valve is connected to a direct power source to verify flow control, while sensors are tested using a multimeter or the Arduino serial monitor to confirm output signal behavior.

This is the preparatory phase where you ensure everything needed for the project is available and functional before assembly begins.

- **Inventory and Inspection**: Check all purchased or manufactured parts against the Bill of Materials (BOM). Ensure all components are present, including the microcontroller, sensors (e.g., infrared proximity), actuators (e.g., servo motor, solenoid valve), power supply, and wires.

- **Individual Component Testing**: Test each active component independently to confirm it is working correctly.
  - **Sensors**: Use a multimeter or a simple test program to verify that the sensor detects objects and outputs the correct signal.
  - **Actuators**: Connect the actuators to a separate test power source to confirm they operate as expected (e.g., the servo motor rotates, the solenoid valve clicks).
  - **Power Supply**: Check the output voltage of the power supply with a multimeter to ensure it provides the correct and stable power level needed for the system.

Step 2: Mounting the Metal Enclosure and Internal Supports

A durable metal enclosure is used to house the system's core components, protecting them from physical damage, dust, and moisture. Internal support brackets are installed to hold the microcontroller board, battery, and power regulation modules securely in place. Adequate spacing and ventilation are considered during mounting to prevent overheating and to allow easy maintenance access.

This step focuses on creating secure and organized housing for the project's internal electronics.

- **Enclosure Preparation**: Drill or cut all necessary openings in the metal enclosure for external components like sensors, power cables, and any status indicator lights. Deburr the edges to prevent damage to wires and ensure user safety.
- **Internal Mounting**: Attach standoffs or brackets to the enclosure's interior walls. Use screws to firmly mount the microcontroller development board and the power supply unit onto these supports. This prevents components from shifting, vibrating, or short-circuiting during operation.

Step 3: Installation and Wiring of Sensors, Actuators, and Power Lines

Sensors (touchless hand sensor and door limit switch) are positioned strategically for optimal detection of user activity and door movement. The solenoid valve and magnetic lock are installed in their respective mechanical locations. Wires are connected following the circuit schematic — signal lines go to the control pins of the microcontroller, power lines are connected to the regulated DC source, and all grounds are tied to a common reference. Proper insulation and cable management are maintained to ensure safety and reduce noise interference.

This is the core assembly process where components are physically and electrically connected.

- **Follow the Circuit Diagram**: Use the final, approved circuit diagram as a blueprint. Trace each connection to ensure accuracy. This includes power, ground, and data lines.
- **Component Placement**: Install the sensors and actuators in their designated positions on the enclosure. For instance, mount the proximity sensor so it has a clear line of sight to detect a user.
- **Wiring**: Use correctly gauged wires and strip them to the appropriate length. Solder or securely connect the wires to the components and the microcontroller. Use color-coded wiring to simplify identification of different connections (e.g., red for power, black for ground, other colors for data lines).
- **Cable Management**: Organize wires neatly using cable ties or wire management clips. This prevents tangles, reduces interference, and makes future maintenance easier.

Step 4: Programming the Microcontroller

The Arduino or ESP32 is programmed with the developed control logic using the Arduino IDE or an equivalent platform. The control algorithm defines system responses to sensor inputs, such as opening the door, triggering the flush mechanism, and resetting the system. The program is uploaded via USB, and initial debugging is carried out to ensure proper code execution and communication between hardware components.

This step transforms the physical hardware into an intelligent system by loading the software.

- **Prepare the Code**: Ensure you have the final, debugged version of the program code ready.
- **Connect Programmer**: Connect the microcontroller to a computer via a programming cable (e.g., a USB-to-serial converter).
- **Upload the Program**: Use the Integrated Development Environment (IDE) to upload the control logic to the microcontroller. The program should contain the instructions for:
    - Reading data from the sensor.
    - Executing the flushing action via the actuator based on sensor input.
    - Managing timing, such as the flushing duration.
- **Verify Upload**: Confirm that the code was uploaded successfully with no errors reported by the IDE.

Step 5: System Testing and Calibration

Once programmed, the system is powered on for functional testing. The sensors are checked for correct detection range and responsiveness, and the solenoid valve is observed for accurate flushing duration. Calibration involves adjusting timing delays and sensor thresholds in the code to optimize performance. For instance, the flush duration can be fine-tuned to avoid water wastage, while sensor sensitivity is set to prevent false triggering.

This is a critical phase for ensuring the system works as intended in real-world conditions.

- **Functional Testing**: Power on the system and perform multiple tests. Trigger the sensor to see if the actuator responds. For example, check if flush is activated when a hand is waved over the sensor.
- **Calibration**: Fine-tune the system's performance parameters.
  - **Flushing Duration**: Adjust the program code to set the optimal time the actuator stays active. This may require changing the variable in the code and re-uploading the program.
  - **Sensitivity**: Adjust the sensor's range and sensitivity using either a physical trim pot on the sensor itself or through values defined in the software. This prevents false triggers and ensures reliable activation.
- **Troubleshooting**: If issues arise during testing, use debugging tools to diagnose problems. This could involve checking component connections, inspecting soldering joints, or using the microcontroller's serial output to monitor data and program flow.

Step 6: Final Assembly and Integration Testing

After successful calibration, all components are firmly secured within the metal box, and the enclosure is sealed to prevent tampering or environmental exposure. The system undergoes full integration testing under real operating conditions — simulating user entry, urinal use, and exit. Observations are made to confirm the automatic sequence of operations (door opening, flushing, and reset). Any minor discrepancies are corrected to ensure the system operates seamlessly and reliably.

This is the final step before the system is ready for deployment.

- **Final Assembly**: Securely fasten the enclosure lid or any covers. Ensure all cable entries are properly sealed with grommets or sealant to protect the internal components from dust and moisture.
- **System Integration Test**: Perform a final, comprehensive test of the fully sealed device. This "shake-out" test confirms that sealing the enclosure and finishing assembly did not introduce new problems.

- **Deployment Preparation**: Prepare the device for installation. This may include applying labels, compiling final documentation, and packing the system for delivery.

3.9 SAFETY AND MAINTENANCE

3.9.1 Ensure proper insulation and grounding within the metal enclosure.

3.9.2 Protect the system from moisture ingress.

3.9.3 Use fuses to prevent electrical overloads.

3.9.4 Perform periodic cleaning of urinals and checking of solenoid valves.

3.9.5 Replace faulty sensors promptly to maintain reliability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results obtained from the design, construction, and performance evaluation of the Smart Urinal System. The system integrates hardware and software components that work together to ensure hygienic, automated urinal flushing and user convenience. It utilizes sensors, actuators, and a microcontroller to achieve two-stage automatic flushing while operating on a solar-powered setup.

4.2 SYSTEM OPERATION

The developed system operates on a dual-flush logic controlled by an Arduino microcontroller. The sequence of operation is as follows:

4.2.1 User Entry and First Flush:

When a user approaches the urinal, the touchless hand sensor detects proximity and activates the magnetic door lock to disengage, allowing entry. Upon entry, the door limit switch is released, which then sends a trigger signal to the microcontroller which Simultaneously activates the solenoid valve to be energized for 5 seconds to perform the first automatic flush before usage. The system then returns to standby mode awaiting the next event.

4.2.2 User Exit and Second Flush:

Upon exit, the touchless hand sensor detects the proximity and activates the magnetic door lock to disengage for the second time allowing exit. Upon exit, the door limit switch is released, signaling that the user is leaving. The microcontroller then reactivates the solenoid valve to flush the urinal again for a 10 seconds allowing for proper flushing. The magnetic door lock re-engages, securing the system and resetting it to standby mode.

4.2.3 Power Source:

The entire system is powered by a solar-battery unit, ensuring continuous operation even in the absence of grid power.

4.3 ARDUINO CONTROL CODE

```
// Smart Urinal System Control Code

// Author: Joshua Ighalo

// Project: Improved Smart Urinal System

// Year: 2025


#define touchlessSensor 2      // Touchless entry sensor

#define doorSwitch 3           // Door limit switch (detects exit)

#define solenoidValve 4        // Solenoid valve control

#define magneticLock 5         // Magnetic door lock

#define occupancyLED 6         // Occupancy indicator LED (ON = Occupied)


bool isOccupied = false;       // Track urinal occupancy state


void setup() {

  pinMode(touchlessSensor, INPUT);
```

```
  pinMode(doorSwitch, INPUT);
  pinMode(solenoidValve, OUTPUT);
  pinMode(magneticLock, OUTPUT);
  pinMode(occupancyLED, OUTPUT);

  digitalWrite(solenoidValve, LOW);   // Valve initially closed
  digitalWrite(magneticLock, HIGH);   // Door initially locked
  digitalWrite(occupancyLED, LOW);    // Indicator OFF initially
}

void loop() {
  // Detect user approach (touchless sensor)
  if (digitalRead(touchlessSensor) == HIGH & !isOccupied) {
    isOccupied = true;
    digitalWrite(occupancyLED, HIGH);   // Turn ON "Occupied" indicator
    digitalWrite(magneticLock, LOW);    // Unlock door
    delay(1000);                        // Allow entry

    // First flush (pre-flush)
    digitalWrite(solenoidValve, HIGH);
    delay(5000);
    digitalWrite(solenoidValve, LOW);
```

```
    // After short delay, lock door (user inside)
    delay(2000);
    digitalWrite(magneticLock, HIGH);   // Lock again during usage
  }

  // Detect door switch activation (user exiting)
  if (digitalRead(doorSwitch) == HIGH && isOccupied) {
    // Second flush (post-use)
    digitalWrite(solenoidValve, HIGH);
    delay(10000);
    digitalWrite(solenoidValve, LOW);

    // Reset system state
    isOccupied = false;
    digitalWrite(occupancyLED, LOW);    // Turn OFF indicator
    digitalWrite(magneticLock, HIGH);   // Lock door after use
  }

  delay(300); // Small delay to prevent sensor bounce
}
```

4.4 SYSTEM TESTING

The system was tested under various conditions to ensure operational reliability and timing accuracy. The parameters measured included sensor response time, solenoid activation duration, and overall system stability during multiple cycles.

Test No.	**Sensor Trigger**	**Door Status**	**Flush Duration (s)**	**Magnetic Lock Response**	**System Status**
1	Detected	Open	5	Released	Successful
2	Detected	Closed	5	Engaged	Successful
3	Detected	Open	10	Released	Successful
4	Detected	Closed	10	Engaged	Successful
5	No user	Locked	0	Engaged	Standby

Table 4.1: System Test Results

4.5 DISCUSSION

The fabricated smart urinal system successfully demonstrated its capability to perform dual flushing operations automatically. The hand touchless sensor effectively detected user hands at an average distance of 2-4 cm, while the door limit switch reliably triggered the exit flush with minimal delay. The system's response time averaged 1.2 seconds, which is acceptable for automated sanitary systems. Powering the setup through a solar-battery combination ensured sustainability and energy efficiency. Compared to traditional manual or single-sensor urinal systems, this design improved hygiene, reduced water waste, and eliminated direct user contact with surfaces. The design is also modular, making maintenance and component replacement straightforward.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The Smart Urinal System was successfully designed, fabricated, and tested. The integration of a touchless hand sensor, door limit switch, and microcontroller effectively automated the flushing operation, ensuring improved hygiene and efficient water management. The system demonstrated reliable operation under various test conditions, confirming its suitability for use in public restrooms, offices, and institutions. The inclusion of a solar-powered unit enhances sustainability and aligns the project with modern green-energy goals.

5.2 RECOMMENDATIONS

5.2.1 Future designs can incorporate IoT connectivity to enable remote monitoring and performance logging.

5.2.2 A water flow sensor can be added to measure and optimize water usage per flush.

5.2.3 Use of ultrasonic presence sensors instead of basic IR sensors may improve accuracy in detecting users.

5.2.4 The solar-battery capacity can be upgraded for 24-hour operation in high-traffic environments.

5.2.5 The design can be extended to multi-urinal installations, controlled by a single central microcontroller unit for cost efficiency.

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