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Design of an IoT-based Smart Bio-Toilet Scheme with Hygiene-Preserving

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Abstract

This research report focuses on designing and implementing an IoT-based bio-toilet system that prioritizes health, hygiene, and eco-friendliness. This work encompasses deep knowledge of IoT, microcontrollers, bio-toilet systems, engineering design issues, and health and hygiene issues. This is an interconnected sub-system or component having a wide range of applications, including a PV system, sensor systems, microcontroller, structural system, etc. In this smart toilet, a proper hygiene maintenance system has been incorporated. Focus was given to reducing the water consumption in this bio-toilet system. Besides, the method of power generation from biogas and human waste in the toilet system was exploited. Also, an effort was made to produce biofertilizers from human waste. In this work, a method of purifying water by absorbing water from waste was used. In this bio-toilet, extra electricity was provided from solar energy, thus preventing wastage of electricity. The Internet of Things (IoT)-based smart bio-toilet with a hygiene-preserving system uses IoT cloud monitoring for centralized and remote monitoring, control, and analysis of several bio-toilets together. The simulation was done with the Proteus software, and hardware implementation was done using an Arduino microcontroller. Both simulation results and experimental results are obtained.

Keywords

PV Energy, Biogas, Internet of Things, Smart Bio-Toilet, Eco-Friendly, Water Consumption, Cloud Monitoring.

Introduction

An IoT-based smart bio-toilet with a hygiene preservation scheme is a toilet system that uses technology and eco-friendly practices to maintain hygiene and sanitation (Shaikh et al., 2019). The work of such a toilet system would include the exact needs and wants of the re-users, as well as the environmental effects of the system. The inadequate maintenance of bio-toilets in various parts of the country has resulted in unclean air and unpleasant odors in both the toilets and the nearby

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areas (DoE, 2014). This not only contributes to pollution but also increases the transmission of diseases among living beings. As per the UN-Habitat report, Dhaka city failed to meet the Biological Oxygen Demand (BOD) standard for tertiary treatment accepted worldwide (UN-Habitat, 2023). To address these issues, the implementation of innovative technologies in the development of automatic and smart toilets has been widely discussed. Additionally, this paper explores energy conservation techniques that can be incorporated into smart toilets. The bio-toilet systems available to consumers are Pre-manufactured units, eliminating the need for users or planners to be involved in the design process. As a result, manufacturers are largely responsible for developing proper design requirements.

Literature Review

Rajendran et al. (2012) have made a house biogas digester. They worked on how to reduce waste and generate energy. Household digesters may create biogas, which can be used as a useful energy source for cooking. Household digesters help produce renewable energy and reduce trash, but if they are not correctly maintained, they might have negative environmental effects. Adoption of home digesters may be significantly hampered by the upfront expenses involved, particularly for small-scale farmers and rural populations with limited financial means. In his comprehensive review, Dincer (2011) analyzed the photovoltaic (PV)-based electrical power generation standing, probability, and policies of the foremost nations in solar energy. He focused on the dominance of solar energy because solar energy is a prominent source among renewable energy resources. He discussed fissile fuels and emphasized investing in research and development of renewable energy technologies. However, it could improve upfront costs, energy efficiency, and the environmental impact of manufacturing.

Loizou et al. (2015) worked on monitoring water level in storage tanks. They highlighted the sensors' much-reduced production cost compared to the available commercial equivalent. The limitation lies in the limited scope of the experimental evaluation, which may not fully capture the sensors' performance in diverse environments, tank sizes, or water distribution networks. Huang et al. (2012) did research to assess physiological indicators, including body weight, body fat percentage, and ECG. Nowadays, it can be used to explore heart-related symptoms such as dizziness, shortness of breath, palpitations (suddenly detectable heartbeats), and chest discomfort. What I understood after reading the article is that it does not mention any comparisons or validation of the smart toilet equipment with existing methods or technologies for measuring physiological parameters. However, they did not discuss the monitoring of physiological data utilizing a handheld electrode device or electrodes put on a smart toilet seat.

Scarlat et al. (2018) focused on a green and low-carbon economy, highlighting that the biogas manufacturer is a part of the bioenergy sector, contributing to the development of a green environment. They are working on a low-carbon economy. They did not give a comprehensive examination of the underlying causes of these policy changes, instead concentrating on the possible effects of reduced funding for biogas facilities. Shaikh et al. (2017) worked on the PV module system. However, they could discuss the CSP plants, because CSP plants cost 1% of the investment, whereas PV plants cost 2% monthly.

Jan et al. (2022) demonstrated how IoT technology may be used to automate tank refills effectively to monitor water levels and find leaks. It highlighted the lack of an existing assessment in the literature that primarily focused on IoT-based solutions for individual customers. They did not explicitly mention the potential limitations of implementing IoT-controlled water storage tanks. Bae and Lee (2018) mentioned in their work that the integration of IoT in healthcare. They used a sensor-based urine and feces segregation process for classifying the toilet wastages. They applied it to several situations and then analyzed the urine parts using a wireless messaging method to communicate information from the smart toilet to the end-user. This research focuses on developing an IoT-based, eco-friendly, and sustainable bio-toilet that maintains health and cleanliness. The bio-toilet system may be created utilizing IoT technologies.

Methodology

The bio-toilet is a mechanical decomposition toilet system that uses high-quality aerobic or anaerobic bacteria to break down human waste in the digester tank, producing water and methane as byproducts. The system receives human waste. A bio-digester tank is to be created. Wastewater is transformed into clean water by disinfection.

- **Hardware Model**

The proposed system consists of three parts: smart toilet, IoT-based connectivity, and bio-degradable toilet. The first portion includes all the hardware components that pick up all the data to be motioned. The hardware includes a gas sensor, an IR sensor, a microcontroller, and a GSM module. The second portion includes IoT-based GSM connectivity through apps, as in Figure 1. The third portion took out a bio-degradable toilet, which indicates sustainable development.

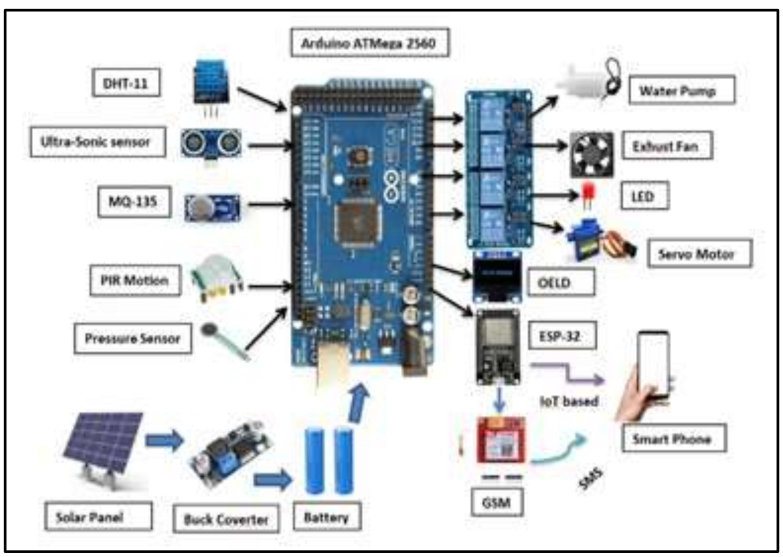


Figure 1. Component diagram of the overall scheme

The architectural design of the bio-toilet consists of three parts: upper, middle, and lower parts. The upper part consists of a water tank which has a capacity of 20 liters. The water tank is a low-cost plastic tank, and it can be replaced if any damage occurs. The water tank is fitted with a pipe for the flow of water into the toilet for the flushing process. The solar panel with 12W is fitted on the top layer for the generation of power. The solar panel is environmentally friendly. The completed setup is shown schematically in Figure 2.

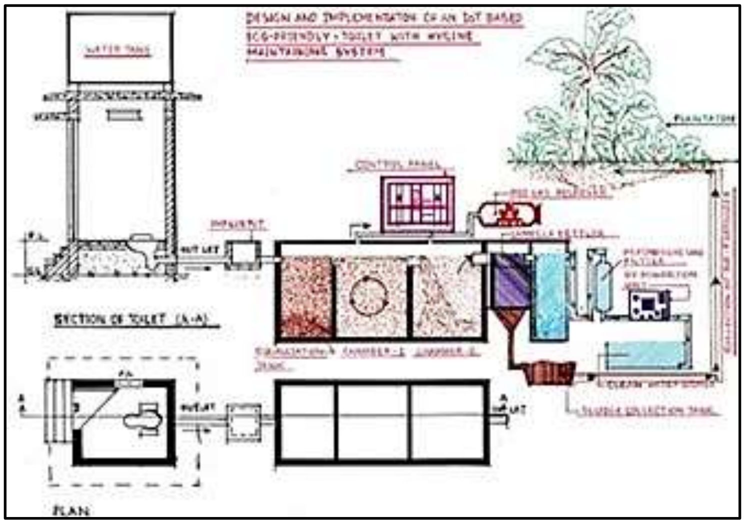


Figure 2. Architectural design of the smart bio-toilet

The hardware used in the prototype includes a display module, four sensors (viz., a PIR sensor, an MQ-135 sensor, a DHT11 sensor, and a voltage sensor), an Arduino Mega microcontroller, a GSM module, and other components. To operate the microcontroller, codes were written, compiled, and uploaded to the microcontroller using the Integrated Development Environment (IDE). The system is housed in a casing and shown in Figures 3 (a) and (b).


(a) (b)
Figure 3. Hardware prototype of a smart bio-toilet management system

This research proposes the cheapest and most sustainable green energy prototype for producing biogas from human waste because the Anaerobic Digestion Model (ADM1) is a generally utilized means to design a prototype for physical and biological methods in biogas fermenters (Chen et al., 2016). A biogas digester tank and fertilizer management system are shown in Figure 4.

Figure 4. Biogas digester tank and fertilizer management system

- **Bio Toilet with Waste Management System**

A bio toilet is a type of special toilet that utilizes advanced technology to recycle wastes and produce fertilizers, methane (CH_4) gas, and wastewater. This is shown in Figure 5.

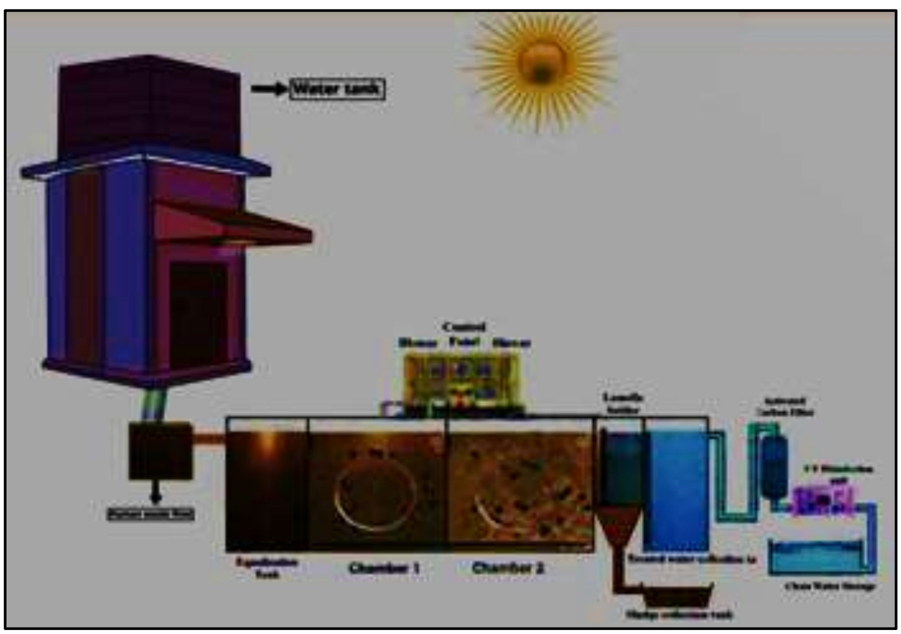
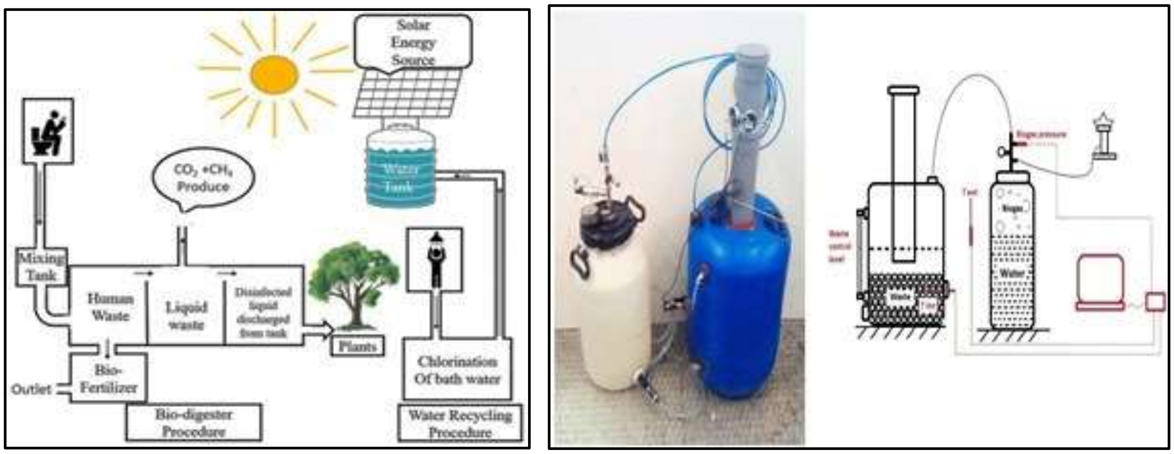


Figure 5. Bio-toilet with waste management system

This system will reduce water consumption and provide plant feed. This prototype model composts waste in a chamber, where liquid evaporates and solid waste is sludged at the bottom, to be sent to the waste management system associated with the bio-toilet, as shown in Figures 6 (a) and (b).

This creates environmentally friendly organic matter, which mixes oxygen from the composting pile and eventually yields a rich, top-soil-like substance for human use.

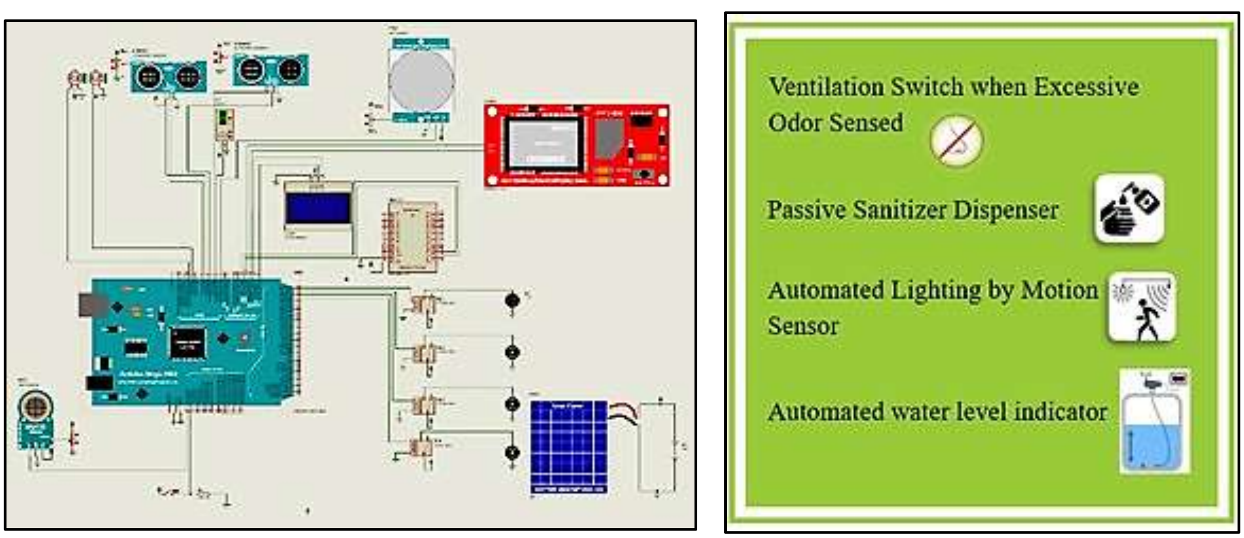


(a) (b)

Figure 6. (a) Block diagram of the cycling process; (b) bio product separation process

- **Simulation Model**

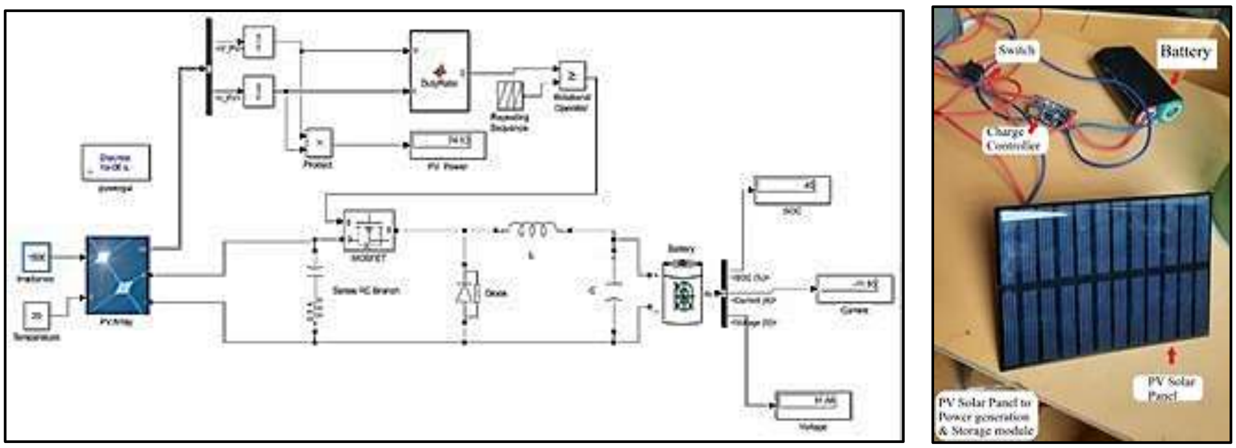
The simulation of a system is used for system testing before the hardware-level implementation by analyzing the simulation outcomes. If the simulation results are correct, then the hardware implementation part becomes easier for the designers. However, if the simulation result analysis shows that the desired outcomes are not obtained, then a few design parameters may be modified to get the desired outcomes. In this way, it is possible to revise the design several times before going into hardware implementation. In this work, we used the Proteus simulation method, as in Figures 7 (a) and (b), to investigate the expected outcomes in each stage (Bhuyan & Hasan, 2020). As such, the simulated results are systematically scrutinized to identify anomalies and possibilities.



(a) (b)

Figure 7. Simulation for the automation process at Proteus

The MATLAB simulation and the PV solar panel are integrated to make it easier to analyze and improve power generation and battery storage systems, as shown in Figures 8 (a) and (b). It offers a thorough framework for modeling and simulating solar energy systems, enabling accurate evaluation of performance, efficiency, and design characteristics, and enabling informed choice for the best use of solar energy resources. The simulation can be done using both MATLAB Simulink and HOMER (Sadek et al., 2022).

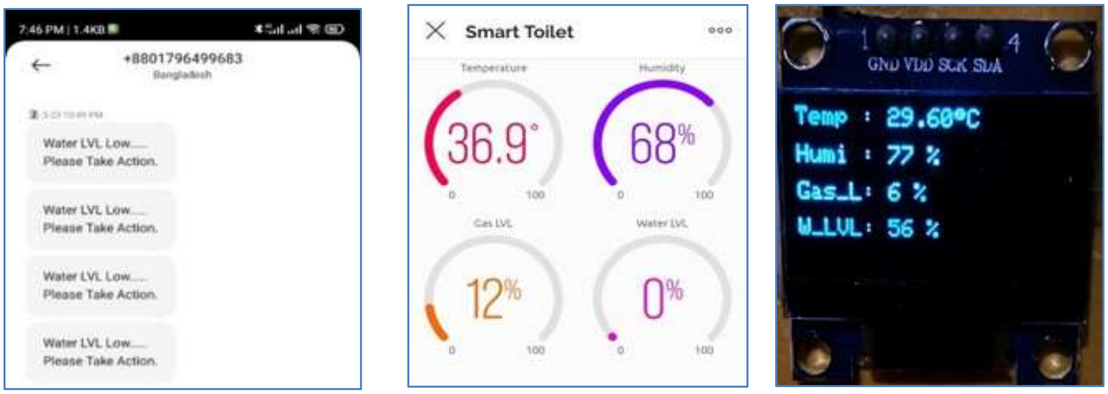


(a) (b)

Figure 8. Solar panel for power generation and battery storage (a) MATLAB Simulink model; (b) corresponding hardware prototype

Results and Discussion

The Adriano Mega serves as the main microcontroller for guiding and coordinating the operation of other components. The DHT-11 monitors humidity and temperature within the toilet to provide comfort and control ventilation. This data is used by Arduino to modify the fan speed and ventilation system to give the user a pleasant atmosphere. Utilizes an ultrasonic sensor to determine whether someone is using the washroom. FSR 402 measures the weight of the toilet seat to ascertain whether it is occupied. The FSR 402 and ultrasonic sensor are used to determine whether the toilet seat is occupied. The ultrasonic sensor detects a person entering the bathroom and alerts the Arduino when it does so. FSR 402 determines occupancy by detecting weight on the toilet seat. The OLED display shows the parameter identified by the sensor, which collects data such as temperature, humidity, gas level, and water level. All these are shown in Figures 9 (a), (b), and (c).



(a) (b) (c)

Figure 9. Notification messages: (a) on the mobile phone screen; (b) on the IoT server; (c) on the OLED screen

Conclusion

An eco-friendly bio-toilet with an IoT-based hygiene maintenance system offers numerous benefits, ensuring optimal hygiene and addressing the demand for sustainable sanitation solutions. The bio-toilet uses bio-digesters to treat human waste environmentally, avoiding harmful chemicals and reducing water consumption. IoT integration enables effective monitoring and regulation, enhancing efficiency and reducing maintenance needs. This system continuously tracks waste levels, monitors temperature, and detects potential malfunctions, providing real-time data to refine performance and guide strategic maintenance. This proactive approach ensures system reliability and operational continuity. By conserving water and preventing pollution, technology promotes a cleaner, more sustainable environment. The integration of advanced technologies, eco-friendly waste treatment, and automatic hygiene maintenance creates a dependable and user-friendly toilet system. This cutting-edge solution in resource management and operational efficiency addresses sanitation demands while contributing to higher hygiene standards and environmental sustainability.

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