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An Arduino-Based Smart Digital Flushable Toilet for Efficient Water Management and Enhanced Hygiene

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Abstract— Despite flushable toilet invention being helpful to humans, especially in towns and cities, flushing waste has become very expensive both at household and public places coupled with health risks of contracting some infectious diseases like streptococcus, diahoerria, etc, due to its use and these are mostly spread in public toilets such as hospitals, schools, bus stations etc. Global warming and climate change have caused water management to become an issue that requires a concerted effort from all users, if not well managed at household and public levels, the monthly cost becomes high as some people tend to flush urine with the same amount of water as if it were stool by emptying the entire cistern into the bowl which is a waste of water hence pausing an economic challenge at both household and public places. Many people do not sanitize the toilet seat before use which if not well handled may harbor germs which intern may infect users. Therefore, the developed system ensures that there is automated flushing of waste with a distinct amount of water for urine and stool. The developed system also automatically sanitizes the toilet seat before someone sits on it hence reducing infectious diseases like covid-19. The system was developed using technologies and frameworks like Arduino Microcontroller which controls how the various toilet parts operate automatedly and C programming language was used for code.

Keywords: Internet of Things, Current System, Proposed System, Message Queue Telemetry Transport protocol, Smart Zambia, Enhanced hygiene, Efficient water management.

I. INTRODUCTION

Human consumption of food causes waste excretion which if not taken care of can be harmful to our health, hence the invention of toilets is vital. The world today is plagued by diseases that spread with help of myriad of vectors. The Centers for Disease Control and prevention (CDC) and visible effects of Covid-19implies that an outbreak from a remote village can travel in just about 36 hours to all major continental cities with grave economic, social and health implications[1]. Diseases like Covid-19 has revealed the urgency for better and inclusive innovation in the global water, sanitation and hygiene (WASH) sector in mitigating and preventing the spread of fatal infections in the future. Covid-19 pandemic brought to human attention the lack of clean water for hand washing and quality toilets for hygiene in many communities.

At the moment, 55% of human population lives in urban areas representing a figure expected to rise to 70% by 2060 as the global population size is projected to reach almost 10 billion persons by 2050 with a high growth rate in urban and peri-urban areas in low-income countries in Asia and Africa[2]. 40% of Zambia's population living in urban areas is a key developmental challenge as many have limited access to adequate clean water and sanitation [2]. Despite commercialization of water and sanitation by the Zambian government to private utility companies with successive real increases in water and sanitation charges, they are still the lowest in sub-Saharan Africa and most households cannot afford the current tariffs hence continuing to be and the government has to ensure also that the benchmark ratio of household water expenditure to household monthly income does not exceed 5 % as set by the Pan-American Health Organization[3].

Enhancement of hygiene in both household and public toilets is crucial despite high tariffs, some people forget to flush while others urinate on the toilet seat making the toilet unsafe for good health, thereby leading to several diseases, such as Hepatitis, Cholera, Streptococcus, urinary tract infections, Typhoid etc [4]. Bacteria are microscopic organisms found everywhere in the universe, that is, the environment we stay and in the human body, these can be either pathogenic or non-pathogenic of which most people cecum to infections through contact on door handles as well as toilet flushing handles[5].

Microorganisms like gastroenteritis contaminate toilet surfaces, especially when flushing manually causing the virus to spread fast in families and both children and adults become infected [6]. Though public toilets may appear clean to the naked eye they are teeming with bacteria which can cause health issues[7]. Zambia's vision 2030 calls for every citizen to get involved in ensuring research in

behavioral change on water management and sanitation to mitigate the impact of climate change on urbanization [8]. This project presents the role of ICT in actualizing the Smart Zambia Master Plan towards efficient management of water by distinguishing water for urine and stool flushing and enhancing hygiene in both household and public toilets hence reducing water bills and diseases emanating from toilet use respectively. Toilet flushing alone constitutes around 30% of average domestic water consumption [9] hence need to reduce this volume.

II. RELATED WORKS

[10]Technological advancement in sanitation and hygiene have existed in ancient Hellas since the Bronze Age with extensive sewerage and drainage and other elaborate sanitary structures. A perfect bathroom according to [11] is that it must be one that lets the user to never feel uncomfortable, for business houses customers should always think of a particular business place because of the quality of the toilets where a user has a peace of mind when duty cause. Flushable toilets are expensive to own hence most people resort to pit latrine or open fields, Botha in a law suit narrates of someone who has lived in urban city her entire life yet has never owned a flushable toilet [12],hence need for innovations that are cheaper so that many people can have descent flushable toilets.

Toilets can be expensive to manage yet many do not realize this, the amount of water to flush waste is a lot yet there are shortages of drinking water [9]. Great attention over the years has been given to addressing this issue and more still needs to be done in developing countries such as Zambia [3]. Automating flushable toilets could reduce wastage of water by approximately 27% on average as toilet flushing alone accounts for around 30% of the water used in homes and can further be reduced to approximately 8% if automated systems are employed [9].

[13]Water flushing duration is an important factor when designing an automatic flushing toilet bowl to avoid too little which may not flush away all the human waste in the bowl but too much water may lead to wastage of clean water. This is done by controlling water flushing duration through a sensor, able to control any electronic device via the internet by using MQTT (Message Queue Telemetry Transport Protocol) to send data to the database and the collected data is used for the analysis of water optimized water release. The system finds an appropriate time to use each time hence saving clean water which can be used for other activities.

[14] This automatic flushing system uses infrared transmitters that transmit an infrared signal to a sensing area directly in front of a toilet bowl. The user's presence in the sensing area is detected by the system from a reflection of the transmitted infrared beam off the user. While in the sensing area, the user is detected for a predetermined minimum period causing an automatic courtesy flush, once the user leaves the sensing area, the automatic flushing system will provide the main flush. The automatic flushing system includes a lift arm operated by a flush motor positioned within the toilet tank, an activation of the motor causes the lift arm to push against a flush arm in the toilet tank to flush the toilet. The lift arm is positioned beneath the flush arm to allow for manual flushing. [15] This is a self-contained electric flushing toilet bowl in which water for flushing the bowl is automatically controlled by a unique control mechanism to perform a series of cyclic operations in which the supply of water to the bowl and outlet flow from the bowl will be so coordinated as to impound a volume of water in the bowl at a raised water level for use in flushing and cleaning the bowl, the control mechanism being housed in an accessible rear compartment of the bowl structure. The outlet flow from the bowl is controlled using a valve structure embodied in a line trap of elastomeric material connected to the bowl outlet.

[16] Bowl flushing device controls the rate of flow of flushing water supplied to a toilet bowl to wash out waste with a minimum amount of flushing water for a maximum flushing effect. The flushing device is composed of a water supply system for supplying flushing water through a water supply pipe to a toilet bowl, a flow rate control valve disposed in the water supply pipe, for varying the rate of flow of flushing water supplied to the toilet bowl through control of the opening of the valve, and a controller for controlling the operation of the actuator. The controller controls the operation of the actuator to vary the opening of the valve stepwise with time in one flushing cycle according to a predetermined flow rate pattern so that the flushing water is supplied to the toilet bowl at a flow rate that varies stepwise with time. [17] This system automatically adjusts the amount of water released in each flush by a facility capable of analyzing the content of the toilet bowl and accordingly decides water volume to be released for flushing content. The decision on the amount of water will be taken automatically based on the quantity of waste detected by a simple digital camera in the toilet bowl. [18] This system is electrically operated and to flush, it causes an automatic lid-lifting and flushing device for a water closet which is adapted to be used in existing water closets and comprises a control circuit, through a motor, transmission gear, and cam means, all incorporated with a link and pull string, to open or close the lid and/or the seat ring of the water closet to flush the closet automatically after the lid is closed.

[7] This system is a management system that uses IoT to ensure toilets especially public toilets are always kept clean for better hygiene. The system is mainly anchored on two sensors, the smell and turbidity sensors which detect any foul smells and the clarity of the water in the bowl, If the smell and/ or water is detected to be bad signals are sent to a microcontroller which in turn exchanges data with the database which is accessible by management via a mobile application and a cleaner is sent to clean the toilet. [18] This invention is a digital electronic volume/flow control sensor toilet with all components of a flushable toilet. The system has several buttons that trigger a particular activity, such as feeling the water tank and emptying the water into the bowl to flush the waste. For a flush to be effected in this system the user must press a button(s) that is connected to the digital electronic volume/control sensor circuitry

causing the motor to rotate for a determined amount of time in a clockwise direction and then back in a counter-clockwise direction to stop the flush, however, the water container remains empty until next activation.

[18]invented a digital electronic volume/flow control sensor toilet with all components of a flushable toilet with several buttons that trigger a particular activity, such as filling the water tank, emptying the water into the bowl to flush waste, however to effect a flush a user presses a button with hands which then causes the volume/control sensor circuitry connected to a motor to rotate and determine amount of water to flush and the tank remains empty until next activation. Of all the types this system has focused on conserving water emphatically, the technology used is that of getting pictures of feces or urine in the bowl, then the image size determines the amount of water to be used automatically. Cameras are used to capture the waste in the bowl, however, it is a challenge to determine the amount of water to be used when there is foam due to urine or other detergents, this causes the image to appear slightly big which causes the system to flush hence wasting water [17].

[19] This system is purely mechanical in construction and function. The main parts of this system are the platform used as a mechanical switch, cistern for water storage, and lever used to pull the flush handle. Its working principle is that flushing is activated when a person steps off the wooden platform, after using the toilet, this decompresses the springs hence causing the vertical rod attached to the upper half of the base to move along with it, this lever mechanism moves the up crossing the cistern handle hence flushing water into the bowl.

TABLE 1: COMPARISON WITH OTHER WORKS

Below is TABLE 2 showing a comparison of existing systems and the proposed system. In TABLE 3 below, the "x" means the system has no specified feature, the "– " means unknown and the "Tick" means the specified feature is present. "Electrically" means the system is operated using electrical components, "Mechanical" is operated without any electrical or electronic devices but mechanical components only. "Embedded" means the system is operated by software installed in the microcontroller while "Electronic" is operated using electronic components.

III. PROPOSED SYSTEM

The proposed system is aimed at developing a smart digital toilet that manages water efficiently by distinguishing the amount of water used when flushing urine and/or stool with enhanced hygiene by sanitizing the toilet seat before the person can use it avoiding any use of hands.

Control System Architecture

Below is Figure 1 showing a UML diagram depicting the architectural view of the proposed system for technical understanding of how the various processes link and control both sensors and actuators.

Author/ Invertor	Name	Operation Type	Seat Sanitizing	Flush Buttons (sensor/foot/ hand)	Different Water Volume between Urine and Stool	Flushes after Lid Closes	Platform
Yu-Hsing Liu	Automatic Lid lifting and Flushing Device for Water Closet	Electrically	×	By hand	–	✓	–
Sujeetha, R.	Toilet Management System Using IoT	Embedded	×	By hand	×	×	Arduino
Wiseman	Adjustable and Automatic Flush Toilet	–	×	–		–	–
Dilworth D. Sanderson n	Digital Electronic Volume/Flow Control Sensor Toilet	Electronic	×	By hand	×	–	–
Parimal, B; Barua, H	Smart Toilet for Automatic Flushing	Mechanical	×	By foot	×	–	–
	An Arduino Based Smart Digital Flushable Toilet for Efficient Water Management and Enhanced Hygiene in Zambia	Embedded	✓	By foot	✓	✓	Arduino

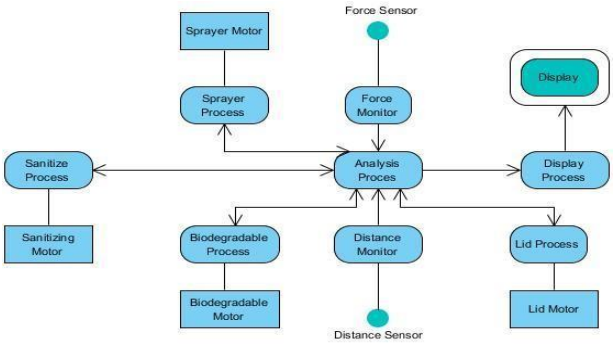

Figure 1: Control system architecture for proposed system

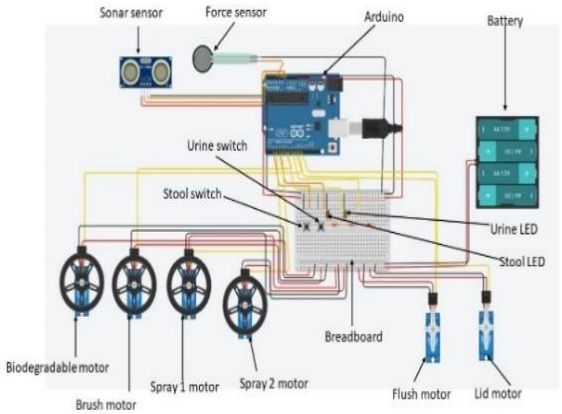

Figure 2: Architectural design of proposed system with electronic components designed in fritzing

Working Model

Figure 2 on the right side is a working model showing how the smart hardware components of the proposed system are connected. These include the servo motors, sonic sensor, force sensor, piezo buzzer, switches, LEDs, and battery which are all connected to the Arduino through the breadboard, this was done using fritzing software.

Assumptious Calculations for Flushing Water by the Proposed System

Various toilet systems are constructed with varying volumes such as 9L, 7L, 6L, etc (Keating et al., 2000). In this calculation, a consideration of 9L is made as these are common. The calculations are based on one person and a family of five on how they use the toilet respectively.

In these calculations, a factor of 1/5 (0.2) for urine and 2/5 (0.4) for stool respectively is used. This means $1\,uFlush = 0.2 * 9L = 1.8L$ (1)

$1\,sFlush = 0.4 * 9L = 3.6L$ (2)

Further assuming that a person passes urine thrice and stool twice respectively then the following calculations are made per family of five in a day and for a month.

$puDaily = 1.8L * 3 = 5.4L$ (3)

$psDaily = 3.6L * 2 = 7.2L$ (4)

Therefore,

$1\,pdFlush = puDaily + psDaily$ (5)

For $f5Daily = 12.6L * 5 = 63.0L$ (6)

Assumptious Calculations for Flushing Water by Most Current System

Most current systems do not distinguish flush volume between

ABSDFT Algorithm

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1. User presses either **Stool** or **Urine** switch to select mode
2. Mode input read by system
3. **if** *water in cistern* >= 2 && *counter*==1 && *sanitizer*==**true**
4. **then** call **sanitization** function
5. Wait for **timer** to open lid
6. **if** weight sensor == **true**
    a. Wait for **timer** to close lid
    b. Call **flush** function when urine switch pressed && *counter*==2
7. **else** lid remain closed && user warned
8. **if** *water in cistern* >= 4 && *counter*==1 && *sanitizer*==**true**
9. **then** call **sanitization** function
10. Wait for **timer** to open lid
11. **if** *weight sensor* == **true**
    a. Wait for **timer** to close lid
    b. Call **flush** function when *stool switch pressed* && *counter*==2
12. **else** lid remain closed && user warned

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urine and stool hence just uses the same amount of water for either stool and/or urine. These calculations are based on this, therefore with a factor of 10/10 (1) for both, hence,

$$1\,uFlush = 1\,sFlush = 10/10\,(1) * 9L = 9L \quad (7)$$

$$puDaily = 9.0L * 3 = 27.0L \quad (8)$$

$$psDaily = 9L * 2 = 18.0L \quad (9)$$

$$1\,pdFlush = puDaily + psDaily \quad (10)$$

For $f5Daily = 45.0L * 5 = 225L$ (11)

This means that the saved volume can last for about 2 months and 3 weeks which is a very efficient management of water and reduces costs on the user as the water that is used in a month by most current systems can be used for 3 months and 3 three weeks.

[20],discusses the statement of services that a system needs to have and how the system reacts to particular inputs, and how the system should behave in particular situations. Therefore, below is the algorithm depicting the functionality of the proposed system

IV. IMPLEMENTATION

This section explains the implementation of the proposed model. Once all sensors and actuators have been installed, programmed, and powered accordingly and a user steps on either switch for urine or stool a signal is sent to the microcontroller which activates the sonar sensor to read the depth of water in the cistern and makes volume calculations. The LEDs and the buzzer are off and only powered on when the microcontroller determines that there is not sufficient water. Each of the motors is only powered on if there is enough water. This is a stand-alone system that can be powered by any form of electricity.

Working Prototype

Below is Figure 3 which is a completed working prototype, it has two switches on the floor. The user steps on the appropriate switch, if for urine then the system checks if there is enough water in the cistern to flush urine then the sanitizing agent is sprayed and rubbed on the seat and finally the lid opens. Once the user is done, he steps on the same switch, and the lid closes which then triggers flushing. The operation for stool is the same, they just differ in flushing duration. However, if there is not enough water for either the appropriate LED to light up and a distinct sound is produced, the lid won't open until there is sufficient water in the cistern.

Figure 3: Completed Prototype

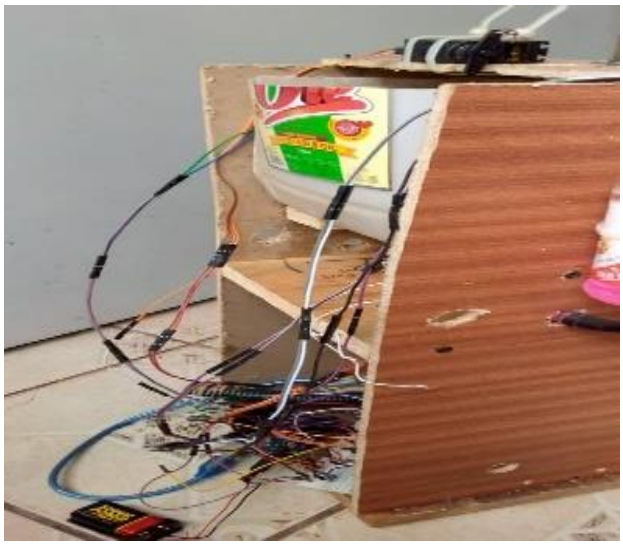

Figure 4: Connections of smart components

Figure 5a: Enough water hence lid open

Figure 4b: Not enough water for stool hence red light

Figure 5c: Not enough water for urine hence yellow light

V. RESULTS AND DISCUSSION

This innovation ensures that the amount of water to flush urine or stool is distinguished and that only an appropriate amount of water is used causing water to be used effectively thereby reducing water and sanitation bills at the same time the conserved water can be supplied to other needy areas by utility companies at least effectively. Automatic sanitization of the toilet seat enhances hygiene in the toilet thereby reducing infectious diseases that emanate from the use of toilets especially for women because of their physiological makeup. The system prevents people from using it when there is no water as some would still want to use it. This hygiene enhancement at least guarantees a healthy citizenry who in turn becomes more productive for the good of the nation. Using the [21] tariffs it can be deduced that for a month of 30 days then a family of five can spend K8.45 using the proposed system and K30.17 using the current system respectively taking water unit charge of $1m^3$ is K4.47 for metered domestic use. Some future work improvements on the system are that it should wash and sanitize the seat cleaning brushes and automatically hide them thereafter. It should also be linked to some database especially the public toilets of which the data on water and chemical usage can be monitored using an app this will make an efficient and effective collection of funds as well for public toilets as most users don't collect receipts. Ensuring that there is total automation, the next person must be alerted when the toilet is in use or not, and the door linked to the system so that the user has no point of contact concerning the use of hands. The system should be able to clean the user automatically, hence contributing to less usage of paper thereby preserving trees in a small way and encouraging a green environment.

VI. CONCLUSION

The proposed system will create awareness among the public on efficient and effective management of water which in turn reduces their respective monthly water and sanitation utility bills and enables water utility companies to distribute the conserved clean water to other needy areas. The probability of diseases that spread from the use of toilets, especially among the public will be reduced hence fewer people frequenting hospitals. This efficient management of water contributes to reducing the effects of climate change as water is now well managed and there could be a reduction in domestic water shortages because of conservation and public awareness.

VII. REFERENCES

[1] J. Crawford, K. Gandara, P. Kumar, and E. Xu, "THINKS The Case for Self-Cleaning Technologies and Methodologies in Public Toilets," no. March, pp. 1–14, 2021.

[2] S. C. Hubbard *et al.*, "Household illness and associated water and sanitation factors in peri-urban Lusaka, Zambia, 2016–2017," *npj Clean Water*, vol. 3, no. 1, pp. 2016–2017, 2020, doi: 10.1038/s41545-020-0076-4.

[3] H. Dagdeviren, "Waiting for miracles: The commercialization of urban water services in Zambia," *Dev. Change*, vol. 39, no. 1, pp. 101–121, 2008, doi: 10.1111/j.1467-7660.2008.00470.x.

[4] M. K. Elavarasi, M. V Suganthi, and M. J. Jayachitra, "Developing Smart Toilets Using Iot," vol. 119, no. 15,

pp. 3061–3068, 2018, [Online]. Available: http://www.ijpam.eu.

[5] F. A. Olajubu, "Bacterial Contamination of Selected Public Toilet Door Handles within Adekunle Ajasin University Campus ," *Int. J. Sci. Basic Appl. Res.*, vol. 43, pp. 76–86, 2019, [Online]. Available: http://gssrr.org/index.php?journal=JournalOfBasicAndApplied%0D.

[6] J. Barker and M. V. Jones, "The potential spread of infection caused by aerosol contamination of surfaces after flushing a domestic toilet," *J. Appl. Microbiol.*, vol. 99, no. 2, pp. 339–347, 2005, doi: 10.1111/j.1365-2672.2005.02610.x.

[7] R. Sujeetha, D. Abhinav, R. Rithik, and S. Abishek, "Toilet management system using iot," *Int. J. Sci. Technol. Res.*, vol. 8, no. 12, pp. 3193–3196, 2019.

[8] MNDP, "7TH National Development Plan," Lusaka, 2017.

[9] T. Keating, R. Lawson, and W. Sussex, "The Water Efficiency of," no. December, 2000.

[10] S. Yannopoulos, C. Yapijakis, A. Kaiafa-Saropoulou, G. Antoniou, and A. N. Angelakis, "History of sanitation and hygiene technologies in the Hellenic world," *J. Water Sanit. Hyg. Dev.*, vol. 7, no. 2, pp. 163–180, 2017, doi: 10.2166/washdev.2017.178.

[11] Convery P, " Public Sanitation, Toilets, and Restrooms."

[12] N. Botha, "The Portable Flush Toilet: From Camping Accessory to Protest Totem," *Des. Cult.*, vol. 10, no. 1, pp. 17–31, 2018, doi: 10.1080/17547075.2018.1430985.

[13] K. Boonyakan, N. Heamra, and A. Changkamanon, "Water efficient toilet: Setting a suitable automatic flushing duration," *3rd Int. Conf. Digit. Arts, Media Technol. ICDAMT 2018*, pp. 143–146, 2018, doi: 10.1109/ICDAMT.2018.8376512.

[14] Z. Retroflush and S. R. F. Valvekit, "United States Patent (19)," *Auto Flush Tank Toilet*, no. 19, 1997.

[15] P. E. E. Aegerter and A. E. S. Levy, "United States Patent (19)," no. 19, 1976.

[16] P. E. M. Fetsuga and P. Joseph, "FG1," no. 19, 1995.

[17] Y. Wiseman, "Adjustable and Automatic Flush Toilet," vol. 13, no. 4, pp. 1–10, 2020.

[18] B. et al, "(12) United States Patent Date of Patent :," *Syst. Method Program. a Weigh. Scale Usinga Key Signal To Enter a Program. Mode*, vol. 1, no. 12, p. 14, 2009.

[19] B. Parimal, H. O. D. Barua, and M. Ranbir Kalita, "Development of a Smart Toilet for Automatic Flushing," 2016, [Online]. Available: https://jecassam.ac.in/wp-content/uploads/2018/10/DEVELOPMENT-OF-A-SMART-TOILET-FOR-AUTOMATIC-FLUSHING.pdf.

[20] I. Sommerville, "Software Engineering 9 Solutions Manual," pp. 1–96, 2010.

[21] "Approved Water Supply and Sewerage Tariffs," 2021.