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DESIGN AND IMPLEMENTATION OF AN IOT-ENABLED WASTEWATER AND FLOODWATER RECOVERY SYSTEM FOR THE PHILIPPINE HOUSEHOLD

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ABSTRACT

Less than 10 percent of Philippine households are connected to a proper sewage system. Considering this, the proponents intend to develop a prototype capable of recycling wastewater but also treating floodwater to provide potable water in the event of flooding. Sensors will be placed in the system to guarantee adequate acquisition of data, in which the data gathered should comply to the corresponding water quality parameters. The prototype is aimed to be integrated into future constructions, allowing for wastewater recycling back into the household, in which the water produced is suitable for recreational uses, as well as an extra system parallel to it which will enable the production of potable water from floodwater.

KEYWORDS: Domestic sewage recycling, floodwater processing, IoT for water recycling, wastewater treatment.

INTRODUCTION

Data enables society to gather new insights that help develop new technologies and techniques. The collection thereof gives us a broader sense of what is happening around us and helps us analyze why that is. With the internet and modern computers, data collection has become easier, enabling further interpretation of data. The synthesis of embedded systems and networking (ergo, the internet) has led to the development of the field of the Internet of Things (IoT).

The concept of IoT usually involves the gathering of data through sensors attached to devices, making up a "thing". These "things" are then connected to the internet. This collection of live data can be used for various purposes, such as predictive maintenance, planning & decision-making, and optimizing infrastructure and system performance. Such technology can be integrated in the local Philippine setting, specifically in the realm of floodwater and wastewater recovery systems.

Water is necessary for life. With an increasing global population and a projected 9.7 billion human count by 2050 (United Nations, n.d.), the importance of water cannot be underestimated; there must be enough water, potable and semi-potable, to support an individual's basic needs. In the Philippine context, the Philippine Statistics Authority estimates the archipelago will grow to 142 million individuals by 2045, adding 49 million individuals between 2010 to 2045 (Philippine Statistics Authority, 2015). Though the Philippines is surrounded by water, clean water can be scarce. Thus, it is important to have an efficient and clean way to recycle water after being used, integrating it into a "sustainable economy" (R. Darra, 2022).

Following this sustainable economy model will ensure that wastewater—used water from domestic, commercial, or industrial uses—can be returned to a valid water source and even gather nutrients, energy, fertilizer, etc. from it (R. Darra, 2022). To facilitate this, it is important to have high quality irrigation, sanitation, and wastewater management. Mismanagement of such waste from any source can negatively impact public health, environment, and even economic progression (S. Domingo, 2021). The Philippines have passed laws and even plans to facilitate and standardize wastewater management. The main law, handled by the Department of Environment and Natural Resources (DENR), was passed in 2004 known as the "Clean Water Act of 2004" which aimed to standardize and regulate water pollution, ergo, wastewater. Additionally, the National Sewerage and Septage Management Program (NSSMP) was also established to eliminate public defecation (Langlois, 2020).

However, the problem arises in the implementation, funding, and coherency of the plan (Vicente B. Tuddao, 2021), (S. Domingo, 2021). One of the major recommendations from reports such as (Vicente B. Tuddao, 2021), (S. Domingo, 2021) is to enhance the research and development of in the field. Technology that is efficient and cheap must be available and developed to help solve the pitfalls of the system. Aside from the inadequate sewage systems found in the country, flooding is also a problem faced by the country. This is due to the overabundance of water (which is not necessarily potable) that comes from monsoons (PAGASA, n.d.). However, flooding can cause damage to buildings, bridges, agriculture, etc. Because infrastructure is damaged, necessities become compromised, which include potable water. Thus, it is important to have potable water that is not contaminated.

In an article made by the World Health Organization, highlights the Philippines lack of infrastructure towards is sewerage and treatment system.[8] The Philippine relies on decentralized wastewater treatment systems, specifically the septic tanks as the main technology of containing the wastewater in rural and urban areas. This is further supported by a study made by the department of public works and highways, which gives insight on the current situation. (HIghways, 2013) The study found that there is a lack of enforcement regarding regulations and maintenance with decentralized sewage systems, especially in rural areas. There is also a lack of funds for technical solutions and blame shifting in the governments part which led to the stagnation of the floodwater situation (Loh & Pante, 2015). As stated in the historical study, Singapore was more effective in policies and the technical aspect than the Philippines. There is also no innovation that originates from the Philippines, albeit analyses on flood patterns on various parts of the Philippines (Plyushteva & Schwanen, 2022).

When approaching with an IoT stack, an event-driven architecture was desired. Apache Kafka, an open-source, Java-based data-streaming platform is used in industry. It has been utilized as well by (Hugo, Morin, & Svantorp, 2020) and showcased good performance for their IoT solution for C-ITS. Given that Apache Kafka has been utilized beforehand, it was beneficial to utilize it for the project's use case. The Philippine Statistics Authority or PSA is the primary governing body that collects data from the population and provides relevant statistics back to the community which will be used for the improvement of quality of life for all. However, the means and methods of the PSA to gather data from the population are quite laborious. This is why efforts are being made to improve the means of collecting data. The development of a new way to gather data among various households is a must since the population is growing at an exponential rate. Traditional means of collecting data are no longer sufficient, which is why the PSA is shifting its priorities to other statistics which leaves other topics with a gap in data.

One such example is that the group encountered a lack of data regarding the current wastewater infrastructure of the Philippines. Information such as the volume of wastewater generated, and its characteristics were not provided by any governing body. If there was, the data was divided by each zone around NCR, not by each household. The group believes knowing this information would allow for better planning in infrastructure and the promotion of water conservation. In addition, less than 5 percent of Philippine households are connected to a proper sewage system; Most Filipinos utilize septic tanks as a pre-treatment before discharging the wastewater to the sewage system. Additionally, only 10 percent of wastewater is treated in the entire country. The lack of research and development, along with the absence of coherency and implementation, leads to such conditions of wastewater management in the country.

There is also the issue of the flood-prone nature of the country, where the lack of potable water becomes a problem when such natural calamities hit those without adequate backup water management systems. Dehydration is a factor that must be taken into consideration during calamities. Though water is abundant during flooding, drinkable water is scarce. Without intervention and focus from stakeholders, sanitation and wastewater management can lead to illness and even death. Poor living conditions due to such mismanagement are problems that should be addressed since they affect the quality of life for millions. The ideal situation was supposed to be that all houses are linked to a sewage system that leads to functional wastewater treatment plants/centers or at least should have its own backup and management system for clean water if it is unavailable. However, for the reasons above, that is not the case here in the Philippines. The lack of research and development for a sustainable solution is currently limiting the growth of our current infrastructure. The goal of such a system should allow for little to no human intervention and constant monitoring.

MATERIALS AND METHODS

Given the problems stated, the group intends on developing a prototype capable of being deployed to future households. This prototype would then be capable of wastewater management using three primary stages which contain the physical, chemical, and microbiological processes of wastewater treatment. The expected output of this system would be clean water classified under Class B under the "Philippine Clean Water Act of 2004" which has purposes for recreational activity such as bathing (Vicente B. Tuddao, 2021). This water will go back to the household. Due to the constraint being in the domestic setting, it must be cheap and easily maintainable. Attached in parallel to this domestic wastewater management is the floodwater management system.

Such floodwater recovery system will then be a replica of the domestic wastewater management system already available, however, additional laboratory testing would be needed in order to verify that the water is indeed potable, and in compliance to the Philippine National Standards for Drinking Water of 2017 (2017 Philippine Drinking Water Standards, 2017). Thus, the output of this system would be of class AA. This floodwater recovery subunit would only activate when the area begins to flood. The said management subunit does not have to be on when there is no flood currently present in the area. Thus, it is important that there be a flood monitoring system along with it. Figure 1, shows the general expected system design for the proposed project. The septic tank and the floodwater system have similar block diagrams; however, their final outputs are different. To ensure the system fully functions, a sensor system managed by a microcontroller is installed. The microcontroller will also control the floodgate and the power of the system. The sensors will feed its information to the microcontroller and will then be transported to the single-board computer. This single board computer will act as a web server and as a data repository. This will enable web access for the system which can be further interfaced with either a web application or some custom-tailored interface. Delving deeper into the software, the following software-specific design was developed.

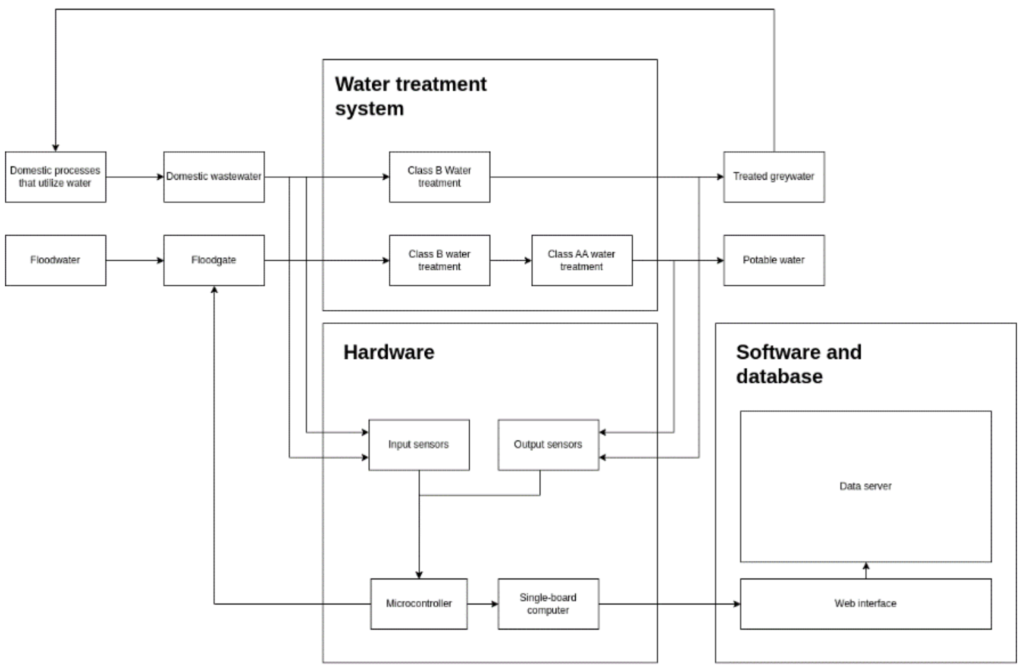

Figure 1: General system design.

The system's design will use IoT sensors to track and monitor the incoming data. The researchers will abide with the sensors' documentation in terms of use and capabilities to ensure that the data incoming is read accurately and utilize third-party tools to validate its accuracy. The sensors will dictate the characteristics of the input wastewater and the end-product of the system. It will check characteristics such as pH levels, turbidity, conductivity, volume, and temperature. The IoT architecture shown in Figure 2, revolves around Apache Kafka and ensures that other software can sink and source data to the data-streaming platform. The "things" component utilizes MQTT to allow for microcontrollers to subscribe and publish toward topics in a fast and efficient manner (MQTT, 2022) Through Apache Kafka Connect API, it is possible for Apache Kafka to subscribe to the data being generated across the microcontroller-side of the architecture. Information can go over the internet through a virtual private network, adding an additional layer of security and consistent IP addressing to the system (What Is a Virtual Private Network (VPN)? - Cisco, 2019). Once the data enters the data component, it is stored in Kafka and can now be distributed toward any other software through the API.

This API enables the reading and sending of data to and from Apache Kafka. In the case of this project, MongoDB was utilized through a Mongo connector. Through MongoDB, data was sunk toward a WebSocket Server, which then allows WebSocket clients to retrieve data when it is generated from the microcontrollers. Having both Apache Kafka and MongoDB has an interesting side-effect: data redundancy. To test the capabilities of the system's IoT module, the group have decided to implement a two-node system that will connect and communicate to a central server. These two nodes will act as households which will generate the data that will populate the central server. The data taken from the sensors will be used to fill in the gaps in research such as finding out the amount of wastewater generated by households in the Philippines. The sensors will help determine and characterize the end product of the researchers, whether class B or class AA.

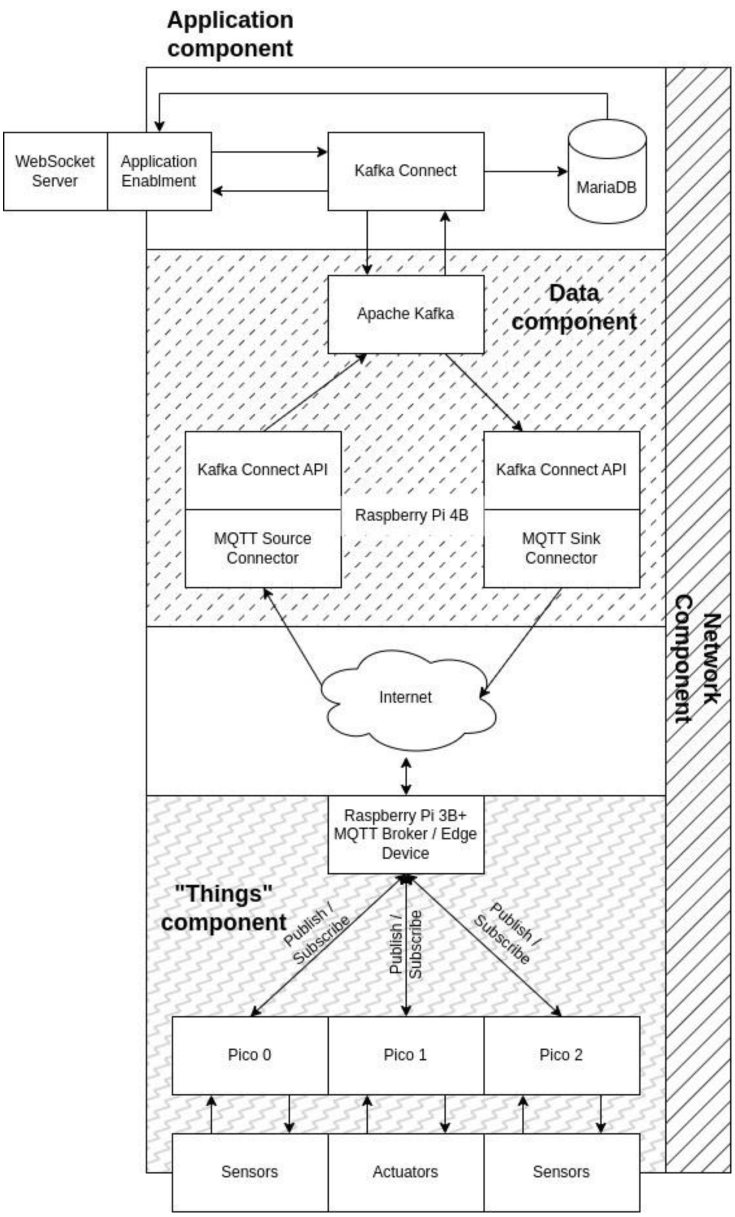

Figure 2: IoT architecture.

Figure 3, shows the system that treats the domestic wastewater and the floodwater to make sure it obtains a “Class B” level of treatment. It goes through the settling tank where the solids will settle to the bottom of the tank. It will then go to the pump aerator which will lead it to the next tank where the wastewater, as much as possible, will have already eliminated the usual smell of wastewater. The water pump will use air to make the water go to the clear water tank. It will then go through the different stages of water treatment through the other water tanks, such as chemical and biological treatment. Another water pump will be used to bring the treated water from the holding tank to another tank where sensors will determine if it is possible to be reused or it will go to the next system of water treatment that will make the treated water from “Class B” to “Class AA”, depending on what the input to this system is.

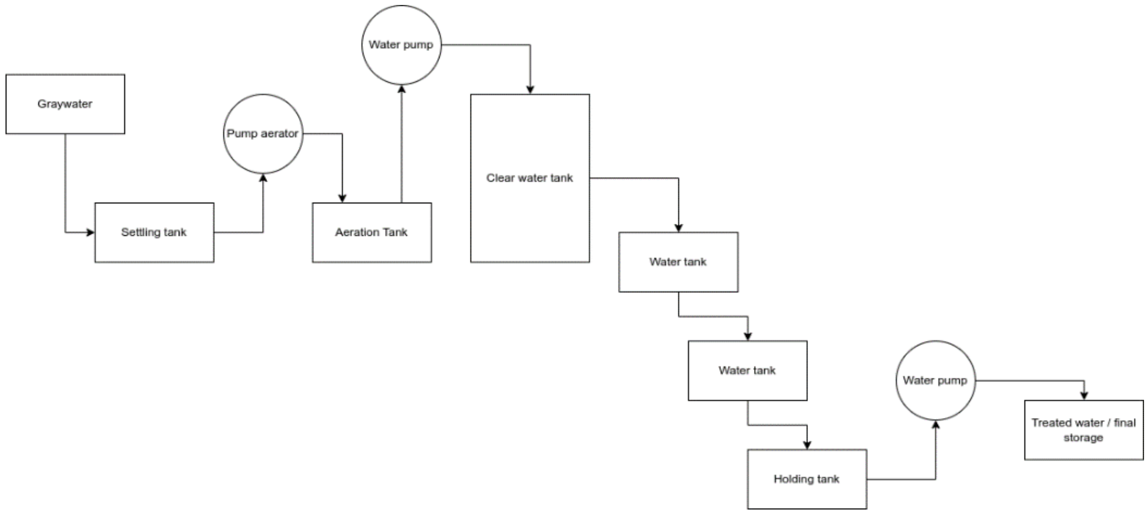

Figure 3: Process flow for generating class B water.

RESULTS AND DISCUSSION

The system developed was a water filtration system connected to an IoT-platform designed and built with open-source technologies such as MQTT, Apache Kafka, NodeJS, Linux, MongoDB, and WebSockets, just to name a few. The platform conforms to an event-driven architecture, allowing pieces of software to communicate with each other when certain events take place. In this project's case, these events are the sinking and sourcing of data, aggregated through topics in both MQTT and Apache Kafka. The water filtration system designed on the other hand, could produce Class B and Class AA water with the latter confirmed by an external third-party, Department of Health-certified laboratory. To ensure that the sensors work as intended, calibration steps were made and comparisons toward the specifications for Class B and Class AA were made. A summary of the sensor data and its comparison toward the given standards are provided in Table 1.

Table 1: Sensor data in comparison with standards.

Parameter	Unit	Class B Water Specification	Sensor reading	Class AA Water Specification	Sensor reading
pH (range)		6.5-8.5	6.27756	6.5-8.5	6.1719
Temperature	°C	26-30	26.46	26-30	27.954
Total dissolved solids	mg/L	-	95.59575	50-300/600	168.656
Turbidity	NTU	0-10	0	0-10	0

CONCLUSIONS AND RECOMMENDATIONS

In this study, an IoT system that can give the means to provide data generated by a water management system was presented. The said water management system was also capable of recycling greywater into Class B water, while, during emergencies, can provide potable Class AA water.

By maximizing event-driven, data-streaming software along with containerization, the deployment, configuration, and streaming of data was fast, reliable, and cloud agnostic. MQTT with Apache Kafka subscribed to the topics allowed for communication over the internet and MongoDB's ChangeStream feature allowed for real-time data to be streamed to interfaces like a WebSocket Servers, and from the server, toward WebSocket clients such as the custom written front-end.

The proponents believe that the IoT system and its underlying architecture can be expanded to other areas of the Philippines that may benefit from constant data generation. This enables BigData consumers to do what they please with the data.

Though the system, both hardware and software, are functional, the currently implemented system has some certain pitfalls.

A. Timing-based state machine instead of event-driven state machine

i. The timings generated during the different runs of the system do not have enough flexibility. Utilizing the flow sensors present, it would be possible to expand on the current state machine and utilize the sensor data instead of timing data to allow for flexibility in the system.

B. Expanding the definition of floodwater

i. The floodwater utilized in the prototype assumed amounts of soil but not other possible contaminants in the water such as biomaterial.

C. Expanding utilized sensors and actuators.

i. The prototype utilizes off-the-shelf sensors and actuators bought based on convenience and budget. The system can become more robust if industrial-grade sensors and actuators were utilized. An ideal solenoid valve that should be used is a direct acting solenoid valve for a gravity-based system.

D. Emphasis on IoT security

i. The only form of security present in the current prototype is the VPN utilized which requires an administrator. However, if the system were to be published over the public internet, the attack vector for the system poses a problem. Thus, it is recommended to further expand the security of the IoT system.

E. Holding containers of the system / Maintenance

i. As some of the tanks are cut open, it is better to have it closed in future developments. The purpose of it being open is for it to be easier to put additional materials inside, but it should also be closed for better maintenance, and to prevent issues that would affect the water.

ii. There is loss of water from each stage going to the next, as the containers should be tilted to get all the water out from one tank to another.

iii. In cleaning these tanks or containers, it would be a recommendation to pressure wash the insides and have water continuously flow. That should be considered especially if the containers then are not easy to disassemble and so on.

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