IoT Architectural Design for Household Water Quality Control

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***Abstract*—Access to clean and safe water is essential for daily needs and the overall well-being of society. However, the water quality in Indonesia falls below health standards, leading to various health and environmental issues. To address this challenge, this research proposes the implementation of simple water filters in households combined with the utilization of Internet of Things (IoT) technology for real-time water quality monitoring. The system involves filtering the water supplied by the Public Water Supply (PDAM) using activated carbon, zeolite, and silica sand as filtration components. The filtered water is then stored in household water storage tanks. Within the tank, a turbidity sensor measures water cloudiness, while a pH sensor detects the pH level. These sensors are connected to a microcontroller, which communicates with a cloud database through a Wi-Fi module. A mobile application provides users with real-time monitoring of water quality, displaying turbidity and pH values on a dashboard. Device effectivities are measured by controlled experiments. This IoT-based household water quality control system aims to improve water quality, enhance monitoring capabilities, and promote healthier water consumption practices.**

Keywords*—*water filtration, Internet of Things (IoT), real-time monitoring, pH sensor, turbidity sensor

I. Introduction

Water is a vital necessity for society and is used for daily primary needs such as drinking, cooking, washing, and bathing. Unfortunately, the water quality in Indonesia is still below health standards. This is evidenced by the World Economic Forum (WEF) Travel and Tourism Competitiveness Report 2019, which ranked Indonesia 102nd out of 130 countries in the health and hygiene category [1]. Data from the World Wide Fund for Nature (WWF) Indonesia in 2019 showed that 82 percent of the 550 rivers scattered throughout Indonesia were polluted and in critical condition [2]. A study shows that around 14,000 tested drinking water sources in Indonesia exhibited traces of fecal waste contamination, which consequently led to the proliferation of ailments like diarrhea [3]. Based on data collected by Katadata, 9.8 percent of infant deaths out of 20,266 individuals in the post-neonatal age group were caused by diarrhea [4]. Water issues are a significant problem considering their impact on health. Water that is tasteless, odorless, colorless, free from harmful microorganisms, and devoid of heavy metals is considered healthy and safe for direct consumption [5].

The water produced from the source of the Regional Water Supply Company (PDAM) serves as the primary source of water supply for households. PDAM has a main pipeline network connected to various regions or areas. These pipelines function to convey water from the PDAM source to residential areas. Subsequently, the water is distributed through a network system involving branch pipes, water pumps, and flow control valves. This system ensures that water is delivered with sufficient and consistent pressure to households in different locations. In each household, there is a water meter that measures the volume of water consumed. These meters assist PDAM in calculating water consumption and billing customers accordingly. The water supplied by PDAM is then stored in a water storage tank. The function of the tank is to store reserved water that can be used when the water supply from PDAM is interrupted or disrupted. However, the supplied water is not always clean, and sometimes users need to filter or precipitate the water in a container before using it for daily needs. Thus, exploration of technological interventions is needed to improve water quality and distribution.

To address this issue simple water filters can be implemented in households. Based on the previous research, solution for water quality problems only focuses on making filters, without providing media for users to carry out the easy access for monitoring. Thus, utilizing the Internet of Things (IoT) and mobile application can help provide real-time water quality monitoring at home. Water filters are able to help communities obtain clean water by filtering the water supplied from the public water company (PDAM) into the household water storage tank. Some components that can be used in the water purification process are activated carbon, zeolite, and silica sand. Then, these three components will be arranged in a container to filter the water from PDAM before it enters the household water storage tank. After the water is filtered, the water quality control device will measure the pH and turbidity of the water. This device is connected to the internet allowing user to monitor the water condition in real-time from mobile application. User will be able to check on the water condition in a graph and generate a monthly report regarding the household water quality. The goal of this research is to create an architecture design for an IoT based household water quality control system with the aim of providing better water quality for households and easy monitoring of the water quality. This research will have an impact on the quality of life of Indonesian society. With monitoring controls on household water quality, it is hoped that the society can have a better water quality, leading to healthier life.

II. Theoretical Foundation

A. Previous Study

A research study on the implementation of IoT for monitoring water quality and administrative system in small-scale clean water management was conducted in Pangkalan Lada Village, Central Kalimantan. In the village many residents still rely on rainwater collection wells with inconsistent water quality. Thus, research involving the implementation of IoT, where sensors connected to the internet to monitor water quality was done to monitor water quality and implement an administrative system for small-scale clean water management. An administrative system was also developed to manage data and information related to clean water management. This research can provide a better understanding of water quality in Pangkalan Lada Village and help to improve small-scale clean water management [6].

A research study on the design of a household water purification device was conducted in Sumbersari Sub-district, Lowokwaru District, Malang City. The goal is to design a simple and easy to use household water purification device. Variations in the thickness and components of the filtering media were explored to determine the best alternative. Furthermore, tests were executed to assess the filtering media's ability to reduce iron, manganese, and other parameters. Then the best alternative from various arrangements are selected from the filtering media. Activated carbon, sand silica, and zeolite has the best result so these components are evaluated to check the ability to reduce the content of iron (Fe) and manganese (Mn), as well as other parameters such as pH, turbidity, Dissolved Oxygen (DO), color, and odor [7].

A research study on the clean water filter planning for household scale was conducted in South Kradenan. The aim of improving the quality of water used by the community, obtained from boreholes at depths of 70 meters (SB-1) and 120 meters (SB-2). However, the water from SB-2 has a yellow color, unpleasant odor, and high iron content. Initially, water samples were taken from SB-2 and analyzed in the laboratory. The analysis results showed an iron content of 65.6 mg/L and a pH of 6.17, rendering the water unfit for consumption. To improve the water quality, efforts were made using the filtration method with sand, activated carbon, and zeolite filters, with variations in filter thickness. Subsequently, a filter trial was conducted at the SB-2 water storage location using a 6-inch diameter PVC pipe with a height of 110 cm, the filtered water was tested in the laboratory. The laboratory test results showed that the iron content before filtration decreased after the filtration process while the pH value increased. Thus, the filtration process improved the pH of the water and reduced the iron content. However, further follow-up actions are necessary to improve the filtration results to meet the standards of water quality suitable for consumption [8].

B. Distribution of Water From PDAM to Household

PDAM has an extensive water distribution network that is used to distribute water to household, government institutions, and public places. PDAM's distribution network is very important to ensure an adequate supply of clean water for daily needs. Raw water from PDAM that comes from water sources cannot immediately be used for clean water needs in buildings. The water must first meet the requirements for quality, quantity and continuity. To maintain the quality of the raw water, usually the water will through a treatment process [9]. This treatment process can generally be done in 3 ways: physics, chemistry and biology. Physical processing is usually done by utilizing the mechanical properties of water without the addition of chemicals. Examples of its application are settling, adsorption, filtration, etc. Chemical processing is carried out by adding chemicals such as alum, chlorine, etc which are usually used to remove heavy metals contained in water. Meanwhile, biological treatment uses certain microorganisms that can help purify water [10].

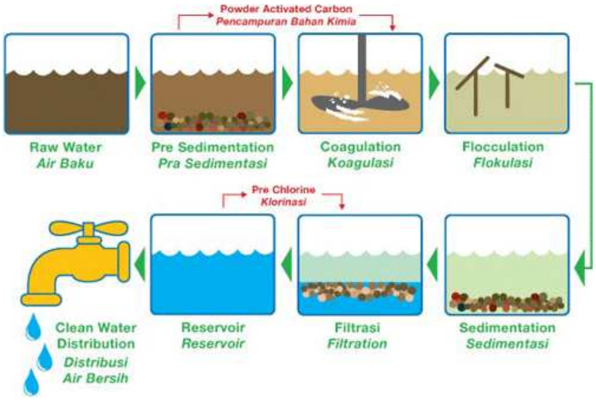

Fig. 1. The Process of Water Distribution

1. PDAMs in Indonesia generally use Instalasi Pengolahan Air (IPA) physically and chemically. Basically, the process is divided into 3 parts, such as: Intake Building: used as the first place of entry water from the water source.
2. Water Treatment Plant: processing at STP that makes water fit to use. There are several steps taken, such as: Coagulation, Flocculation, Sedimentation, Filtration, and Disinfection.
3. After the water has been processed, the water will be put into a temporary shelter in the reservoir before being distributed to houses and buildings. To drain the water, HDPE pipes and PVC pipes are usually used.

C. Water Filtration

Water filtration is a method for eliminating undesired chemicals, organic and inorganic components, and biological contaminants from water. Analyzing water quality based just on appearance is practically impossible. There are numerous procedures that have been developed to determine the levels of contamination, such as physical, chemical, or biological examinations. In order to assess the quality and level of contamination in the water, it is frequently necessary to examine levels of both organic and inorganic substances [11]. Water filtration is employed to generate potable water that is devoid of impurities. Through the process of filtration, the presence of contaminants is diminished. There are several layers in the raw water filtering system and process, such as:

1. Sand to gravel or Coarse silica: Silica sand is an excellent filtration medium due to its high purity [12]. Because it contains little clay, silt, and organic matter, water going through the filter won't be tainted by contaminants in the sand. This high level of purity helps to produce water that is clean and safe to drink.
2. Zeolite: Zeolites are useful at many stages of the filtering process, including as a secondary filtration unit after biological purification and/or aeration, as a substrate for bacteria, and as a filter medium for the simultaneous removal of undesirable ions and solid and suspended particles [13].

3. Activated Carbon: A filter that contains granular activated carbon (GAC) has been shown to be effective in removing some pollutants from water, especially organic compounds [14]. Aside from removing chlorine and hydrogen sulfide, which give water an unpleasant taste or smell (like rotten eggs), GAC filters can also be used to remove other pollutants.

D. Internet of Things

The Internet of Things (IoT) constitutes a network of tangible objects, referred to as "things," which possess sensors, software, and additional technological components. These elements enable these objects to establish connections and share data with other devices and systems via the internet. [15]. The concept of M2M (machine-to-machine) and IoT are closely related to one another. As a result of their communication capabilities, the M2M tools are referred to as a smart devices.

The fundamental idea behind IoT is rather straightforward, revolving around the functionality of three primary components within the IoT framework: Physical items integrated with IoT modules, Internet-connecting devices like high-speed modems and wireless routers commonly used in households. The fundamental operational concept of IoT devices involves assigning distinct identities to real-world objects, which can then be replicated within a computer system and depicted as data within the digital realm [16]. IoT works by utilizing programming instructions in which each command can generate interaction between connected devices automatically without any user intervention, even remotely. The vital factor that becomes the smooth running of IoT devices is the internet network which is the connector between the system and the device. Meanwhile, humans in this stage only become monitors for every device behavior when they work. The several components that make up the IoT include artificial intelligence (AI), connectivity, sensors, active involvement, and the use of small devices [17].

E. Technology Readiness Level

Technology Readiness Levels (TRL) provide a structured assessment framework for gauging technology maturity. With nine levels in total, TRL ratings are assigned based on a technology project's progress, starting from TRL 1 where scientific research begins. TRL 2 signifies the exploration of basic principles and potential applications, although experimental proof remains limited. Progressing to TRL 3, active research and design take place, involving analytical and laboratory studies to assess viability. TRL 4 involves integrating components and initial testing, leading to TRL 5 where rigorous breadboard testing occurs, often through simulations in realistic environments. Upon successful testing, TRL 6 is achieved, characterized by a fully functional prototype. Demonstrating the prototype in a space environment marks TRL 7, while TRL 8 indicates "flight qualification" for integration into existing systems. Finally, a technology attains TRL 9 status when it is "flight proven" through successful mission implementation [18].

III. Research Method

The research method covers several aspects, including system and hardware design, the framework for IoT architecture, and evaluation method.

1) System Design:

System design encompasses the formulation of the IoT framework for monitoring water quality. This entails structuring data, devising system architecture, and shaping interface elements. This phase entails employing the Unified Modeling Language (UML) to craft diverse model diagrams. In the realm of system planning, UML design components like use case diagrams and activity diagrams are employed. Moreover, interface design is executed to conceive interfaces for both input and output.

2) Hardware Design:

The hardware design component focuses on designing simple water filtration, specifying the arrangement of the components for filtration process, and sensors. This stage aims to provide a comprehensive understanding of how the hardware components of the IoT system fit together.

3) IoT Architecture Design Framework:

The IoT architecture design framework concentrates the infrastructure of a three-layer architecture, which consists of the sensing layer, transport layer, and network layer. This framework outlines the structure and functionalities of each layer within the IoT system, emphasizing how data is collected from sensors (sensing layer), transmitted and processed (transport layer), and communicated across the network (network layer).

4) Evaluation

After the IoT device and mobile applications have been made, the next step is to evaluate them. Evaluation of the effectiveness of the tool can be done by conducting controlled experiments. Experiments will be carried out to test the sensor and filter capabilities. Water that does not go through the IoT device will be measured for its pH level and turbidity level using a turbidimeter and a pH meter. Then, the water that passes through the IoT device will also be measured for its pH level and turbidity using a turbidimeter and a pH meter. The results will be compared with the measurement results with the pH sensor and turbidity sensor to test their effectiveness. The results of filtered water will also be compared with water that has not been filtered to measure the clarity of the water produced.

IV. Finding and Discussion

A. Proposed System

The water supplied by the Public Water Supply (PDAM) is directed to a simple water filter for initial filtration, producing clean water. Then, the clean water is stored in a water storage tank at home. Within the tank, a turbidity sensor measures the level of water cloudiness, while a pH sensor detects the pH level of the water. A microcontroller connects these sensors to a cloud database for data storage, utilizing a Wi-Fi module for communication. The sensor readings are sent to the database, and a mobile app displays the values of turbidity and pH on a dashboard page. The data is collected periodically every 20 minutes. Regarding the pH indicator, if the water pH is below 6.5, the application sends a notification indicating acidic water. The pH status on the dashboard turns orange. If the water pH is above 8.5, the app sends a notification indicating alkaline water. The pH status on the dashboard turns dark green. However, if the water pH falls within the range of 6.5 to 8.5, there won't be any notification, and the pH status on the dashboard remains blue. For the turbidity indicator, if the value is above 25, the app sends a notification indicating cloudy water. The turbidity status changes to brown. If the value is below 25, the status remains blue. Then, the collected data is presented in the form of a graph displaying the date, pH value and turbidity value. The accumulated data can also be accessed as monthly report in the form of graphs and detailed information to help user monitor the water quality.

a) Flowchart

The following figure is a flowchart depicting the workflow of the system and device.

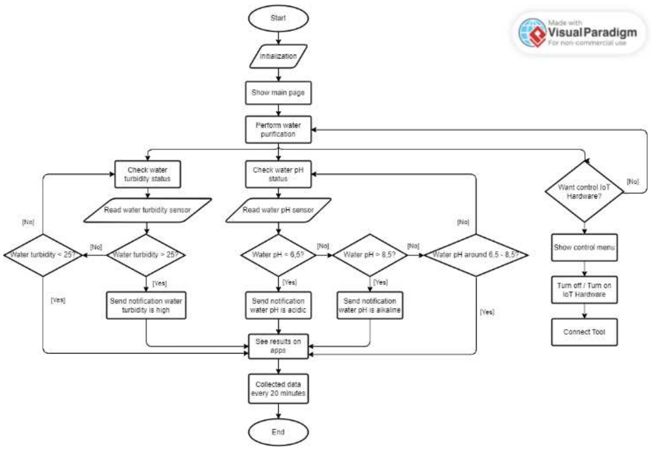

Fig. 2. Flowchart

b) Use Case Diagram

The examination of functional requisites outlined within the use case diagram and the system's operations is delineated in figure 3. Figure 3 features participants engaged within the forthcoming application, specifically users. The utilization scenarios or actions achievable by users encompass linking with IoT hardware, activating and deactivating IoT hardware, executing water purification, and verifying the pH and turbidity water status.

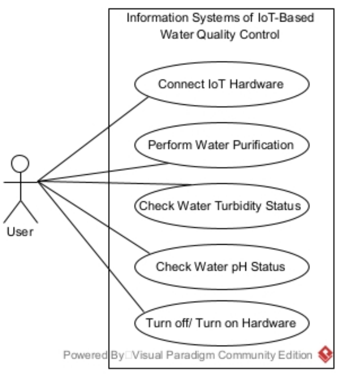

Fig. 3. Use Case Diagram

c) Database Model

In this example, the Household table stores information about each household, and the WaterQualityMeasurement table stores the collected data including date, time, pH value, turbidity value, and water volume. The HouseholdID in the WaterQualityMeasurement table serves as a foreign key linking the measurements to the respective household. Please note that this is a simplified model and may need to be extended based on the requirements, such as additional attributes or relationships. Additionally, the data types and precision of numeric values (pHValue, TurbidityValue, WaterVolume).

```
CREATE TABLE Household (
    HouseholdID INT PRIMARY KEY,
    Address VARCHAR(255),
    OwnerName VARCHAR(255),
    -- Other attributes
);

CREATE TABLE WaterQualityMeasurement (
    MeasurementID INT PRIMARY KEY,
    HouseholdID INT,
    Date DATE,
    Time TIME,
    pHValue DECIMAL(5, 2),
    TurbidityValue DECIMAL(8, 2),
    WaterVolume DECIMAL(10, 2),
    -- Other attributes
    FOREIGN KEY (HouseholdID) REFERENCES Household(HouseholdID)
);
```

Fig. 4. Database Model

d) User Interface Design

The user interface designs are created as a mobile app, enabling users to oversee water conditions. Within the app's dashboard, users can view the water's turbidity and pH status.

Fig. 5. Splash Screen

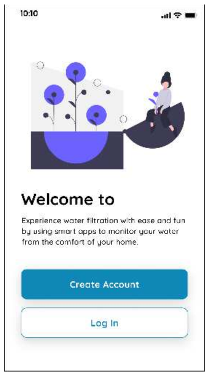

Fig. 6. Welcome Page

Fig. 7. Sign Up Page

Fig. 8. Login Page

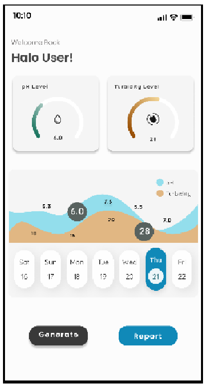

Fig. 9. Dashboard Monitoring

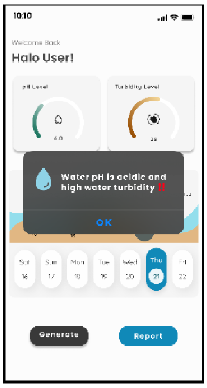

Fig. 10. Water Quality Notification

e) Hardware Design

The hardware design involves integrating the microcontroller with the Wi-Fi module, turbidity sensor and pH sensor. The turbidity sensor and pH sensor are placed in the water tank, monitoring the water quality every 20 minutes. The turbidity sensor is responsible for measuring the level of turbidity or suspended particles in the water, while pH sensor is used for measuring the acidity or alkalinity of water. This can provide real-time data on the clarity and pH status of the water, which can be indicators of water quality. The microcontroller will act as the central processing unit, controlling and coordinating the function of the various components. This setup allows the system to collect data on turbidity levels and pH values wirelessly to a central server or monitoring system by communicating with the Wi-Fi module to enable wireless connectivity, allowing data to be send and receive over the network.

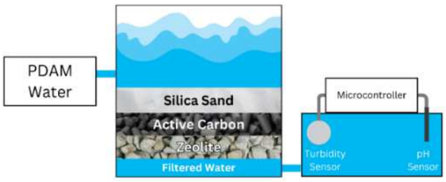

Fig. 11. Hardware Design of IoT Based Household Water Quality Control

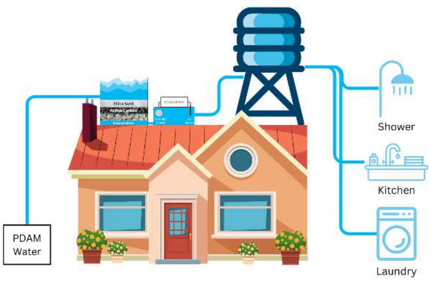

Fig. 12. Architecture Design of IoT Based Household Water Quality Control

f) IoT Architecture Design Framework

The foundational operation of the Internet of Things (IoT) is rooted in three core strata termed the Perception Layer, Network Layer, and Application Layer. The elemental structure of the fundamental three-tier IoT arrangement, illustrated in Figure 12, envelops devices and technological components within each stratum. In IoT parlance, the Perception Layer is alternatively known as the "Sensor" layer. Its principal role involves the acquisition of data from the surroundings through sensors and actuators. Within this stratum, information is detected, collected, processed, and subsequently channeled to the Network Layer. Furthermore, it fosters collaboration among IoT nodes situated within localized and short-range networks. The Network Layer within IoT assumes the responsibility of directing and dispatching data to various hubs and IoT devices via the Internet. In this tier, state-of-the-art technologies such as WiFi, LTE, Bluetooth, etc., are in operation, alongside platforms of cloud computing, internet gateways, switching and routing apparatus, and more. Notably, the network gateway functions as an intermediary mediator, amalgamating, refining, and transmitting data between diverse IoT nodes and their corresponding sensors. The Application Layer, situated at the pinnacle of the IoT framework, ensures the credibility, soundness, and confidentiality of data. Within this layer, the central aspiration of IoT or the creation of an intelligent environment finds its realization.

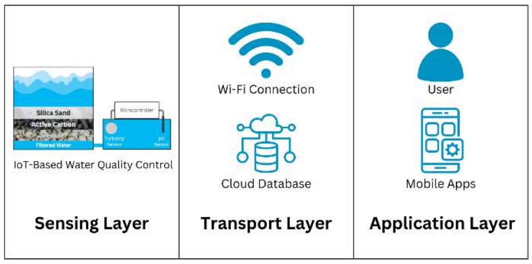

Fig. 13. Architecture design of IoT Based Household Water Quality Control

As shown in Figure 11 the system has two sensors that are used to collect data. The data collected by the system is sent via the internet to cloud and can be accessed by user through mobile apps. Once the connection is established the system can operate automatically. During operation, this system does not require manual input. In addition, this system allows monitoring to be carried out from anytime and anywhere. Whenever clean water is produced through a filtration process, sensors connected to the system will monitor the pH value and turbidity of the water. Thus, data records can be stored quickly and accurately in the database. This allows stakeholders connected to devices and databases in real-time to determine water filtration optimization policies.

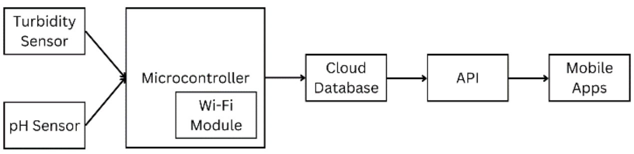

Fig. 14. Block diagram of IoT Based Household Water Quality Control

g) Technology Readiness Level

In TRL 1, the research focuses on the conceptualization and theoretical framework of the IoT architectural design. Key components and functions required are identified for effective monitoring of water quality within households. The literature review guides the selection of suitable sensors, communication protocols and data acquisition techniques..

The development to TRL 2 marks a significant advance in our IoT architecture design. During this stage, we turn theoretical concepts into functional prototype systems. Hardware components, including a pH sensor, turbidity sensor and communication module, were selected to create a true representation of our proposed solution. The achievement of TRL 2 provides a solid foundation for our IoT architecture design for household water quality control. As we progress to higher stages of TRL, we will build on the achievements of TRL 1 and TRL 2. Subsequent phases will include prototyping, system refinement, data analysis algorithms, integration with cloud-based platforms, and comprehensive real-world testing.

V. Conclusion

The application of a simple water filter at home, coupled with Internet of Things (IoT), can improve water quality and enable real-time monitoring at home. By filtering the water supplied by the Regional Drinking Water Company (PDAM) using components such as activated carbon, zeolite, and silica sand, clean water can be obtained and stored in household water storage tanks. Turbidity and pH sensors, measure and record water clarity and pH levels when connected via a mobile app connected to the system, users can monitor water conditions in real-time, view graphical representations of pH and turbidity data, and generate monthly reports on home water quality ladder. This proves that technological interventions to improve water quality are necessary and can help improve the quality of life for Indonesian people. By combining filtration, sensor technology and IoT connectivity, the system contributes to addressing water quality issues and promoting healthier water consumption practices. While this system aims to improve water quality, further research is needed to assess its real impact in reducing waterborne diseases and improving overall public health. Experiments need to be carried out to test the TRL further, also the results need to be tested with controlled experiments.

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