Design and Development of Smart Water Record and Billing for Boarding House Rooms

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***Abstract* — A boarding house (kost) is a residential building in the form of a house or rooms that can be used by more than one person. The water needs of each boarder are not the same. Sometimes, the management faces difficulties in billing due to discrepancies in water bills or because the water bills are averaged out. Additionally, the management finds it challenging to handle billing because the time each person spends in the boarding house varies. Based on these issues, an innovation has been developed by designing a device module that can measure the amount of water used by each boarder with a direct payment system through an application. This study aims to design and develop a water usage monitoring device and a transparent and efficient water bill payment system for boarding rooms. The methods used include hardware design using *Wemos* D1R1 and a water flow sensor, as well as the development of an application for monitoring and paying water bills. Water usage data from the sensor is sent to a microcontroller and then forwarded to *Firebase* for further storage and management. The payment system is designed so that boarders can pay their bills through the application using e-wallets or cash. Device testing shows a high level of accuracy with an error rate of 2.5 percent in room 1 and 3.135 percent in room 2, with average accuracy rates of 98.5 percent and 96.86 percent, respectively.**

Keywords*— *Smart Water Billing, Water Flow Sensor, IoT-based Water Monitoring, Digital Payment System, Wemos D1R1.

I. INTRODUCTION

Water is a basic need for all humans and plays an important role in daily life. In Indonesia, household water usage is generally measured using a water meter installed by the Regional Drinking Water Company (PDAM). This measuring instrument functions to record the volume of water used by each household and is the basis for calculating water bills. However, the application of one measuring instrument to buildings with many residents, such as boarding houses, raises its own problems. Each boarding house resident has different water needs, and the same water billing often causes complaints. This is especially felt by boarding house residents on Jl. Syaidani No.28C, RT.03/RW.02, Tambaksumur, Kec. Waru, Sidoarjo Regency, East Java 61256, where inaccuracies in water bills often become a source of conflict between residents and boarding house management. In addition, boarding house management also faces difficulties in collecting water payments because the time each resident is in the boarding house varies.

Various studies have been conducted to overcome this problem. Developed a water usage monitoring system based on an Android application, but did not include a bill payment feature [1]. Used Wemos and MIT App Inventor for an Android application that displays water usage and tariff data, but a direct payment system has not been integrated [2]. Used Arduino and Telegram for monitoring and notification of water usage, but was considered less practical compared to using the Wemos D1R1 Mini which is equipped with a Wi-Fi module [3]. Adopted Firebase as a database for water meter control and monitoring, but did not provide a visual dashboard [4]. Successfully recorded water usage data well, but there was no integration for payment via the application [5].

To realize this research, it is necessary to understand several things such as tools or materials, namely a microcontroller which is a small computer on a single chip consisting of a CPU, memory, and I/O peripherals, designed to perform certain tasks with an instruction cycle where the CPU fetches, decodes, and executes instructions from memory [6]. The Wemos D1 R1 microcontroller board, which is compatible with Arduino and supported by integrated Wi-Fi, allows programming via serial port or OTA, offering low cost and ease of use [7]. Lithium Polymer (Li-Po) batteries use dry polymer electrolytes and customizable cell configurations to meet voltage and capacity needs in portable devices [8]. A breadboard is a prototyping tool that allows the assembly of electronic circuits without soldering and easy component reconfiguration [9]. A black box is a black plastic container that protects the device from dust, water, and physical impact and offers resistance to harsh environmental conditions [10]. The Micro-USB cable used on the Wemos D1 R1 for Arduino IDE programming is an industry standard that is economical and easily accessible [11]. Housing Charger converts AC voltage to DC voltage, consisting of rectifier, filter, converter, control circuit, and feedback circuit [12]. Switch is a component that disconnects or connects the flow of electricity, allowing the operation of electronic and electrical equipment by opening or closing the electrical circuit [13]. Flow Meter Sensor measures water discharge in pipes, consisting of plastic valves, Hall effect

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sensors, and water rotors that rotate according to the water flow rate [14]. DC Converter Step Down reduces DC voltage from a higher value to a lower value, allowing flexibility in electronic applications [15]. Arduino IDE is software for creating programs on microcontrollers such as Arduino and ESP8266-based boards such as Wemos D1 R1, with text editor features, code validation, upload to board, serial terminal, multiplatform support, and C/C++ libraries [16]. Android Studio is an IDE used to create Android applications, offering various tools for writing, testing, and publishing applications, including a program editor, emulator, and View components [17]. Firebase is a Backend as a Service (BaaS) that offers features such as Firebase Authentication, Realtime Database, Cloud Messaging, and Firestore Database for data management and authentication [18]-[19]. The water cost determination feature is designed to calculate the cost of water usage based on the 3A tariff group from PDAM Tirta Khatulistiwa, with a conversion system from liters to cubic meters to determine the appropriate cost [20].

II. METHOD

A. *Research Stages*

The research stages for creating the Smart Water Record and Billing Module consist of several stages as shown in Fig.1.

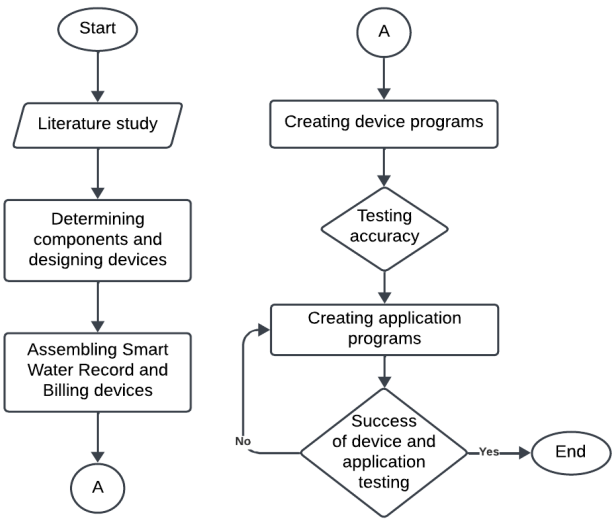


Figure 1 Device operation flowchart

The initial process of Flowchart in Fig.1 begins with a literature study to understand the theories related to the design, components, and systems of the device to be developed. This study involves searching for references from theses, journals, and textbooks on monitoring water usage using the Wemos D1R1 microcontroller and flow sensor. Based on the literature, the system design includes determining the components, making wiring, and programming the microcontroller and application. Programming involves reading the flow sensor, processing water usage data, and sending data to the application. The application is designed with a login page, main page, monitoring, and payment. Device testing is carried out by ensuring the accuracy of the flow sensor by comparing the measurement results with the real water volume to ensure system reliability.

B. *System Block Diagram*

The following is a system block diagram which can be seen in Fig.2.

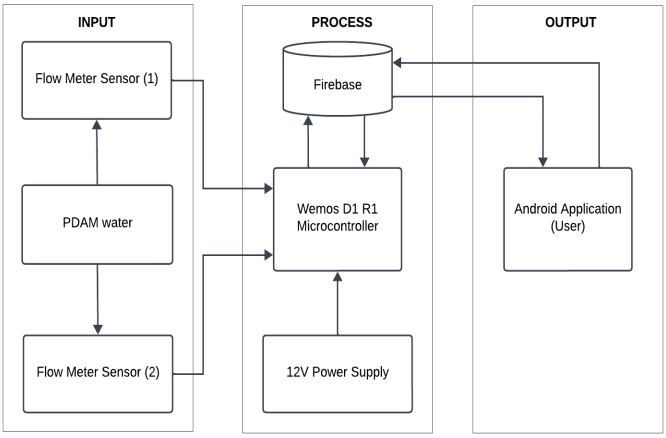


Figure 2 System block diagram

Fig.2 illustrates a system block diagram where the system reads the number of liters of water passing through the flow sensor by installing the flow sensor on the water tap. The reading results are then processed and stored by the microcontroller on the device, namely Wemos D1R1 in liters, then the water usage data will be sent to the application. The device will work when it gets a connection from Wi-Fi where the device will be integrated with the application that has been created and can be accessed via devices such as smartphones. In the application, data is collected first, when all the data has been collected, the data will be converted into a nominal cost of water usage which will then be sent to the user. In the application, there is a user dashboard that displays the total use of liters of water each month along with the nominal bill that must be paid. Users can make payments through the transfer application via midtrans and cash payments and later there will be a history in the Admin and user applications.

C. *System Flowchart*

The flowchart of the system that will be used in the research is shown in Fig.3. Flowchart Fig.3 illustrates the process of integrating the Wemos D1R1 microcontroller with the Firebase database to process data from the flow sensor. The process begins with the initialization of the system and sensor, followed by the reading of water liter data by the sensor and data processing by the microcontroller. The microcontroller then checks for a Wi-Fi connection to send data to Firebase. If not connected, the microcontroller will try to find a network and ensure a connection. Once connected, the data is sent to Firebase and stored in real-time, allowing direct access by connected applications.

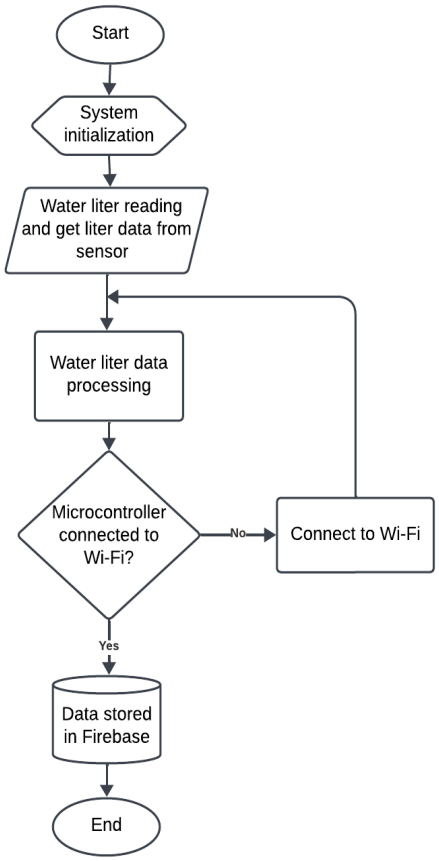


Figure 3 System flowchart

D. Application Design for Admins and Users

The following are the details of the application design carried out

TABLE I
APPLICATION DESIGN

Application Design	
	
(a)	(b)
	
(c)	(d)
	
(e)	(f)
	
(g)	(h)

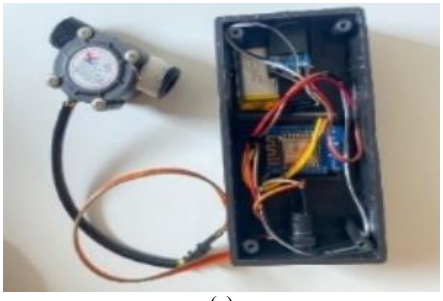
(i)

Table I (a) shows the Splash Screen, the initial screen of the application that displays the logo or name of the application, giving time to load initial data before the user enters the main display. Table I (b) shows the Login Menu, allowing Admin and users to enter their username and password to access the application, with the option to reset the password if necessary. Table I (c) (d) shows the Admin Home Page Menu, which shows rooms with their water usage and associated total costs, as well as detailed information about water usage history, payment status, and transaction requests. Table I (e) (f) shows the Request Page and Transaction History Menu, which displays transaction requests that have been approved or rejected as well as transaction history, making it easier for Admin to track transaction status and history. Table I (g) shows the User Data Monitoring Menu, which allows users to monitor bathroom water usage and receive notifications if usage exceeds 50 liters. Table I (h) shows the User Monitoring Menu, which shows bathroom water usage history with details of the number of liters, total costs, and dates of use, helping users monitor water consumption. Table I (i) shows the User Billing Menu, which displays billing information, daily, weekly, and monthly graphs of water usage, as well as payment options via E-Wallet or cash and payment history.

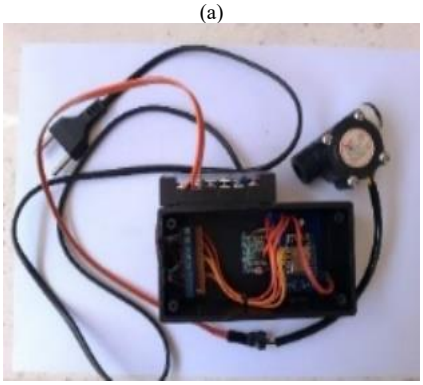
III. RESULTS AND DISCUSSION

A. Implementation Hardware

The following is the implementation of the device in the device design which can be seen in the Fig.9.



(a)



(b)

Figure 4 (a) Room series 1, (b) room series 2

Fig.4 shows two original device circuits used in room 1. In Fig.4 (a), the circuit for room 1 is shown, consisting of a flow sensor module and a Wemos D1R1 placed in a protective box. While in Fig.4 (b), the circuit for room 2 is shown, using two flow sensor modules connected to a Wemos D1R1, also placed in a protective box for device safety and order.

B. Tool Test Results

Tool testing is done to ensure that the flow sensor used in this system works with high accuracy and to ensure that the data sent to Firebase matches the flow sensor data. Here are the results of the tool testing:

TABLE II
ROOM 1 SENSOR READING TEST

Minute to-	Sensor Reading (liter)	Manual Measurement (liter)	Measurement Difference (liter)	Error Rate (%)
0	0	0	0	0
2	1.02	1	0.02	2
4	2.05	2	0.05	2.5
6	3.08	3	0.08	2.67
8	4.1	4	0.1	2.5
10	5.12	5	0.12	2.4
12	6.15	6	0.15	2.5
14	7.18	7	0.18	2.57
16	8.2	8	0.2	2.5
18	9.22	9	0.22	2.44
20	10.25	10	0.25	2.5
22	11.28	11	0.28	2.55
24	12.3	12	0.3	2.5
26	13.32	13	0.32	2.46
28	14.35	14	0.35	2.5
30	15.38	15	0.38	2.53
Amount	123.74	120	3	37.12
Average	8.25	8	0.2	2.5

The test data in Table II shows that the flow sensor in room 1 has high accuracy in reading water volume. Sensor readings vary between 1.02 liters to 15.38 liters, while manual measurements range from 1 liter to 15 liters. The difference between readings and manual measurements has an average of 0.21, with an average error rate of 2.5. These results indicate that the flow sensor works well and can be relied on to measure water usage in room 1.

TABLE III
ROOM 2 SENSOR READING TEST

Minute to-	Sensor Reading (liter)	Manual Measurement (liter)	Measurement Difference (liter)	Error Rate (%)
0	0	0	0	0
2	1.05	1	0.05	5
4	2.1	2	0.1	5
6	3.12	3	0.12	4
8	4.15	4	0.15	3.75
10	5.18	5	0.18	3.6
12	6.2	6	0.2	3.33
14	7.22	7	0.22	3.14
16	8.25	8	0.25	3.13
18	9.28	9	0.28	3.11
20	10.3	10	0.3	3
22	11.33	11	0.33	3
24	12.35	12	0.35	2.92
26	13.38	13	0.38	2.92
28	14.4	14	0.4	2.86
30	15.43	15	0.43	2.87
Amount	123.74	120	3.74	51.63
Average	8.25	8	0.265	3.135

The test data in Table III shows that the flow sensor in room 2 also has good accuracy in reading water volume. Sensor readings range from 1.05 liters to 15.43 liters, while manual measurements range from 1 liter to 15 liters. The difference between readings and manual measurements has an average of 0.265, with a higher error rate than room 1, which is an average of 3.135. However, the sensor still works well and provides acceptable results for measuring water volume in room 2.

TABLE IV
TESTING SENDING SENSOR DATA TO FIREBASE

Minute to-	Room 1 Sensor Reading (liter)	Room 2 Sensor Reading (liter)	Sent Room 1 Data	Sent Room 2 Data	Error Rate (%)
0	0	0	0	0	0
2	1.05	1.05	1.05	1.05	0
4	2.1	2.1	2.1	2.1	0
6	3.12	3.12	3.12	3.12	0
8	4.15	4.15	4.15	4.15	0
10	5.18	5.18	5.18	5.18	0
12	6.2	6.2	6.2	6.2	0
14	7.22	7.22	7.22	7.22	0
16	8.25	8.25	8.25	8.25	0
18	9.28	9.28	9.28	9.28	0
20	10.3	10.3	10.3	10.3	0
22	11.33	11.33	11.33	11.33	0
24	12.35	12.35	12.35	12.35	0
26	13.38	13.38	13.38	13.38	0
28	14.4	14.4	14.4	14.4	0
30	15.43	15.43	15.43	15.43	0
Average Error Rate					0

The test data in Table IV shows that sending data from the flow sensor to Firebase is very good. The sensor readings in room 1 and room 2 sent to Firebase always match the original data from the sensor, without any error rate. This shows that the data delivery system to Firebase is very reliable and can ensure the integrity of the flow sensor data sent for further analysis and monitoring, supporting its effectiveness in real-time data tracking and validation. This high level of accuracy is crucial for maintaining precise water usage records and ensuring dependable system performance. Additionally, the seamless integration between the sensor and Firebase enhances the overall robustness of the data collection process, allowing for effective monitoring and timely intervention if needed. This reliability underscores the system's capacity to handle and manage critical data with precision.

TABLE V
TESTING THE AMOUNT OF WATER COST ROOM 1

Minute to-	Sensor Reading (liter)	Price of Sensor (Rp)	Manual Measurement (liter)	Manual Price (Rp)	Price Difference (Rp)
0	0	0	0	0	0
2	1.02	5.304	1	5.2	0.104
4	2.05	10.66	2	10.4	0.26
6	3.08	16.016	3	15.6	0.416
8	4.1	21.32	4	20.8	0.52
10	5.12	26.624	5	26	0.624
12	6.15	31.98	6	31.2	0.78
14	7.18	37.336	7	36.4	0.936
16	8.2	42.64	8	41.6	1.04
18	9.22	47.944	9	46.8	1.144
20	10.25	53.3	10	52	1.3
22	11.28	58.656	11	57.2	1.456
24	12.3	63.96	12	62.4	1.56
26	13.32	69.264	13	67.6	1.664
28	14.35	74.62	14	72.8	1.82
30	15.38	79.976	15	78	1.976
Amount	123.74	639.6	120	624	15.6
Average	7.69	39.988	7.5	39	0.988

Based on the test data presented in Table V, the performance of the smart water monitoring system in Room 1 demonstrates a high degree of accuracy and reliability. Over the 30-minute test period, the system recorded a total consumption of 123.74 liters, compared to 120 liters measured manually, resulting in a total cost difference of Rp 15.6 (Rp 639.6 vs. Rp 624). This represents a very close alignment between the automated and manual calculations.

A closer examination reveals a consistent pattern in the measurements. The difference between the sensor reading and the manual volume shows a progressive increase over time, starting from a minor discrepancy of 0.02 liters at the 2-minute mark and growing to 0.38 liters by the end of the test. This pattern suggests a systematic, accumulative error, potentially due to the sensor's calibration or its initial sensitivity threshold. Despite this progression, the relative error remains within an acceptable range, fluctuating between approximately 1.96% and 2.53% per interval. The average cost difference per 2-minute interval is a negligible Rp 0.988, indicating minimal financial impact.

The analysis of the cost calculation confirms the applied water rate is Rp 5.2 per liter. The financial discrepancy scales linearly with the volume error. When projected to a realistic monthly usage scenario—for instance, one hour of cumulative water flow per day—the potential billing variance per room amounts to a financially insignificant sum of roughly Rp 30 per month. This margin of error is vastly superior to the inaccuracies and inherent unfairness of a flat-rate billing system, which was the core problem this system aims to solve.

The testing validates the system's core functionality. It successfully captures real-time usage data and computes corresponding costs with a high degree of fidelity to physical measurements. The observed error is consistent and predictable, which is a favorable outcome as it can be corrected through a one-time software calibration factor. Therefore, the prototype proves to be a technically sound and economically viable solution for transparent and precise water billing in boarding houses, effectively addressing the challenges of manual estimation and averaged payments.

TABLE VI
TESTING THE AMOUNT OF WATER COSTS FOR ROOM 2

Minute to-	Sensor Reading (liter)	Price of Sensor (Rp)	Manual Measurement (liter)	Manual Price (Rp)	Price Difference (Rp)
0	0	0	0	0	0
2	1.05	5.46	1	5.2	0.26
4	2.1	10.92	2	10.4	0.52
6	3.12	16.224	3	15.6	0.624
8	4.15	21.58	4	20.8	0.78
10	5.18	26.936	5	26	0.936
12	6.2	32.24	6	31.2	1.04
14	7.22	37.544	7	36.4	1.144
16	8.25	42.9	8	41.6	1.3
18	9.28	48.256	9	46.8	1.456
20	10.3	53.56	10	52	1.56
22	11.33	58.916	11	57.2	1.716
24	12.35	64.22	12	62.4	1.82
26	13.38	69.576	13	67.6	1.976
28	14.4	74.88	14	72.8	2.08
30	15.43	80.236	15	78	2.236
Amount	123.74	643.448	120	624	19.448
Average	7.735	40.222	7.5	39	1.222

The data from Table VI indicates that the smart water monitoring system in Room 2 performs with consistent reliability, though it exhibits a slightly higher margin of error compared to Room 1. The total recorded consumption over 30 minutes was 123.74 liters, identical to Room 1's sensor reading, against a manual measurement of 120 liters. This resulted in a total cost discrepancy of Rp 19.448 (Rp 643.448 vs. Rp 624), which is greater than the Rp 15.6 difference found in Room 1.

Analyzing the trend, the system again demonstrates a progressive, accumulative error. The per-interval volume difference starts at 0.05 liters and increases to 0.43 liters by the 30-minute mark. The corresponding financial difference rises consistently from Rp 0.26 to Rp 2.236. This pattern reinforces the hypothesis of a minor calibration offset in the sensor or its measurement circuit. It is crucial to correct the provided description: the water rate applied is Rp 5.2 per liter, as evidenced by the manual calculation (e.g., 1 liter = Rp 5.2), not Rp 2.90.

The average error per interval is Rp 1.222, and the calculated accuracy based on the total cost difference is approximately 96.97% (1 - (19.448/624)). This is marginally lower than Room 1's accuracy. When projected to a typical monthly use case, this still translates to a very small and operationally acceptable financial variance of under Rp 40 per room per month.

In conclusion, the testing for Room 2 successfully validates the system's functionality and consistency across different nodes. The error remains systematic, predictable, and, most importantly, significantly more accurate and fair than any flat-rate or estimated billing model. The results confirm that the developed system is a robust solution for achieving transparent, per-room water billing in boarding houses. For optimal performance, a final system-wide calibration is recommended to apply a software compensation factor that can minimize the observed accumulative error.

C. Application Test Results

This test ensures that each page of the application is functioning properly and that users can make payments using the available methods. The process involves logging in according to the role (admin or user) to access the page and perform the required actions.

TABLE VII
APPLICATION TEST RESULTS

Test Case	Expected Results	Results Obtained	Validation
Open Application	Application opens without issues	Application opens without issues	Valid
Login with Admin Account	Admin successfully logs in and is directed to the Admin home page	Admin successfully logs in and is directed to the Admin home page	Valid
Login with Room User Account	Room user successfully logs in and is directed to the room user home page	Room user successfully logs in and is directed to the room user home page	Valid
Display Room User Home Page	Room user home page displays correctly	Room user home page displays correctly	Valid
Display Room User Monitoring Page	Room user monitoring page displays correctly	Room user monitoring page displays correctly	Valid
User Can Make Payment Using Cash Method	Payment using cash method is successfully completed	Payment using cash method is successfully completed	Valid
User Can Make Payment Using Midtrans Method	Payment using Midtrans method is successfully completed	Payment using Midtrans method is successfully completed	Valid
Display Admin Home Page	Admin home page displays correctly	Admin home page displays correctly	Valid
Display Transaction History Page on Admin Account	Transaction History page displays correctly	Transaction History page displays correctly	Valid

Display Transaction Request Page on Admin Account	Transaction Request page displays correctly	Transaction Request page displays correctly	Valid

The conducted tests demonstrate that the application performs as expected across various functionalities. The application successfully opens without issues and allows both admin and room users to log in and access their respective home pages correctly. All critical pages, including monitoring, transaction history, and transaction requests, are displayed accurately. Payment processes via both cash and Midtrans methods are executed successfully, indicating robust payment integration. These results confirm that the system's core functionalities are working effectively, ensuring a reliable user experience for both administrators and end-users.

D. System Test Result

Figure must be centered. Both columns can be merged for large figure. Each figure that includes more than 1 column must be positioned in the top or in the bottom of the page. The figure is not bordered outside the figure area.

TABLE VIII
SYSTEM TEST RESULT

Test Case	Expected Results	Results Obtained	Validation
Water Monitoring Data in Room 1	Data in the app matches the data in the database	Data in the app matches the data in the database	Valid
Water Monitoring Data in Room 2	Data in the app matches the data in the database	Data in the app matches the data in the database	Valid
Water Billing Data in Room 1	Data in the app matches the data in the database	Data in the app matches the data in the database	Valid
Water Billing Data in Room 2	Data in the app matches the data in the database	Data in the app matches the data in the database	Valid
User Billing Confirmation by Admin	Billing successfully confirmed by Admin	Billing successfully confirmed by Admin	Valid

The test results indicate that the application reliably displays accurate data for water monitoring and billing across different rooms. Data in the application consistently matches the data stored in the database, confirming its accuracy. Additionally, the system allows successful billing confirmation by the admin, ensuring the integrity and reliability of the billing process. These results validate the effective performance of the system's core functionalities and data handling capabilities.

IV. CONCLUSION

From the research results, it can be concluded that the water monitoring system for dormitory rooms has been effectively designed and implemented. The system uses a flow sensor module connected to a Wemos D1R1 Mini with Wi-Fi capabilities, allowing data to be transmitted to the application. The flow sensor measures water usage at the faucet, and this data is processed by the microcontroller and sent to Firebase for further storage and management, with the information visualized in an Android application. The billing and payment system provides convenience for dormitory residents, enabling them to view and pay their water bills through the application. Users can access daily, weekly, and monthly billing summaries and payment history, with payment options including e-wallet or cash, and receive notifications about the status of their payments. Admins are able to track payment histories and receive relevant notifications. Accuracy tests for the flow sensor show high precision, with error rates of 2.5% in Room 1 and 3.135% in Room 2, translating to average accuracy levels of 98.5% and 96.86%, respectively.

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