Indonesian Journal of Electrical Engineering and Computer Science
Vol. 22, No. 2, May 2021, pp. 744~751
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v22.i2.pp744-751

Development of an IoT-based water and power monitoring system for residential building

Engr. Leah Q. Santos[1], John Carlo D. Bautista[2], Matt William S. Estanque[3] Christian John B. Paloa[4], Ana Beatrice A. Villaran[5]
[1]Department of Engineering, Lyceum of the Philippines University-Cavite, Philippines
[2,3,4,5]Lyceum of the Philippines University-Cavite, Philippines

Article Info

Article history:

Received Jan 19, 2021
Revised Feb 5, 2021
Accepted Mar 3, 2021

Keywords:

Android application
Internet of things
Monitoring system
Power meter
Watt meter

ABSTRACT

This study provides information between tenants and landlords on the use of Internet of Things for power and water monitoring system. It is one way to make reading meters and water meters easier to access using the available internet connection. The developed android application installed on a smartphone/tablet was verified to fully working on android versions from 4.1 (jellybean) to android 9.0 (pie). Tests were carried out in residential apartment where the prototype was installed. The data collected was monitored in the android application and viewed by the tenants and landlords. The results from the mean comparison of the power and volume readings measured by the wattmeter and water meter claimed that the readings from the conventional meters and designed prototype have no significant difference using mann-whitney U test. Evaluations were conducted showing that the device and the developed android application using IoT is reliable, accurate, functional and user-friendly to use by tenants and landlords.

Corresponding Author:

Engr. Leah Q. Santos
Department of Engineering
Lyceum of the Philippines University-Cavite
Governor's Drive, Bgy. Manggahan, General Trias City, Cavite, Philippines
Email: leahquiritsantos@gmail.com, leah.santos@lpu.edu.ph

1. INTRODUCTION

Utility sub-metering is the implementation of meter systems that allows the operator of a multi-unit property to bill each unit for individual utility usage through the installation of additional meters behind a utility meter [1], [2]. With this method, tenants and landlord be able to build a harmonious relationship when it comes to electric and water billings. According to the national science, technology council (US) [3], sub-metering provides the operations and maintenance transparency necessary to enable more efficient management of energy and water resources. Sub-metering offers accurate details about their consumption habits for building occupants, which in turn encourages resource conservation.

In almost every residential building, there is usually a main meter for each type of utility. Since there are numerous tenants occupying each building, the landlord requires a precise method to split the price of the utilities between tenants. The landlord would bring the monthly utility bill and split it and share it with each tenant on the basis of their unit size. Household renters who pay a set rental rate do not face the price of their own energy use have little incentive to use energy effectively. Based on the study of levinson [4], the explanations for the obvious market failure fall into two categories: family tenants value such agreements more than they value the additional energy they consume, or landlords value the agreements more than the additional energy costs. Having this kind of issue happening made the researchers come up with an idea of designing and developing a monitoring system for power and water meters with the application of internet of things (IoT).

2. OBJECTIVES OF THE STUDY

The main objective of the study is to design and implement a power and water monitoring device for a residential building using internet of things (IoT).

Specifically, the study aims:

a) To design the electric power and water sub metering control system in a residential building based on the existing standards.
b) To develop a program that could give access to both tenants and landlords via IoT technology.
c) To develop an android application for smartphone using android studios software, thru Wi-Fi.

3. RESEARCH METHOD

The researchers used quantitative type of research to gather the necessary data in order to conceptualize the development of an IoT-based water and power monitoring system for residential buildings. The researchers noted tenants' lack of awareness of their consumption of electricity and water, particularly when paying for fixed rents. As well as the tenants who paid for the utilities individually and based their consumption thoughts exclusively on the monthly payment letter, they were provided to them without actually understanding how much their consumption actually costs [5].

3.1. Block diagram

Figure 1 shows how the whole system works and how each part interacts with each other in order to make a system. Based on the concept of Hussain [6], the researchers designed a system that detects and measures the equivalent amount for the households' actual electric and water consumption. Once the data was already measured, it will be sent to the cloud storage. Once the data is in the cloud, the tenants and landlord can now access the information using a smartphone.

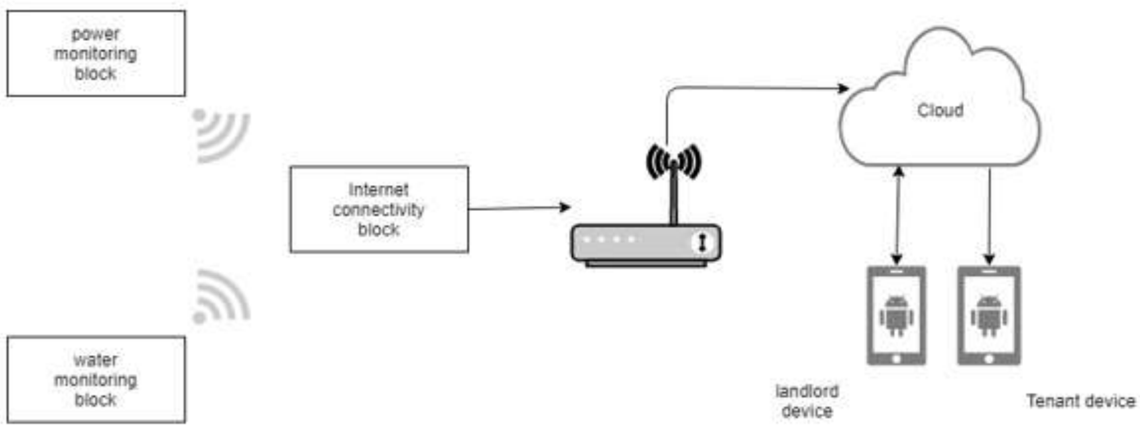


Figure 1. System block diagram

3.2. System flowchart

Figure 2 shows the design process flowchart of the IoT-based water and power monitoring system for residential buildings based on the concept of Fussan [7]-[15]. The user must first consume water and/or electricity in his household. While using the utility, the meters will now read and measure the values. Once the values are already there, the meters will now process the equivalent values and merge them. The data gathered and stored to a memory for compilation. Once the data is already in the database, this will be sent from both the tenants and landlord's smartphones to display the data gathered while the landlord has another end process where he needs to input the data of the local electric company.

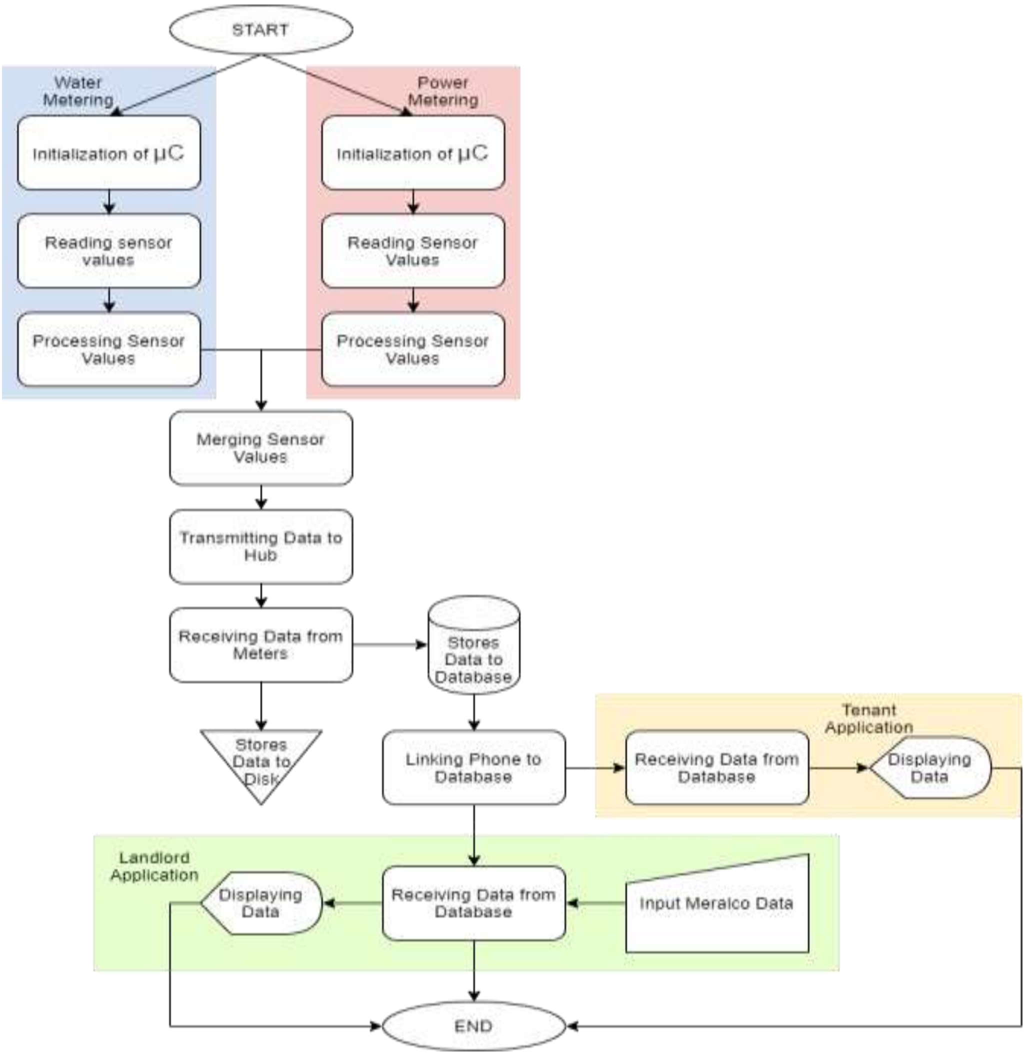


Figure 2. System flowchart of an IoT-based water and power monitoring system

3.3. Project design

3.3.1. Hardware development

Figure 3 and 4 shows the actual image of the power meter circuit box and the water meter prototype based on the concept of Binggeli [16]-[22].

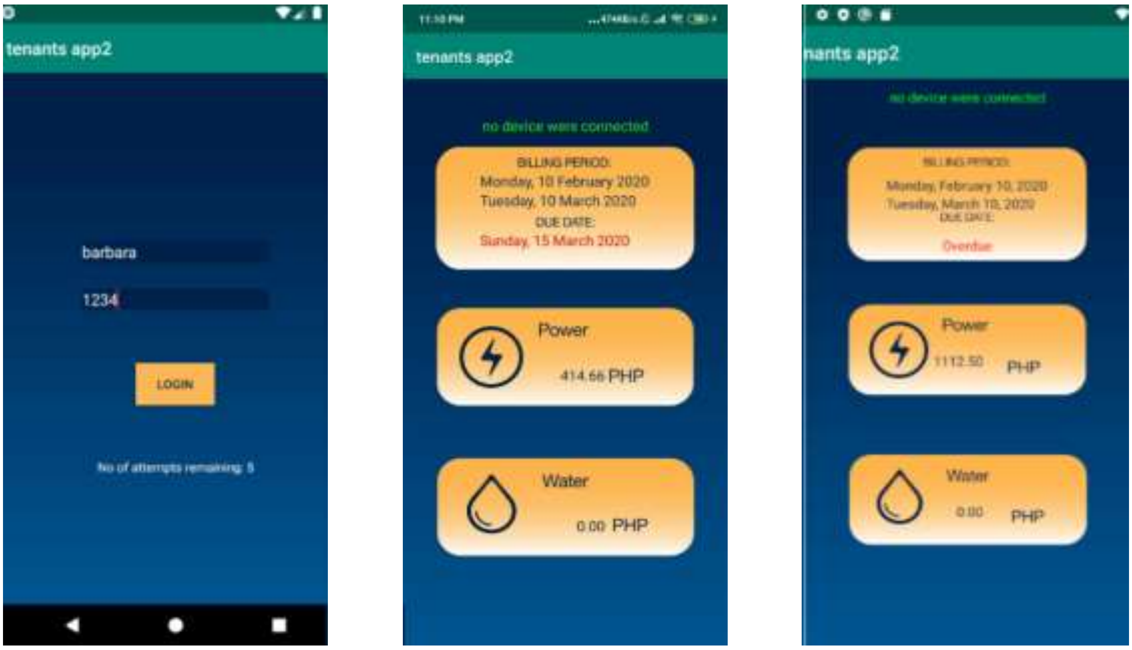
Figure 3. Actual image of power meter prototype circuit box

Figure 4. Actual image of water meter prototype

3.3.2. Software development

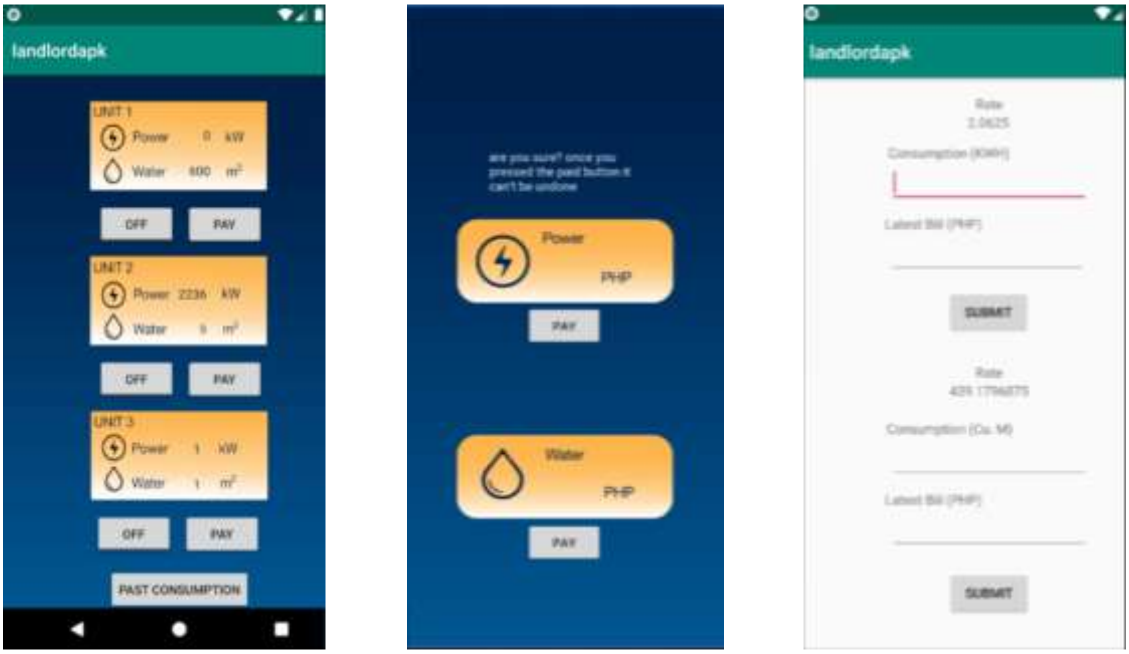
Figure 5 shows the graphical user interface of the tenant’s application. Part A shows the main screen which requires a username and the password of the tenant. There will be a maximum of five (5) attempts in order to sign in and refresh instruction after failed five (5) attempts. Part B shows the user interface components: the device Identifier, the billing period the due date, the equivalent amount in philippine peso (PHP) for the power and water consumption within the indicated billing period. Part C shows the notification for past due/ overdue once the tenant failed to settle the outstanding balance within the period of ten (10) days. Unsettlement of the balance prior to allowable number of days given is ground for the deactivation of the tenant's power and water supply. The android design was based on the concept made by Ashok [23]-[30].

Figure 6 shows the graphical user interface of the landlord android application. Part A shows the user interface components: the monitoring for residential unit, deactivation (OFF) button, pay button, past consumption button. Part B displays the landlord user interface once "PAY" button is selected. The screen shows the corresponding amount for the power and water consumption of the chosen unit. Once the residential unit has been settled the payment to landlord, "PAY" button must be pressed for the resetting of the residential unit bills. Part C shows the display for the landlord once the "PAST CONSUMPTION” button is pressed from the main screen of the user interface. In this section, the landlord can input values such as the rate of power and water consumption, and the latest power and water bill of the residential unit. The "SUBMIT" button will then again measure the power and water consumption of the tenants for each unit.



(a) (b) (c)

Figure 5. Tenant application user interface



(a) (b) (c)

Figure 6. Landlord application user interface

4. RESULTS AND DISCUSSION

This part discussed the outcome of the project, together with the findings of monitoring and evaluation procedures. The data obtained during the testing evaluation and validation procedures were analyzed, interpreted and presented in tabular form.

4.1. Results of testing and interpretation of data

Table 1 shows the results of the accuracy testing of the developed power meter. For this testing, different appliances were used: two (2) electrical fans, one (1) CRT television, one (1) refrigerator, four (4) light bulbs, one (1) TV Plus, and one (1) internet router in accordance to the tenants of the residential units. It shows an 88.82% accuracy for the developed power meter device.

Table 1. Accuracy testing result for power meter

Day	Measured Power by Device (kWh)	Actual Power Reading by Device per Day (latest – recent)	Measured Power by Wattmeter (kWh)	Actual Power Reading by Wattmeter per Day (latest – recent)	Percent Error of the Actual Power Reading by Device based on Wattmeter (%)
Initial	0.550	-	2231	-	-
Day 1	3.876	3.326	2234	3.000	10.87
Day 2	7.070	3.194	2238	4.000	20.15
Day 3	11.171	4.101	2242	4.000	2.53
		Average Percent Error			11.18
		Accuracy Rate in Percent (%)			88.82

Percent error equation:

$$\text{Percent Error} = \frac{|\text{Actual Reading by Wattmeter} - \text{Actual Reading by Device}|}{\text{Actual Reading in Wattmeter}} x100\%$$

Table 2 shows the results of the accuracy testing of the developed volume reading devide. For this testing, a 20 liters per test is used as part of the demonstration. In order to determine the water consumption of each residential unit. It shows that the developed water meter has 98.9822 % accuracy. Table 3 shows the mean comparison of the designed power and volume reading device with the conventional wattmeter and water meter with the use of mann-whitney U test. The values indicated in the table claims that there is no significant difference between the designed device and the conventional wattmeter.

As seen in Table 4, the testing of the developed android application is conducted to determine the compatibility to different android versions together with the sample brand for each. The result shows that the developed android application is compatible to the android 4.1 version to android 9.0. A simulator android studios is used for the compatibility testing.

Table 2. Accuracy testing result for water meter

Trial	Measured Volume by Device (m^3)			Measured Volume by Water Meter (m^3)			Percent Error of the Actual Volume Reading by Device based on Water Meter (%)
	Initial Reading	Final Reading	Difference (Actual Reading)	Initial Reading	Final Reading	Difference (Actual Reading)	
1	0.2822	0.3021	0.0199	1388.4125	1388.4322	0.0197	1.0152
2	0.3021	0.3219	0.0198	1388.4322	1388.4519	0.0197	0.5076
3	0.3219	0.3418	0.0199	1388.4519	1388.4715	0.0196	1.5306
Average Percent Error							1.0178
Accuracy Rate in Percent (%)							98.9822

Table 3. Mean comparison of the power and volume reading measure by device, and wattmeter and water meter using mann-whitney u test

Quantity	Power	Volume
Mann-Whitney U	4.000*	0.000*
Wilcoxon W	10.000	6.000
Z	-0.221	-2.023
Asymp. Sig. (2-tailed)	0.825	0.043
Exact Sig. [2*(1-tailed Sig.)]	1.000	0.100
Interpretation	No Significant Difference	No Significant Difference

*Note: * - No Significant Difference at 0.05 level of confidence.*

Table 4. User-friendliness for the application in phone and tablet

Android Version	Brand (Phone)	Result	Brand (Tablet)	Result
Android 4.1	LG Optimus L1	Checked	Asus Google Nexus 7	Checked
Android 4.4	LG F60	Checked	Samsung Google Nexus 10	Checked
Android 5.0	Motorola Nexus 6	Checked	HTC Nexus 9	Checked
Android 6.0	LG Nexus 5X	Checked	Google Pixel C	Checked
Android 7.0	HTC One A9	Checked	Samsung Galaxy Tab S3	Checked
Android 8.0	Google Pixel 2	Checked	Samsung Galaxy Tab S4	Checked
Android 9.0	Google Pixel 3	Checked	Lenovo Tab V7	Checked

4.2. Results of evaluation

Overall evaluation results:

Based on Table 5, the overall mean is 4.38 and it can be interpreted that the respondents strongly agreed that the device is reliable, accurate, functional and user-friendly.

Table 5. Overall Evaluation on water and power monitoring system

Characteristics	Mean	Std. Deviation	Interpretation
Reliability	4.33	0.538	Strongly Agree
Accuracy	4.21	0.596	Strongly Agree
Functionality	4.69	0.414	Strongly Agree
User-Friendliness	4.30	0.525	Strongly Agree
Overall Evaluation	4.38	0.400	Strongly Agree

Note: 5.00 – 4.20 Strongly Agree 4.19 – 3.40 Agree 3.39 – 2.60 Slightly Agree 2.59 – 1.80 Disagree 1.79 – 1.00 Strongly Disagree

5. CONCLUSION

The researchers set out the purpose of this study to represent as a power and water volume monitoring system for both tenants and landlords using the internet of things (IoT) via the developed android device. The developed power and water volume monitoring system for residential buildings has been proven to be reliable, accurate, functional and user-friendly with an overall evaluation mean of 4.38, indicating that respondents strongly agreed. The survey fully described the fact that the respondents agreed on the proposed device and were able to be used for an operation such as monitoring the electricity and water consumption of tenants and landlords.

REFERENCES

[1] Durkay, J. (Jan, 2016). Utility Submetering. NCSL National Conference of State Legislatures. [online]. Available: https://www.ncsl.org/research/energy/utility-submetering.aspx

[2] Bacarro, R. R., Espaldon, A. P., & Morite, A. S., "Automated Energy Meter and Controller for Rural Residential Structures," *Journal of Science & Technology,* vol. 4, no. 37, pp. 37-50, 2018.

[3] National Science, Technology Council (U.S.), "Subcommittee on Buildings Technology, Research, & Development," *Submetering of building energy and water usage: analysis and recommendations of the Subcommittee on Buildings Technology Research and Development,* 2011.

[4] Levinson, A., & Niemann, S., "Energy use by apartment tenants when landlords pay for utilities," I*n Resource and Energy Economics*, vol. 26, no. 1, pp. 51-75, 2004, doi: 10.1016/s0928-7655(03)00047-2.

[5] Eissa, M., "Smart Metering Technology and Services: Inspirations for Energy Utilities," *Rijeka, Croatia: InTech*, 2016, doi: 10.5772/61356.

[6] Hussain, F., "Internet of Things: Building Blocks and Business Models," *Switzerland: Springer International Publishing AG*, no. 978-3, pp. 319-55404, 2017.

[7] Fussan, Q., "Internet of Things A to Z: Technologies and Applications," *Hoboken, New Jersey: John Wiley & Sons, Inc*, 2018.

[8] Ali-Ali, A. R., Zualkernan, I. A., Rashid, M., Gupta, R., & AliKazar, M. "A Smart Home Energy Management System Using IoT and Big Data Analytics Approach," *IEEE Transactions on Consumer Electronics,* vol. 63, no. 4, pp. 426-434, 2017, doi: 10.1109/TCE.2017.015014.

[9] Bellavista, P., Giannelli, C., Das, S. K., & Cao, J., "Middleware Solutions for Wireless Internet of Things," *MDPI AG*, 2019.

[10] Bhuvaneswari, T., Hossen, J., Asyiqinbt. N., Velrajkumar, H. K., Jack, O H "Internet of things (IoT) based smart garbage monitoring system," vol. 20, no. 2, pp. 736-743, 2019, doi: 10.11591/ijeecs.v20.i2.pp736-743.

[11] Guma'a, O. S., Hussein, Q. M., Al-Ta'I, Z. T. M. "Dynamic keys generation for internet of things," 2020, doi: 10.11591/ijeecs.v18.i2.pp1066-1073.

[12] International Organization for Standardization "Systems and software engineering-Systems and software Quality Requirements and Evaluation (SQuaRE)-System and software quality models," *Retrieved from*, 2011.

[13] Jernigan, S., Ransbotham, S., & Kiron, D. "Data Sharing and Analytics Drive Success With IoT," *MIT Sloan Management Review*, 2016.

[14] Shah, A. A. I., *et al.* "A review of IoT-based smart waste level monitoring system for smart cities," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 21, no. 1, pp. 450-456, 2021, doi: 10.11591/ijeecs.v21.i1.pp450-456.

[15] Yusof, Z. M., Billah, M. M., Kadir, K., "Real-time water quality monitoring system: an IoT application," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 15, no. 1, pp. 178-182, doi: 10.11591/ijeecs.v15.i1.pp178-182.

[16] Binggeli, C. "Building Systems for Interior Designers (3rd Ed.)," *Hoboken, New Jersey: John Wiley & Sons, Inc*, 2016.

[17] Chee Wei, W.L., Ab Ghafar, A.S., Hairul Rozi, N.N., Saparudin, F. A. "Wireless water usage monitoring system for home/small premises," 2019, doi: 10.11591/ijeecs.v15.i2.pp704-713.

[18] Owen, D. A. "Smart Water and Water Megatrend Management and Mitigation," *Envisager Limmited, Ceredigion, UK*, pp. 87-104, 2018, doi: 10.1007/978-981-10-6695-5_6.

[19] Owen, D. A. "Smart Water Technologies and Techniques: Data Capture and Analysis for Sustainable Water Management," *Hoboken, New Jersey: John Wiley & Sons, Inc*, 2018, doi: 10.1002/9781119078678.

[20] PHCC National Association Educational Foundation, "Plumbing 201 (6th Ed.)," *Mason, OH, United States: Cengage Learning, Inc*, 2016.

[21] Roberts, P., & Baker, M. "Electrical Installation Work Level 2," *New York: Routledge Taylor & Francis Group*, 2016, doi: 10.4324/9781315689180.

[22] Salih, N. A. J., Hasan, I. J., Abdulkhaleq, N. I. "Design and implementation of a smart monitoring system for water quality of fish farms," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 1, pp.44-50, 2019, doi: 10.11591/ijeecs.v14.i1.pp44-50.

[23] Ashok, K. S. "Mastering Firebase for Android Development: Build real-time, scalable, and cloud-enabled Android apps with Firebase," *Birmingham, United Kingdom: Packt Publishing Limited*, 2018.

[24] Cui, H., & Yang, Y, *U.S. Patent No. 133,701.* Washington, DC: U.S, 2019.
[25] Smyth, N. "Firebase Essentials–Android Edition*," Createspace Independent Publishing Platform*, 2017.
[26] Miller, T. "Wireless Communications and Technology*," United States: Larsen and Keller Education*, 2017.
[27] Moroney, L. "The Definitive Guide to Firebase: Build Android Apps on Google's Mobile Platform," *Berkeley, United States: aPress*, 2017, doi: 10.1007/978-1-4842-2943-9.
[28] Murrad, M., Bayt, O., Marhoon, H. "Design and implementation of a smart home system with two levels of security based on IoT technology," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 21, no. 1, pp. 546-557, 2021, doi: 10.11591/ijeecs.v21.i1.pp546-557.
[29] Stonehem, B. "Google Android Firebase: Learning the Basics," *Createspace Independent Publishing Platform*, 2016.
[30] Strum, R., Pollard, C., Craig, J. "Application Performance Management (APM) in the Digital Enterprise," *Cambridge, United States: Morgan Kaufmann Publishers*, 2017.

BIOGRAPHIES OF AUTHORS

Engr. Leah Q. Santos is a Chairperson of Engineering Department at Lyceum of the Philippines University-Cavite, Philippines. She is currently pursuing her doctorate degree for the Doctor of Philosophy in Educational Management at De La Salle University-Dasmariñas, Cavite. A graduate of Master of Engineering in Electrical with Electronics option and with a Bachelor of Science in Electronics and Communication Engineering degree at Technological University of the Philippines-Manila. She is a certified Electronics and Communication Engineer. The areas of her publication and research includes Internet of Things, Automations, Mechatronics, and Renewable Energy.

John Carlo D. Bautista is an Electronics Engineering Student of Lyceum of the Philippines University-Cavite, Philippines. He has a strong electronics background and expert in different programming languages.

Matt William S. Estanque is an Electronics Engineering Student of Lyceum of the Philippines University-Cavite, Philippines. He is a registered Electronics Technician. He is proficient in MS office and with strong knowledge in AutoCAD, Multisim and Arduino family.

Christian John B. Paloa is an Electronics Engineering Student of Lyceum of the Philippines University-Cavite, Philippines. He is highly skilled in software applications and different programming languages.

Ana Beatrice A. Villaran is an Electronics Engineering Student of Lyceum of the Philippines University-Cavite, Philippines. She is skilled in designing electronics project and planning.