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Innovation of Remote Vital Signs Monitoring and Telemedicine Systems Using Internet of Things for Rural Health Care

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Abstract: The emergence of the COVID 19 pandemic called the attention of the public to the challenges that the healthcare system in the Philippines needs to overcome. Rural and remote areas that have geographical disadvantages were also affected due to limited access to healthcare services during the implementation of lockdown in the country. This paper focuses on the developed remote vital sign monitoring and telemedicine system called PaglauM. It is a device that measures a person's heart and pulse rate, blood oxygen saturation, body temperature, heart rhythm, and heart's electrical activity and comes with an application that can be used to monitor the user's vitals and access telemedicine services. This study involved 30 participants for the testing and evaluation of PaglauM compared to available medical devices. The results of the conducted test showed promising output in delivering pre- diagnosis of health. With the use of PaglauM, rural areas that struggle in providing health care because of limited health care facilities and geographical disadvantages can be helped by this cost-effective vital monitoring device that implements the use of telemedicine, providing a way for rural areas to connect to tertiary hospitals regardless of their distance.

Keywords: Telemedicine, pre-diagnostic, remote patient monitoring, cost-effective.

I. Introduction

COVID-19 virus is a viral infection that emerged in the Philippines in the year 2020, exposing the deficiencies in the Philippines' healthcare system. Lockdowns, quarantine, and social distancing were implemented to help in controlling the spread of the virus. To make up for the distance brought up by lockdowns, online medical methods such as telemedicine became popular.

Telemedicine paved the way for online health consultations, bridging patients and doctors amidst the COVID-19 lockdown. With this transformative approach to healthcare, telemedicine provider Medgate, one of the leading telemedicine platforms in the Philippines aside from Konsulta MD, saw an increase in teleconsultation in these platforms by 170-percent in 2020, which delivered almost 70,000 virtual consultation services to patients across the country [1].

Telemedicine lessens the need to travel far to the health centers for medical assessments, brought up by the insufficiency of healthcare facilities and personnel to accommodate the needs of different patients, which are commonly experienced by some places in remote and rural areas. In a data released by Statista [2], tertiary healthcare is commonly found in urban areas, with a total of 59 tertiary hospitals in the National Capital Region out of 119. It can then be said that most of the tertiary hospitals, having medical expertise and equipment, that could accommodate the needs of patients are situated in urban areas.

The insufficiency of primary healthcare facilities has brought the patients being referred to a tertiary hospital where the type of disease can be assessed or observed. Assessments include vital sign monitoring where parameters such as blood pressure, oxygen saturation, temperature, and heart rate are collected and transmitted using sophisticated monitoring equipment, including wearable sensors and integrated monitoring devices [3]. The monitoring of these vitals will help a medical professional assess a patient's well- being, as they provide essential information about your organs [4].

Face-to-face checkups can measure the parameters of vital signs effectively. Being able to monitor vital signs regardless of the distance is achievable and this process can be done using remote monitoring devices, but it is unaffordable for many as it comes at an expensive price.

With that in mind, the researchers developed a device named PaglauM, a remote vital sign monitoring and telemedicine system, which can be used by outpatients for them to be monitored by their doctor regardless of their location. The device developed includes the following parameters: heart and pulse rate, blood oxygen saturation, body temperature, heart rhythm, and heart's electrical activity. In addition to that, it also has an application that can be used to provide parameters and to also conduct teleconsultation with medical professionals, bridging the problem concerning the distance between both parties.

The development of PaglauM supports the Sustainable Development Goals (SDGs) 3 and 10 in the Philippines. The SDG 3 - good health and well-being, is aligned to the goal of PaglauM which is to help improve access to excellent healthcare, especially in rural regions, where gaps exist. Also, this study will help to achieve the SDG 10 – reduce Inequalities by allowing individuals to have an early diagnosis of health issues, that could contribute to lowering healthcare gaps between urban and rural areas.

II. Significance of the Study

The outcome of this study will ease the needed continuous monitoring procedure for health care, while maintaining the confidentiality of the user's health condition and the data that will be gathered by the system. Furthermore, the application of

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telemedicine will be able to help patients that have time availability and long distance to hospital constraints. Therefore, this study will benefit aspects including:

Health and Safety as PaglauM will help improve the quality of healthcare in rural areas, making health consultation available using telemedicine. This will help democratize vital signs monitoring and telemedicine systems, making it an effective way to help protect the health and safety of people.

Social as it will also raise social awareness about health and safety by bringing easier telemedicine access to people. People will have a better understanding of the condition of their health, giving them the knowledge they need to bring awareness and to encourage them to maintain and improve their well-being. The device will also bring peace of mind to people as they gain a better understanding of their health status, especially for elderly people and their loved ones.

Economic as the device will be able to help patients in pre-health diagnosis through vitals sign monitoring and telemedicine, contributing to the assessment of their health concerns. Ethics as individuals will have the opportunity to assess their health condition as this device has monitoring and telemedicine systems that can be used in early diagnosis, even if they are in the rural or urban areas.

And lastly, Public Government as the development of PaglauM aims to democratize the remote monitoring of vital signs and telemedicine systems. It will help improve the monitoring and tracking of common health conditions including heart-related diseases, especially in rural areas.

The Problem

Rural Healthcare Unit's insufficiency of medical equipment and professionals leads to patients being referred to tertiary hospitals. The effect of it includes limited access to healthcare and an increasing number of heart-related diseases, hindering the democratization of health care.

Scope and Limitations

The researchers developed a device named PaglauM, a remote vital sign monitoring and telemedicine system that provides data parameters and health information to the user itself. It gives people a way to assess or remotely monitor their blood oxygen saturation, body temperature, heart rhythm, heart and pulse rate, and heart's electrical activity in a cost-effective manner. Sudden health changes that can lead to emergencies can be better monitored with the help of this device, making it helpful in providing continuous health care.

The prototype PaglauM is only tested to young adults, approximate ages of 18 to 26 years old, since the prototype is not applicable for the use of all ages, considering that infants and toddlers, along with senior citizens have fragile bodies, in addition to their smaller size and build. Moreover, the parameters that are measured by the prototype to assess the medical condition of the user are only limited to the patient's blood oxygen saturation, body temperature, heart and pulse rate, heart rhythm, and heart's electrical activity. These vitals can be monitored and recorded manually to remotely observe one's health condition at a cost-effective manner.

The application of PaglauM is limited only to providing accessibility to the prototype's operation and conducting telemedicine. Vital sign measurements of the patient can be recorded using the application, while telemedicine features include sending recorded vital measurements to doctor, and teleconsultation that uses third- party application for audio and video conference. The speed or strength of internet signal that could affect the telemedicine features of the system is not on the extent of this study. Furthermore, the prototype is for pre-diagnosis and vital signs reading only and will not be intended to replace and compete with the specification, design, and capabilities of high-end or much more expensive and accurate devices being used for admitted patients in tertiary health care.

Lastly, the components, sensors, and other objects used by the researchers are commercially available materials at the time the device of PaglauM is being developed. With that in mind, as technologies develop, further enhancements can then be done by the future researchers of the prototype.

III. Methodology

The researchers used a quantitative research approach in designing a cost-effective remote vital sign monitoring and telemedicine system using internet of things for rural health care. The quantitative approach was employed to achieve the objectives of this study, with its method that uses data and mathematical computations based on the results to assess the variables tested for the study.

Comparison of PaglauM's result to medical devices was done to measure the sensors in providing vital sign parameters of blood oxygen saturation, body temperature, heart and pulse rate, heart rhythm, and heart's electrical activity, a series of tests are conducted. The study involves 30 participants from 4th year Electrical Engineering students at PUP College of Engineering. The researchers performed vital sign checking on each of the participants to evaluate the prototype's reliability and accuracy.

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Table 4: Percentage Difference Analysis Equations

Equation 1	$\%Difference = (\frac{Medical\ Device\ VM - PaglauM\ VM}{Medical\ Device\ VM})(100\%)$
Equation 2	$Mean\ Difference = \frac{\sum \%Difference\ per\ vital\ sign}{No.\ of\ Participants}$
Equation 3	%Accuracy per parameter = 100% - mean difference per parameter
Equation 4	$\%Device\ Overall\ Accuracy = \frac{\sum \%Accuracy\ per\ parameter}{No.\ of\ parameters}$

Assessment of power consumption of the device was done with the use of INA219 component, which was interfaced with the Raspberry Pi Pico core, while the telemedicine was evaluated according to the indicated basic requirements applicable to telemedicine services mentioned in the telemedicine survey paper done by Ong, et.al (2023) in the Philippines.

IV. Analysis & Discussions

The test was conducted at Our Lady of Fatima University Antipolo Campus using medical devices and PaglauM device to acquire the parameters of heart and pulse rate, blood oxygen saturation, body temperature, heart rhythm, and heart's electrical activity.

Table 5: Comparison Of Blood Oxygen Saturation Test Result

Patient Number	**Blood Oxygen Saturation (%)**		**Percent Difference**
	Pulse Oximeter	**PaglauM**	**(%)**
1	98	97	1.02
2	99	98	1.01
3	98	98	0.00
4	98	98	0.00
5	98	98	0.00
6	99	99	0.00
7	99	97	2.02
8	99	99	0.00
9	98	98	0.00
10	98	98	0.00
11	98	97	1.02
12	98	98	0.00
13	98	98	0.00
14	98	98	0.00
15	98	98	0.00
16	98	98	0.00
17	98	98	0.00
18	98	98	0.00
19	98	98	0.00
20	99	99	0.00
21	99	99	0.00
22	98	98	0.00

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23	98	98	0.00
24	99	99	0.00
25	99	97	2.02
26	94	96	2.13
27	98	98	0.00
28	98	98	0.00
29	99	99	0.00
30	99	99	0.00
Mean Difference			0.31

Table 6: Comparison Of Heart Rate Test Results

Patient	**Heart Rate (BPM)**		**Percent**
Number	**Pulse Oximeter**	**PaglauM**	**Difference (%)**
1	73	72	1.37
2	67	67	0.00
3	78	78	0.00
4	98	96	2.04
5	89	89	0.00
6	94	94	0.00
7	80	79	1.25
8	70	65	7.14
9	85	81	4.71
10	78	80	2.56
11	76	75	1.32
12	69	71	2.90
13	84	84	0.00
14	87	87	0.00
15	69	72	4.35
16	103	102	0.97
17	76	76	0.00
18	63	65	3.17
19	88	74	15.91
20	80	66	17.50
21	80	80	0.00
22	71	84	18.31
23	86	86	0.00
24	74	79	6.76
25	77	69	10.39
26	78	78	0.00

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27	86	85	1.16
28	82	82	0.00
29	68	68	0.00
30	60	63	5.00
Mean Difference			3.56

The blood oxygen saturation and heart rate showed a mean difference of 0.31 percent and 3.56 percent from PaglauM results, compared to a pulse oximeter

Table 7: Comparison of Body Temperature Test Results

Patient Number	**Body Temperature (°C)**		**Percent Difference**
	Pulse Oximeter	**PaglauM**	**(%)**
1	36.4	36.4	0.00
2	36.7	36.7	0.00
3	36.2	36.2	0.00
4	36.3	36.3	0.00
5	36.0	36.1	0.28
6	36.6	36.6	0.00
7	35.6	35.5	0.28
8	35.3	35.5	0.57
9	36.4	36.4	0.00
10	35.9	36.0	0.28
11	35.4	35.7	0.85
12	36.2	36.3	0.28
13	36.7	36.7	0.00
14	36.3	36.3	0.00
15	35.9	35.9	0.00
16	35.7	35.7	0.00
17	35.7	36.0	0.84
18	36.4	36.4	0.00
19	36.2	36.2	0.00
20	36.9	36.9	0.00
21	35.8	35.8	0.00
22	35.5	35.5	0.00
23	36.9	36.9	0.00
24	36.6	36.6	0.00
25	36.6	36.6	0.00
26	35.6	35.5	0.28
27	35.7	35.5	0.56
28	36.2	36.2	0.00

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29	36.0	36.0	0.00
30	36.3	36.3	0.00
Mean Difference			0.14

The body temperature results from PaglauM showed 21 out of 30 readings matched results from thermometer, showing less than 1.0 percent difference.

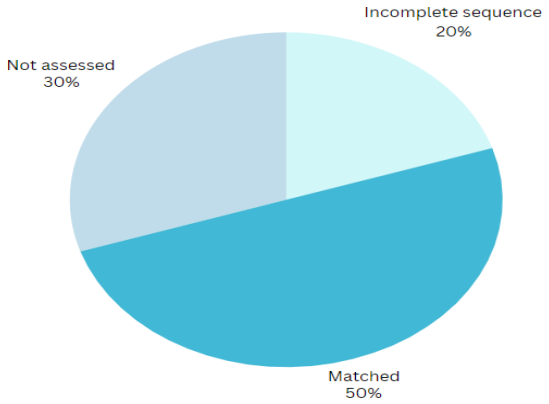

Fig. 38 Electrocardiograph Result from PaglauM

Lastly, PaglauM's electrocardiograph acquired 21 out of 30 readings assessed results. Among these, 15 matched the presence of the PQRST sequence seen in the ECG machine's readings, while the remaining 6 results showed a 20 percent difference as only 4 out of 5 waves appeared in the PaglauM's readings. This electrocardiograph results from PaglauM acquired a 94.29 percent accuracy, excluding the results that could not be assessed.

In terms of PaglauM's reliability of operation, the run time of a fully charged battery of PaglauM, having a battery capacity of 2,000-mAh, discharging at an average current of

61.52 mA is estimated to last approximately 32.51 h as a power source. On the other hand, With the use of a 1.0-A charging pin, PaglauM takes an approximately two hours to fully charge its battery with a capacity of 2,000-mAh.

Table 13: Paglaum's Application Speed

PaglauM's Functions	Time Delay (s)				
	Android Version 14	Android Version 12	Android Version 11	Android Version 8	Average
Opening of App	1.33	1.30	1.65	9.16	3.36
Device Connecting to App	9.22	9.84	10.57	11.29	10.23
App to Zoom App	3.40	5.40	6.12	7.08	5.50
App to Google App	1.94	3.20	3.41	6.57	3.78
App to Teams App	1.68	2.20	2.77	3.94	2.65

The researchers also evaluated the telemedicine application of PaglauM. The system application was tested using four versions of Android mobile phones. During the trials, the time to open the telemedicine application and display its homepage averaged 3.36 s. Connecting the PaglauM device to the application averaged 10.23 s. Furthermore, the transition from PaglauM's application to the Zoom application averaged 5.50 s, 3.78 s to the Google Meet application, and 2.65 s to the MS Teams application.

Table 14: Ram Usage of Paglaum's Telemedicine Application

	RAM Usage (MB)			
	Android Version 14	Android Version 12	Android Version 11	Android Version 8
Average	48.00	8.90	10.50	5.60
Maximum	298.00	188.00	100.00	99.00

The telemedicine application averaged 5.60 MB to 48 MB, and a maximum of 99 MB to 298 MB among the four Android mobile

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phone versions. Overall, the telemedicine system of PaglauM demonstrated minimal usage across the measured modes compared to the four versions of Android mobile phones.

V. Conclusion

The researchers, with the assistance of a medical practitioner who evaluated the results, concluded that PaglauM was reliable for pre-diagnosing an individual's vital parameters including blood oxygen saturation, body temperature, heart and pulse rate, and heart rhythm and electrical activity. PaglauM consistently showed matched and nearly matched values, indicating its accuracy in vital sign reading. Averaging a mean difference of 2.43 percent to the four parameters measured, PaglauM achieved an overall accuracy of 97.57 percent. While further refinement to the design may have been necessary to acquire much more precise measurements, the researchers' findings suggested that PaglauM's performance was promising in the pre- diagnosis of vital signs, making it a valuable tool for early detection of health-related issues. The results on the electrical characteristics of PaglauM demonstrated that the device operated efficiently, with minimal fluctuations in voltage, current, power, and shunt voltage. Additionally, the charging and discharging of the device exhibited promising performance, indicating that the device could be used for extended periods without the need of frequent recharging. This suggested that the device was well-designed and capable of providing reliable and long- lasting functionality for its intended purposes.

The telemedicine-ready application of PaglauM, while functional, was not yet fully developed and has room for improvement. The current features met the basic requirements, such as appearance of real-time vital sign reading and facilitating teleconsultations. However, enhancements were needed to support additional functionalities, such as sending information via email and text, conducting teleconsultation on the telemedicine application itself, and control of the PaglauM device during vital sign reading. Overall, the application showed promise in fulfilling the essential needs of telemedicine services, but further refinement and feature expansion will be necessary to optimize its effectiveness and user experience.

Lastly, the researchers proposed recommendations including enhancing the functionality of PaglauM by integrating additional parameters that can be detected, measured, or analyzed by the vital sensors, providing more comprehensive vital sign checking, considering replacement of the Raspberry Pi Pico W with a more advanced and capable board to optimize the functionality of the device, allowing integration of a more robust system that can stimulate multiple vital sign monitoring of the PaglauM, enhancing the system's functionality by adding periodical reading mode, enabling automatic and scheduled vital sign checking for individuals, and evaluating the ECG tracing results to medical device with equal number of leads.

The researchers also suggest using higher-grade wires, while also considering the cost-effectivity of the device, to minimize grounding issues and inaccuracies in ECG results. The recommendation includes enhancing the functionality of application, enhancing the design by developing a more compact, ergonomic, and streamlined housing and chassis to enhance portability and accuracy of the measurements of vital parameters, making it a wearable wrist or arm device where the sensors are readily positioned at the optimal places where vital signs are to be measured, and increasing the sample size to conduct beta testing.

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