VITAL APP: Development and User Acceptability of an IoT-Based Patient Monitoring Device for Synchronous Measurements of Vital Signs

[1] Manuel B. Garcia, [2] Nino U. Pilueta, [3] Moises F. Jardiniano
[1] *College of Computer Studies*, [2 3]*College of Engineering*
Institute of Technology, Far Eastern University
Manila, Philippines
hi@manuelgarcia.info

***Abstract*—Vital signs monitoring is a customarily repetitive, tedious part of patient care that nonetheless requires constant measurements and documentations to avert significant adverse consequences. Routinely performed by nurses, measurements of vital signs are recorded at regular intervals for safeguarding patient safety yet some evidence concerning the frequency of noncompliance in vital sign collection as well as the inaccuracy of vital sign measurements is still at large. This paper covered the development of a patient monitoring device using hardware modules such as pulse rate sensor, sphygmomanometer, and body temperature sensor that communicates through wireless technology protocol based on IEEE 802.15.4 standard for synchronous measurements of multiple vital signs such as body temperature, pulse rate, and blood pressure. Physiological data accuracy based from the Modified Early Warning Score was measured by Bland-Altman and Pearson correlation analysis, and user acceptability was inspected using IoT technology trust model with the aid of health professionals and patients from hospitals and diagnostic centers. Vital sign measurements by VITAL APP and health professionals correlated well, and the device was accepted as an important tool in patient monitoring.**

Keywords— Healthcare Information Technology, Internet of Things, Patient Care, Remote Health Monitoring, Vital Signs

I. INTRODUCTION

The sacred marriage of Information and Communications Technology (ICT) and healthcare gave birth to a new societal area known as Healthcare information technology (HIT) that revolutionized patient care from hospital productivity [1] and patient safety [2] to the quality of medical care [3]. In the book "Electronic Health Records: Challenges in Design and Implementation", HIT was defined as the application of tools and technologies used to collect, process, store, and display patients' data for health information management [4]. Much of the evidence on the impact of HIT shows positive effect on medical outcomes [5]. For instance, health professionals and patients are now using and playing medical apps [6] and games [7] not only as a clinical communication to remotely monitor patients but also as an evidence-based medicine in patient education [8]. According to a systematic review [9], there is also an emerging utilization of social media in healthcare where doctors and patients alike are using such platforms for patient empowerment (patient-patient) and to a more equal communication (doctor-patient), to name a few. There is also an increased presence of HIT in hospitals, for instance, the application of cloud computing to facilitate an improvement in accessibility of health data, and management and usage of medical resources [10]. In terms of data, the health sector is undergoing big data acquisition [11] to personalized patient care, and use it to predict diseases and for healthcare policy making via data mining and analytics [12]. Wearable sensors and systems are likewise displaying practical applications in the healthcare sector through disease treatment, vital parameter measurement, and diagnosis and monitoring [13]. Brought by the Fourth Industrial Revolution [14], Internet of Things (IoT) is the latest instalment of HIT.

IoT is defined as the interconnection of sensors, devices, applications, and network connectivity [15] whose purpose is to control the physical world using the internet [16]. A broad spectrum of IoT applications delivered by intelligent objects (e.g., sensors, smart appliances, robots) has been dominating the market in different knowledge domains and industries such as environment, smart city, commercial, industrial, and healthcare [17]. Regardless of the field, a mutual application of IoT-based systems is as a monitoring tool. For instance, Li et al. [18] developed an IoT-based monitoring system to control henhouses in chicken farms based on wireless sensor network. Under the care of the system, environmental factors such as henhouse temperature, CO_2 concentration, humidity, and NH_3 concentration were effortlessly monitored via the web. Another instance of IoT monitoring application is the wildlife monitoring system developed by Kim, Lee, and Ryu [19] via low-power wireless sensor networks. Highlighted by the integration of IoT in ecological context, the system was able to monitor wild vegetation environment. Research in the healthcare space has also shown the ability of IoT as a health monitoring system. Ding, Gang, and Hong [20] developed a home monitoring system for detecting patient's physiological signals outside the hospital using intelligent nodes. Attached with the system was the emergency alarm to notify the health professionals with a potential critical emergency. Indeed, the remote health monitoring that enables quality patient care is one of the noblest contributions of IoT to the society [21].

When it comes to standard practices of health monitoring in hospitals, vital signs measurement is at the heart of every patient care. Routinely performed by nurses, vital signs data can detect clinical deterioration [22] – a movement of patient condition from one clinical state to a worse clinical state [23] that can lead to adverse consequences or even death when not identified early [24]. Yet, some evidence concerning the frequency of noncompliance in vital sign collection and the inaccuracy of vital sign measurements is still at large [25]. With the importance of continuous vital sign assessment and surveillance to safeguard patient safety [26], hospitals have initiated interventions by actively embracing HIT. Hernandez et al. [27] developed a multi-agent application system almost similar to VitalMote [28], Vital-SCOPE [29], and a wearable device [30] which are all developed and used for vital sign monitoring in hospital settings. The only disparity lies on the hardware components and configurations. In this paper, the development of a patient monitoring device using hardware modules such as pulse rate sensor, sphygmomanometer, and body temperature sensor that communicates through wireless technology protocol standard for synchronous measurements of multiple vital signs was discussed. This study intended to develop an IoT-based medical device that can measure pulse rate, body temperature and blood pressure, and to determine user acceptance of such device in a hospital setting.

II. Material and Methods

A. *Development of Vital Sign Monitoring Device*

The existential purpose of VITAL APP is to accurately measure and collect pulse rate, body temperature and blood pressure whose data may be used by health professionals to detect clinical deterioration [22]. Towards the achievement of this purpose, an IoT-based device was constructed based from the amalgamation of multiple hardware components. Body temperature is measured with LM35 precision integrated-circuit temperature sensor calibrated directly in Celsius with 0.5°C ensured accuracy. Temperature readings are recorded by connecting the Analog to Digital Converter (ADC) pin to a microcontroller. On the other hand, pulse rate is measured with pulse oximeter that sends two wavelengths to estimate the number of times a heart contracts per minute. Moreover, blood pressure (systolic and diastolic values) is measured with a sphygmomanometer. These modules and sensors are connected through Zencore microcontroller with LM2596 or Linear Monolithic integrated circuit as the adjustable power regulator that communicates through wireless technology protocol based on IEEE 802.15.4 standard for synchronous measurement of multiple vital signs. The schematic diagram of VITAL APP is shown in Figure 1. Following the IoT framework for healthcare monitoring systems [31], VITAL APP also comprises of a mobile android application and a web-based application (See Figure 2 for sample screenshot).

TABLE I. Modified Early Warning Scoring System (MEWS) for Pulse Rate, Blood Pressure (BP) Systolic, and Temperature

	Pulse Rate	BP Systolic	Temperature
3	-	≤70 mmHg	-
2	≤ 40 BPM	71-80 mmHg	≤ 35 ^{0}C
1	41-50 BPM	81-100 mmHg	-
0	51-100 BPM	101-199 mmHg	35-38.4 ^{0}C
1	101-110 BPM	-	-
2	111-129 BPM	≥ 200 mmHg	≥ 38.5 ^{0}C
3	≥ 130 BPM	-	-

B. *Vital Signs Measurement Accuracy Analysis*

Vital sign measurement accuracy was examined before the deployment of VITAL APP in a hospital setting based from the Modified Early Warning Score (MEWS) [32] – a simple, physiological scoring system for monitoring of vital signs. Both manual (nurse) and device measurements were recorded and compared using Bland-Altman analysis which has been established to be effective in clinical studies [33]. In the Bland-Altman plots, every data point represents the difference between vital signs and calculated MEWS by the nurse and VITAL APP. The dashed lines represent the limits of agreements while the middle solid line represent bias. A p-value of less than 0.05 was considered to be statistically significant by using Pearson correlation analysis. The MEWS table below was adopted from Kyriacos et al. [32] where three (pulse rate, body temperature, and BP systolic) out of seven physiological parameters were used for this study. Each parameter in the MEWS table has thresholds with a trigger score of an upper and lower 1 to 3, indicating deviation from 0 which is defined as the normal range.

C. *User Acceptability of VITAL APP in Clinical Practice*

Vital sign monitoring device has been established as an important tool in patient monitoring both inside and outside hospital settings [27-30], however, there are still conflicting views among health professionals concerning its impact on clinical staff-patient relationship [34]. Reduced physical and visual assessment, and decreased bedside interactions with nurses and physicians are among the perceptions of clinical staff [34, 35]. Therefore, it is essential to build evidence on clinical effectiveness and acceptability [24] of VITAL APP based on the perspective of end-users especially that their attitude influences the technology integration into healthcare [36]. To investigate the adoption decision of potential users towards the use of VITAL APP, IoT technology trust model [37] was used. Grounded from the Technology Acceptance Model (TAM) factors, the IoT technology trust model fused behavioral aspects with technological aspects and focuses on consumer trust together with its role in IoT adoption. The IoT technology trust model is comprised of three dimensions of factors such as security related factors (product or service security and perceived risk), social influence related factors (community interest and social network), and product related factors (perceived usefulness, ease of use, helpfulness, and functionality and reliability). Defined as a feeling of certainty that a particular person or object will not fail, trust is accepted as a motivational factor for IoT [37] and medical technology adoption [38]. It is essential that the model for evaluating the acceptability of VITAL APP, or any new device, is grounded from the element of trust since patients generally trust health professionals more than they trust unaided technology.

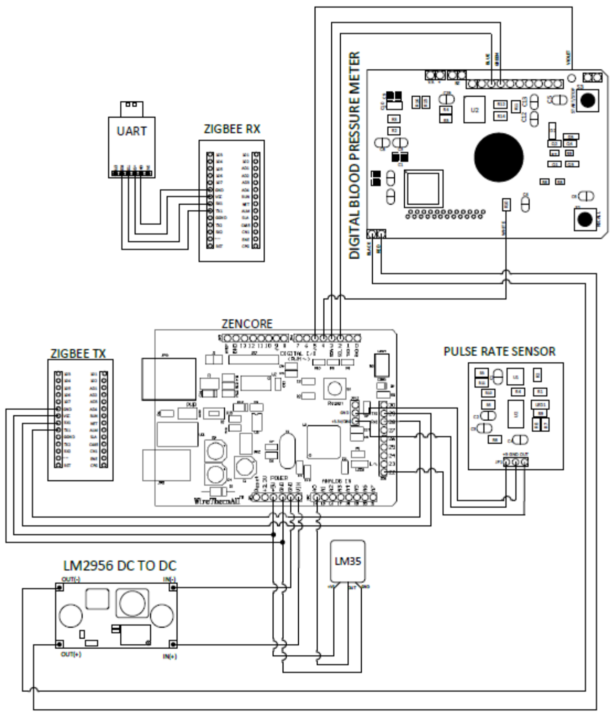

Fig. 1. Schematic Diagram of VITAL APP.

Fig. 2. VITAL APP Mobile Application and Web Dashboard Sample Screenshot showing Vital Signs Measurement.

III. Results

The main findings of the development of VITAL APP - an IoT-based patient monitoring device for synchronous vital sign measurement – were founded from the results of Bland-Altman and Pearson Correlation analysis of MEWS for accuracy analysis, and user acceptance of VITAL APP using the IoT technology trust model. With written informed consents, seventy inpatients from various diagnostic centers and hospitals participated in this experiment as the source of vital sign measurements, which took approximately 10-30 seconds per patient. Furthermore, one doctor and five nurses performed the manual vital sign measurement a minute after for accuracy analysis. Figure 3 shows the Bland-Altman and Pearson's correlation plots per vital sign. The calculation for Bland-Altman plots was conducted on RStudio [39] using R Programming Language [40] and scatter plots were created using ggplot2 library. The mean difference of the pulse rate between health professionals and VITAL APP-calculated scores was 0.45 breaths per minute (bpm) with 95% limit of agreement ranging from -5.4 to 5.3 bpm. Measurements of pulse rate indicate a moderately strong linear relationship based from the Pearson's correlation coefficient of 0.69 ($P < 0.05$). Moreover, the mean difference of body temperature between health professionals and VITAL APP was 0.12 degree Celsius (0C) with 95% limit of agreement ranging from -0.01 to 0.05 0C. Likewise, body temperature scores indicate a strong linear relationship based from Pearson's correlation coefficient of 0.81 ($P < 0.05$). Lastly, the mean difference of blood pressure between health professionals and VITAL APP measurements was 10 mmHg for systolic and 12 mmHg for diastolic with a 95% limit of agreement ranging from 22.4 mmHg to 21.3 mmHg for systolic blood pressure, and from 22.4 mmHg to 21.3 mmHg for diastolic blood pressure. The blood pressure measurements indicate a strong linear relationship for both systolic and diastolic based from the Pearson's correlation coefficient of 0.83 ($P < 0.05$) and 0.84 ($P < 0.05$), respectively. Clearly, the findings of VITAL APP produced visible differences when compared to results as measured by health professionals using their own devices.

The acceptance of VITAL APP was also investigated in order to determine the adoption decision of potential users. Table 2 summarizes the user acceptability based from IoT technology trust model in three dimensions of factors such as security related factors (product or service security and perceived risk), social influence related factors (community interest and social network), and product related factors (functionality and reliability, perceived usefulness, ease of use, and helpfulness). In terms of product related factors, VITAL APP does what is expected from it as a medical device and produces accurate vital sign measurements (87% strongly agree on Functionality and Reliability). The device is not only easy to operate but its graphical user interface both for mobile and web (see Fig. 2 for sample) is clear and easy to understand (82% strongly agree on Ease of use) and displays the necessary response from meaningful animated micro interactions to useful dynamic macro interactions for every process and task (83% strongly agree on helpfulness). Beneficiary of VITAL APP also believed that the use of this IoT-based monitoring device can dramatically improve their work efficiency and enhance their job performance (91% strongly agree on perceived usefulness). On the other hand, the social influence related factors have also received a promising rating. Those who used VITAL APP believed that people who influence them, both relative and non-relative, would most likely to like them to use the device for their own benefit (76% strongly agree on social network). Likewise, people from their community would most likely to possess the same perspective (81% agree on community interest). Participants also concluded that the medical data would be safe within VITAL APP (56% agree on product or service security). However, users were neutral (54%) when it comes to the perceived risk when using this custom-designed medical device for vital sign measurement. A possible explanation is lies on the perception of users that certain non-medical people develop and built the device without proper medical training, supervision or regulation of a panel of medical experts. Also, people tend to protect themselves when it comes to using new and unknown medical devices that may put them in jeopardy.

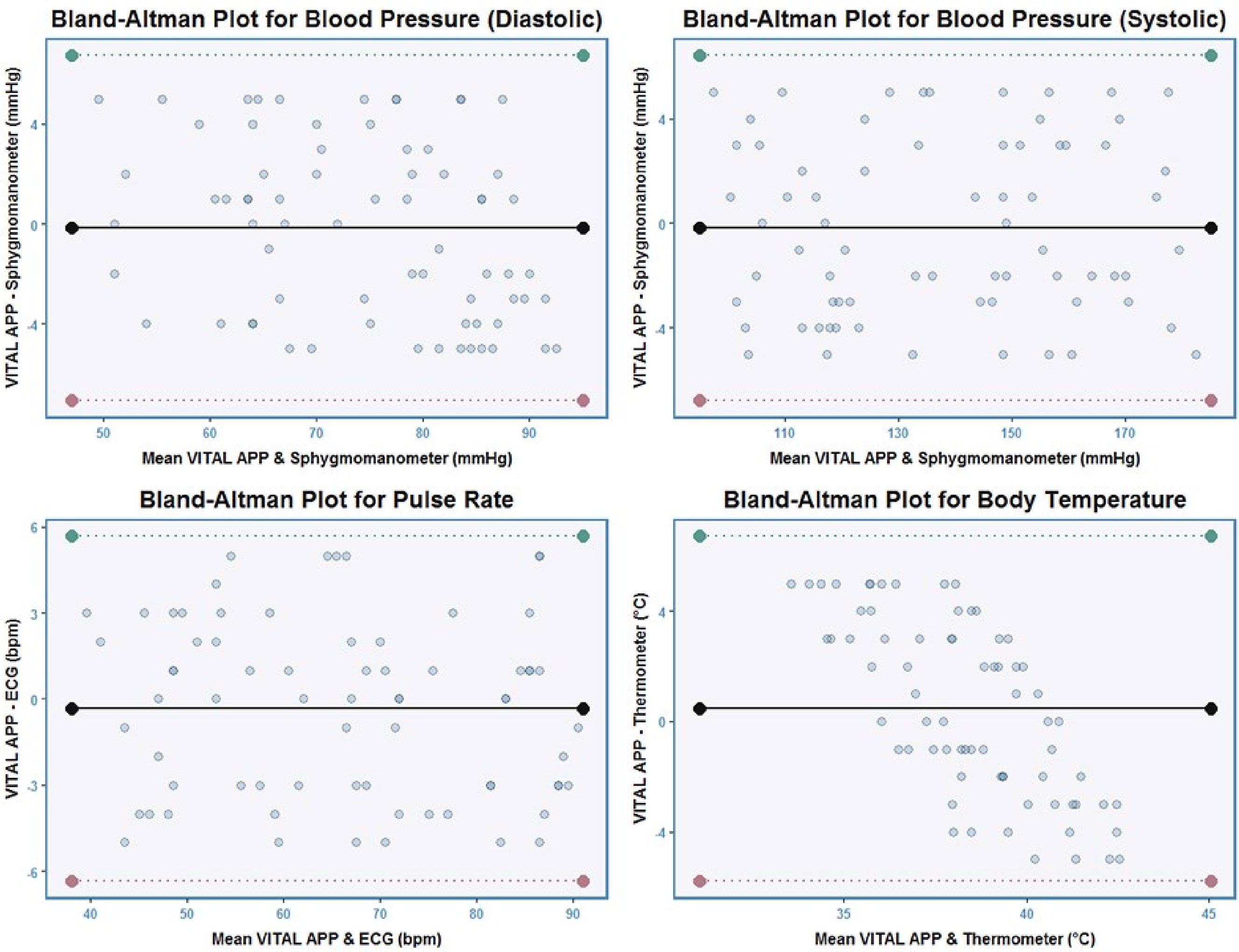

Fig. 3. Bland-Altman Plots for Vital Signs Measured by VITAL APP and Health Professionals.

Fig. 4. VITAL APP – An IoT-Based Patient Monitoring Device for Synchronous Measurements of Vital Signs.

TABLE II. USER ACCEPTABILITY OF VITAL APP USING IOT TECHNOLOGY TRUST MODEL

Dimensions	Factors	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Product Related Factors	Functionality and Reliability	87%	12%	1%	0%	0%
	Helpfulness	82%	16%	2%	0%	0%
	Ease of Use	83%	10%	6%	1%	0%
	Perceived Usefulness	91%	8%	1%	0%	0%
Social Influence Related Factors	Social Network	76%	12%	3%	6%	3%
	Community Interest	19%	81%	0%	0%	0%
Security Related Factors	Product or Service Security	6%	56%	31%	6%	1%
	Perceived Risk	9%	18%	54%	12%	7%

IV. DISCUSSIONS AND CONCLUSION

The measurements of vital signs are considered integral for patient care yet evidence of noncompliance in vital sign collection and inaccurate manual vital sign measurements have been a long standing issue in the medical field mainly in busy hospital settings. Problems such as these convinces healthcare providers to leverage HIT to improve the quality of their service and medical outcomes [5]. VITAL APP, an IoT-based patient monitoring device for synchronous vital sign measurement, is an example of how HIT can renovate and revolutionize patient care inside and outside a hospital environment. Driven by the latest IoT technology, VITAL APP can perform real-time vital sign monitoring that allows nurses to effortlessly observe patients' vital sign status while giving patients a normal life while being monitored. Apart from outdoor, real-time, and remote monitoring, the patient self-monitoring delivered a new sense of medical approach. When nursing their own vital signs, patients improved their self-efficacy and insights into their own health status [41]. Moreover, health professionals seemed to appreciate the fact that there is an additional tool at their arsenal that simplifies their work responsibilities since VITAL APP automatically documents vital sign measurements for later investigation.

In this study, the accuracy and acceptability of VITAL APP were examined in order to scrutinize the potential and the possibility of releasing VITAL APP into the public use. First, the accuracy of vital signs measurements was verified by comparing the measurements of VITAL APP and health professionals using Bland Altman and Pearson Correlation. Although there were some discrepancies in vital sign scores, the difference in readings was statistically insignificant. As little as the difference was, still, sensor calibrations will be performed on VITAL APP in order to improve the accuracy score. With it as being accurate as other measurement tools, VITAL APP can give a sense of peace and trust to its users that this new device could perform well, and possibly better, than the existing vital sign measurement practices. To build evidence on clinical effectiveness and acceptability, the IoT technology trust model was used to identify the perceptions of its potential users. This is vital to the study since there are conflicting views among health professionals concerning the impact of technology-aided vital sign monitoring on clinical staff-patient relationship [34] such as reduced physical and visual assessment, and decreased bedside interactions with nurses and physicians [34, 35]. Fortunately, both patients and healthcare professionals were unanimous in all of the factors of IoT technology trust model (except perceived risk where there was a neutral decision). Although, few doctors were concerned for the security and confidentiality of their patients' health information which is a common impression of patients and physicians alike when a new wearable health gadget [42], even an mHealth app [43], is being introduced. Meanwhile, the perceived risk factor divided the opinion of participants particularly on the effect of imprecise readings or when their medications and treatments heavily rely on the real-time monitoring by VITAL APP. Since perceived risk has been identified to have a direct effect on the intention to use a new technology service [44], it is critical to sway their opinions towards the proposed device. As recommended by Mittelstadt [45] in his paper about Health-Related Internet of Things (H-IoT), a trusting relationship between the H-IoT device providers and users can increase the degree of trust, which in turn could decrease the risks as perceived by users. One way for H-IoT device to demonstrate trustworthiness is by operating transparently which empowers users to hold H-IoT providers accountable for the impact of H-IoT on their medical care and quality of life. In a data-driven device like VITAL APP, it is critical to allow users to decide how their data should be shared (e.g., clear privacy policy, control to privacy features, online/offline mode). At the end of the day, it is only normal for people to want to protect their own data and maintain their autonomy especially when it is concerned with sensitive personal information like medical records.

In conclusion, VITAL APP poses a promising potential as an H-IoT device for concurrently monitoring vital signs. Installing VITAL APP in hospital settings could prevent the usual manual errors and be a time saving tool for nurses. For home uses, VITAL APP could serve as self-monitoring tool. For future works, other vital signs such as oxygen saturation (SpO2) and respiration rate could be incorporated onto the device. Clinical research has declared the oxygen regulation in blood as critical as other vital signs since an oxygen level below 90% can render a condition called Hypoxemia [46]. On the other hand, respiration rate monitoring is also crucial for patient care as the reduction of eight or fewer breaths per minute indicates patient deterioration [47]. Finally, diseases recognition and prediction via a machine learning approach using vital sign trends as the dataset could be accomplished as well although a recent systematic review concluded that the literature in intermittently monitored vital sign trends is still deficient [48]. Nonetheless, the fact that patients are the most important individuals in a medical care system means that healthcare providers must continuously improve patient care in order to accord to a positive patient recovery experience. VITAL APP is a testament of how healthcare providers can provide a better patient care, and aid health professionals to perform their job even better – a proof that HIT can indeed revolutionized patient care and the quality of medical care. The more efforts exerted on providing a quality medical care means that everyone can enjoy the benefits of having one.

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