iVital: A Mobile Health Expert System with a Wearable Vital Sign Analyzer

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***Abstract*—Vital sign monitoring is a core component of nursing care as information regarding 'vital functions' strengthen medical diagnoses. Consequently, various measurement devices have been proposed and utilized from wearable device to custom engineered equipment. To contribute to the existing innovations of monitoring devices for vital signs, this study proposed a different variation of such a medical device by incorporating the principles of an expert system together with its own wearable vital sign analyzer. At this stage of the project, the device (subsequently referred to as *iVital*) was a proposal with a prototype as final the product. The primary goal of *iVital* is to provide both patients and healthcare experts to continuously monitor vital sign measurements remotely. Further, and most importantly, it integrated an expert system where other important data (e.g., patient history and medical records) to detect early signs of clinical deterioration. This work, albeit prefatory, is an evidence of how expert systems can be used in healthcare.**

Keywords—Health Information Technology, Wearable Device, Mobile Application, mHealth, Vital Sign Monitoring

I. Introduction

Since the proliferation of information technology in the field of healthcare, numerous technological advancements have been introduced. According to a systematic review [1], there are three major benefits on quality of health information technology such as decreased medication errors, adherence to a guideline-based care, and enhanced monitoring and surveillance. Meanwhile, in terms of efficiency, it was exposed that decreased utilization of care was the major benefit. With its growing role in the field of healthcare, stakeholders such as policymakers, medical experts, and consumers view health information technology as critical in transforming and revolutionizing the health care industry [2, 3]. Nevertheless, a preceding limitation of health applications was its constrained usage on financial and administrative functions rather than on providing the best clinical care possible [4].

Fortunately, health information technology has moved from its common applications (e.g., hospital management system and computerized health record systems) to innovative solutions. It also started to focus on how patients can enjoy technology rather than concentrating on administrators or healthcare experts alone. For instance, a speech therapy game [5] was proposed not only for therapists to supplement their therapeutic exercises but also to allow patients to enjoy therapy sessions and monitor their own progress as well. In a systematic review, evidence suggests that gamification can have a positive impact for health and wellbeing related interventions [6]. Another example is the pillbox device that used microcontroller-based system for medicine adherence to medicine [7]. From the patient perspective, there are possible reasons as to why they fail to follow a medication routine. With this device, patients can be alerted and reminded when and what medicine to take. Assistive devices like *VISIMP* [8] are likewise becoming a common example of how technology revolutionizes the field of health provision and care. Not only do these devices assist people with disability to communicate but its application is also being maximized by older adults without a pathological communication problem, according to a systematic review [9].

Fig. 1. VITAL APP for Monitoring Vital Signs. Adapted from [10]

One of the areas in which health information technology has been effective is patient monitoring and surveillance [1]. When it comes to standard practices of health monitoring in hospitals, continuous vital sign surveillance is a fundamental component. For this reason, various measurement devices like *VITAL APP* [10] (Figure 1) have been proposed and utilized to automate the measurement of vital functions such as respiratory rate, blood pressure, pulse rate, heart rate, and blood oxygen saturation. Its main goal is to continuously monitor and record vital signs, and detect clinical deterioration that can lead to grave consequences. Following the proposal of *VITAL APP*, this study extended the work and proposed a new version of the mobile application with the integration of an expert system as well as a wearable device. By incorporating an expert system, vital sign measurements can be used to the next level by combining it with other data such as patient history and medical records. In terms of monitoring, the Modified Early Warning Score (MEWS) [11] was utilized as the physiological scoring system to identify patients with declining conditions. The motivation of the present study stems from the belief that patients are the most vital individuals in the medical care system, and healthcare providers and policymakers should attempt to provide the best possible patient care and formulate a strategy for achieving such important goal, respectively.

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II. Related Studies

A. Vital Signs

Vital signs are defined as an objective measurements of the physiological functions of a living organism, and traditionally consist of blood pressure, temperature, pulse rate and respiratory rate [12]. It is routinely measured from all hospital patients and customarily treated as the first set of clinical examinations. It is also taken at the time of triage in order to evaluate the degree of derangement which may help determine patient risk [13]. Early warning systems like MEWS (Table 1) is often use to assess the stability or deterioration of a patient's condition.

TABLE I. Calculation of Modified Early Warning Score

	SBP	HR	RR	TEMP	AVPU
3	< 70				
2	70 – 80	< 40	< 9	< 35	
1	81 – 100	40 – 50			
0	101 – 199	51 – 100	9 – 14	35 – 38.4	**A**lert
1		101 – 110	15 – 20		Reacting to **V**oice
2	>= 200	111 – 129	21 – 29	>= 38.5	Reacting to **P**ain
3		>= 130	>= 30		**U**nresponsive

Note: SBP = Systolic Blood Pressure (mmHg), HR = Heart Rate (bmp), RR = Respiratory Rate (bpm), TEMP = Temperature (°C).

Consistent vital sign collection and monitoring is important as the lack thereof means clinical deterioration will go unnoticed [13-15]. As the noncompliance in vital sign collection becomes a common problem, many hospitals have invested in automated vital sign monitoring devices for a more timely identification of clinical deterioration [16], e.g., early prediction of cardiac arrest [17]. Despite many advancements in monitoring technologies, a potential next level is to go beyond the recorded data. While we constantly monitor and collect vital signs, there should be a way to capitalize on such data to offer preliminary findings ahead of time. To accomplish this, vital sign monitoring technologies like *VITAL APP* must be integrated with other forms of technology.

B. Expert System

An expert system is a knowledge-intensive software that can perform activities or tasks that involve human expertise. It aims to solve problems by using domain knowledge-based reasoning constructed by a knowledge engineer based on the expertise and experience of domain experts. In its kernel, an expert system has two major components: (1) inference engine and (2) knowledge base. In overview, the inference engine attempts to match the condition (*if*) part of each rule in the knowledge base with facts currently available in the working memory. Once the knowledge base (i.e., facts representing the knowledge of domain experts) is built, an expert system can begin making inferences (i.e., rule interpreter) using forward or backward chaining. In comparison, forward chaining begins from facts to uncover information (e.g., conclusion or solution) while backward chaining is the opposite as it starts with a hypothesis and ends with known facts.

Recent decades have witnessed a significant research effort devoted to development of expert systems to deal with complex medical decision making (i.e., medical expert systems). Studies have shown that when medical expert systems are implemented properly can enhance health-related actions and decisions, and thereby improving quality of the care [18]. Consequently, a wide range of medical expert systems have been proposed, developed, and implement over the course of decades. Virtual dietitian [19] is an example of a nutrition knowledge-based system that uses a forward chaining algorithm to recommend personalized dietary recommendations. Albeit a great progress has been made, many challenges still exist around the life cycle of expert systems from acceptance [10] to performance evaluation [20]. As such, many enhancements are being proposed using modern technologies.

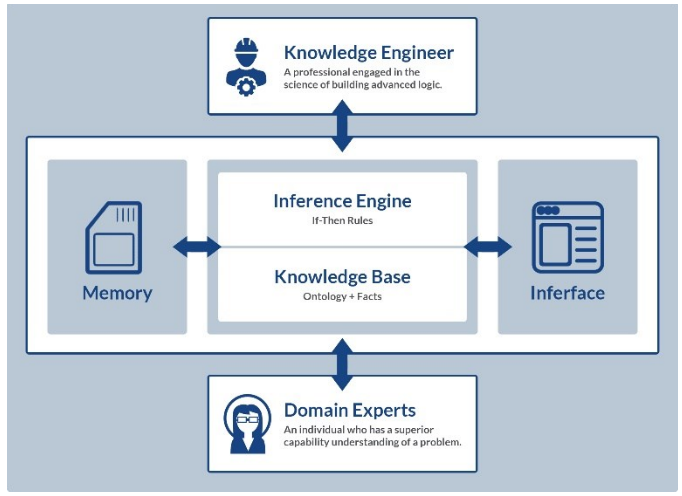
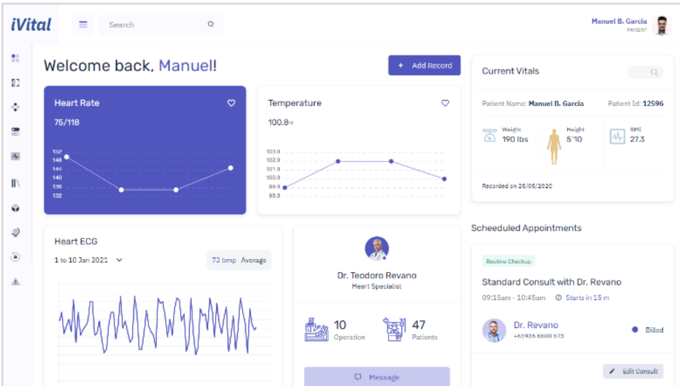


Fig. 2. Architecture of a Knowledge-Based System. Adapted from [19]

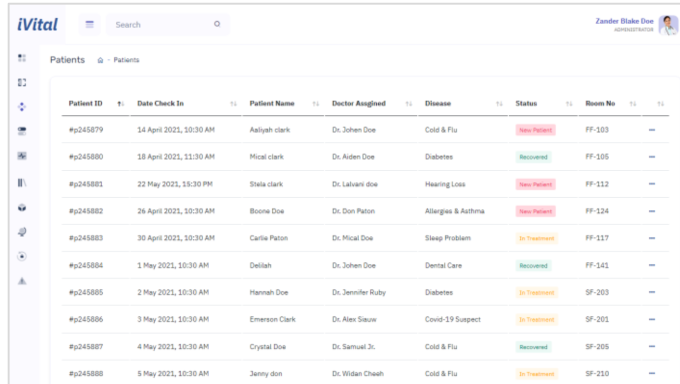
C. Wearable Device

In the medical field, wearable devices are becoming one of the most useful modern technologies. By linking to other smart devices, "wearables" connect doctors, patients, and other parties involved to facilitate various processes (e.g., gauge fatigue, track physical activity, collect vital sign measurements). To a certain extent, the wearable medical device industry have alleviated the shortage of medical resources in low-income countries [21]. In its common form, wearable devices have been designed for use on all parts of the human body. More specifically, these devices are classified into three categories: head, limb, and torso [22]. In terms of head wearable devices, this classification is primarily composed of helmets, glasses, earphones, earrings, hearing aids, and patches. On the other hand, limb wearable devices are often worn on the arms, legs, and feet [23]. Meanwhile, torso wearable devices primarily include belts, suits, and underwear [24]. Most of these wearable devices are used in rehabilitation [25], health monitoring [26], chronic disease management [27], and disease diagnosis and treatment [25]. Apart from Internet of Things (see Figure 3), wearables may also be used in vital sign collection.

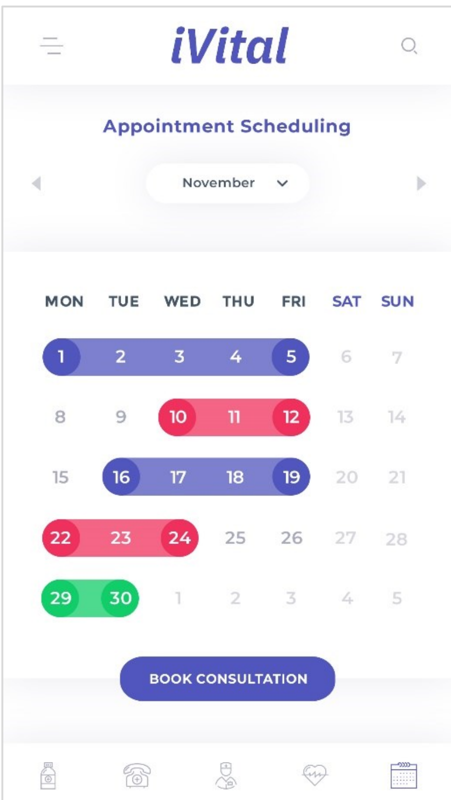
Fig. 3. Vital Sign Monitoring Device. Adapted from [10]



(a) Patient Dashboard

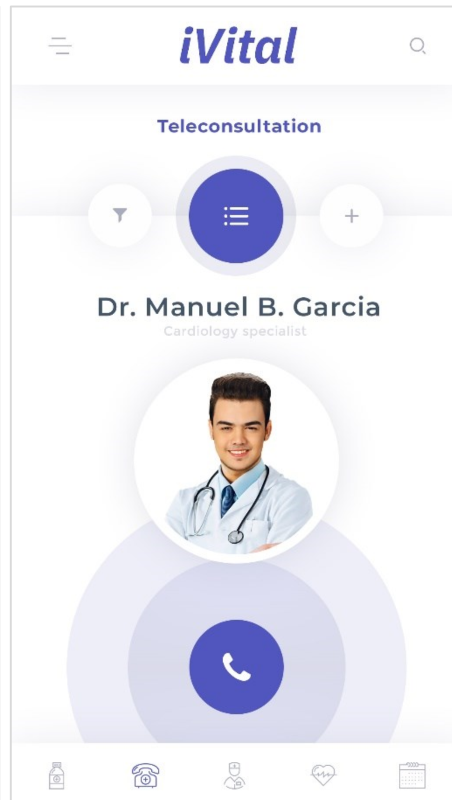


(b) Patient Management



(c) Appointment Scheduling

(d) Vital Sign Monitoring



(e) Teleconsultation

Fig. 4. Screenshots of *iVital* website (4a and 4b) and mobile (4c, 4d, and 4e) applications.

III. System Design

There are two points of access for both doctors and patients in *iVital*: website and mobile application. The web version aims to provide a backend system for all administrators and doctors where they can manage and monitor all data (see Figure 4b for an example of a management module). Although it is intended really for managerial transactions, patients also have an access to the web version (see Figure 4a for the patient dashboard) aside from the mobile application. Meanwhile, this mobile application is connected with the wearable vital sign analyzer, which makes it focused on the patient side. As long as the device is connected to the Internet and with a permission from patients, doctors can see all vital sign data remotely. Other medical records available in the system will be subjected to analysis of the expert system.

While the main purpose of *iVital* is to continuously monitor and collect vital sign data, it still includes the following features:

- **Appointment scheduling** – Book a physical or online meeting with doctors based on their availability.
- **Real-Time Updates** – Vital sign data is continuously uploaded online for further analysis.
- **Symptoms Checker** – Patients can detect a possible diagnosis by choosing a symptom.
- **Prescription Tracking** – Doctors can prescribe while patients can monitor medicine and its schedule.
- **Reminders and Notifications** – Every vital events are being reminded to all patients via SMS and email.

IV. Conclusion

As the present study is still at its infancy stage, the primary focus is to produce a working prototype first. It is crucial that the system is working accurately and that health recommendations through the mobile expert system are valid. Just like with *VITAL APP*, the next step is to perform a systems evaluation with health care professionals and patients both in a clinical setting and as a self-examination and measure the acceptance of stakeholders. It is also important to gather their feedback in order to determine how to improve (e.g., features and requirements) *iVital* usability and performance, as executed in another study [28].

In conclusion, *iVital* presents a more advanced variation than *VITAL APP* though the inclusion of its own expert system and a dedicated wearable device. It showcases its greater potential as a self-monitoring tool for patients who are staying at home, or simply wants to monitor their vital signs. Nevertheless, there are still some future works to be considered. For instance, machine learning can make sense of the data at scale, and produce a more accurate predictions. More specifically, it can play an important role in screening patients at the onset, for instance, through the use of classification algorithms. Although medical experts [29] have started to apply machine learning algorithms in analyzing vital sign data, it is still at the early stage and has not reached the systems production stage. Nevertheless, *iVital* is functional and ready to serve the healthcare industry to its best capacity.

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