A Novel Health Support System with Biometric Data Acquisition Device

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***Abstract*— At present, health related mobile applications have drawn considerable attention from researchers around the world. However, these applications only take disease symptoms as input from the users, but do not take vital signs of body into consideration. To provide vital signs, users need to collect data from external devices like blood pressure machine, blood glucose monitor etc. which may not be affordable for low-to-moderate income people. Besides, services that collects vital data from the user and provides directly into the system need internet connection for checking health status, which may be unavailable for people from less developed areas. The objective of our project is to present an effective health support system to the people from developing and underdeveloped countries in physical troublesome situations in a low-cost and user-friendly way. This system directly collects vital signs of body as biometric inputs with a health kit device. Using these inputs along with additional symptoms directly taken from the users, a mobile application checks their current health status and identifies chances of possible diseases with accurate severity level and provides suggestions accordingly. Moreover, it also provides first-aid counsels to handle accidents on emergency basis. The test results on the prototype show that it has encouraging potential as a tool for regular health checkups and emergency conditions.**

Keywords—health support; mobile health application; biometric data collector; human-computer interaction

I. INTRODUCTION

Access to proper healthcare and medical support is one of the basic human rights. Yet, according to World Health Statistics 2014 by WHO there are only 14.1 physicians per 10,000 people in the world [1]. More than 50% countries surveyed by WHO in 2013 are deprived of healthcare and proper medicine because of different reasons like poverty, living in remote areas, unavailability of well-equipped hospitals and so on [2]. Besides, a large number of patients reach an alarming stage of their diseases only because of late diagnosis. Study shows that more than 73% of breast cancer patients can have a 5-year relative survival rate if it is diagnosed in the third stage where the chances drop to 22% at the fourth stage [3]. Although the long term effects of stroke can be mostly averted if only it is diagnosed and treated within the first 4.5 hours, only 3-5% victims make it within due time because of late detection [4]. According to Bangladesh Health Facility Survey 2014, basic diagnostic capacity in health facilities is low [5]. Only 16-18% of Bangladesh health facilities can provide diagnosis and prescribe treatment for patients with diabetes or cardiovascular diseases. According to this survey, on an average, people get sick from low to medium risk diseases 5 to 6 times per year in each family. Besides, at least one member of the family has to be careful about long-term health issues like hypertension, acidity, back-pain, myopia or allergic reaction to particular food or animal. Only 5% of them have at least one person with proper medication knowledge. However, only 3% of them can consult a doctor before the situation gets very critical as 80% or more of health facilities do not have at least one staff member recently trained to provide necessary services. As a result, cases of wrongly assumed diagnoses and thus worsened conditions due to wrong medication are not rare. Moreover, financial problem, lack of proper medical knowledge and lack of access to information regarding hospitals and doctors also deteriorate the general health condition in underdeveloped and developing countries.

State of Mobile, 2013 – infographic (created by AF-Studio.pl and Super Monitoring.com) shows that almost 56% of all people on earth have a smartphone while they spend 80% of time on mobile apps [6]. Our idea is to use this emerging mobile technology to help people deal with health hazards in a low-cost and user-friendly way. Bearing this in mind, we conducted a survey among 30 families from our community to collect information about their likeliness of using a mobile application to help with health issues, whether they would prefer it with a supporting device or not, their expectation on the results/suggestions provided by the app, the highest cost level they are able and willing to bear for such a system and their expectation on the application's information delivering method. Based on the results of this survey, we propose a mobile based family health support system that takes disease symptoms and emergency conditions as input from the users and shows the list of possible diseases and provide suggestions or first aid instructions accordingly. Upon providing location, it also shows nearby hospitals and available specialists for the corresponding diseases. Existing health related apps [7]-[13] do not take the vital signs of body (e.g. pulse rate, blood pressure, respiratory rate, blood glucose level, and body temperature) as direct input that play key roles to assess the general physical health of a person, give clues to possible diseases, and show progress towards recovery [14]. Thus the detection of possible diseases by these apps is likely to be incorrect in critical situations. A possible solution is to input these vital signs as a disease symptom to these apps (e.g. high blood pressure, or high blood glucose etc.). However, in this case, the user needs to measure the vital signs manually using external devices e.g.,

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blood pressure machine, blood glucose monitor etc. which are rarely affordable for people with low income. Besides, operating these devices properly often requires a minimum extent of medical knowledge which general people of developing and under-developed countries hardly possess. To handle this problem, our system comes with a health kit device to collect five vital signs of body as biometric input. Moreover, we use a logistic regression model to accurately compute the severity level of the possible diseases. In summary, the contributions of our paper are as follows:

- We propose a novel health support system that accurately diagnoses probable diseases by measuring five vital signs of body with a biometric data acquisition device in addition to taking symptoms as input from the users into a mobile app.
- We compute the severity level of possible diseases using logistic regression model.
- We provide step-by-step first aid instructions on emergency conditions as well as show nearby hospitals and specialists.
- We present a comprehensive performance evaluation for our proposed system which shows high accuracy in measuring vital signs and detecting diseases. Besides, the usability test analysis of our system proves its potential as a user-friendly and cost-effective health support system for low to moderate income people.

II. RELATED WORK

The unprecedented spread of mobile technologies as well as advancements in their innovative application to address health priorities has evolved into a new field known as mHealth. According to the second global survey on mHealth by WHO, fourteen types of mHealth initiatives are conducted across the globe [15]. However, decision support system i.e., software that diagnoses diseases based on patient data and medical information, shows low global uptake within the surveyed regions (less than 25%, especially in low-income regions). Possible reasons of this low uptake is higher cost and inaccuracy in diagnose and treatment provided by the existing apps. There are a number of mobile applications (e.g. WebMD [10], Symptomate Symptom Checker [11], iTriage Health [12], First Aid [13] etc.) that have functions like symptoms checkup, condition matching or first aid instructions. However, none of these apps collect vital biometric inputs directly. In recent years, the most talked about biometric data trackers have been developed by Apple, Samsung and Sony Ericsson [6] [7]. Nevertheless, these devices are user specified and track mostly fitness data (e.g. walking or running profile using GPS, Pulse rate for tracking calorie loss etc.) rather than vital signs of body which are important to make disease decisions. Thus, the main purposes of the apps that can be interfaced with these devices (e.g. AmWell, Fitnet, MyFitnessPal) are either of fitness tracking, diet control, or sleep tracking [8]. Very recently, an e-health sensor platform has been developed for collecting biometric data for remote patient monitoring [16]. However, this system only takes biometric data as input, but does not take other symptoms (e.g., headache, pain, bleeding etc.) into consideration. Moreover, this kit and the associated mobile app need internet connection and continuous communication between patient and the medical staff for diagnosis of the disease. Similarly, the Wellness Support platform designed by NTT DOCOMO sends vital data of a person collected using a health device to the service provider via support server over internet and the service provider provides health related suggestions accordingly [17]. Again, Karada Karute by Tanita also provides web-based management of health data recorded by supported devices [18]. However, continuous communication between patients and medical staffs over internet is a striking problem for low to middle income people due to the shortage of medical staffs and health related service providers compared to the number of patients in developing and under-developed countries as well as poor, expensive internet connection. In this regard, we propose an effective offline health support system that comes with a low-cost biometric data input device and user friendly mobile application together.

Furthermore, though existing applications [10]-[12] can show the list of probable diseases based on the symptoms provided by the user, none of them show precise severity level or probability of the possible diseases. The severity level is important in order to determine whether the patient needs to be hospitalized immediately or not, whether medication should be started immediately or postponed for the time being, what amount of a particular medicine should be taken and what measures should be followed for quick recovery [19].

III. SYSTEM OVERVIEW

In this section, we give an overview of our system which has two subsystems - health status checking and first aid.

A. Health Status Checking

In this subsystem, a user (P) can check her health status to know whether there is a chance of developing any disease(s). At first, P selects the option to check health status in the mobile app. The app then switches on the health kit connected with it for taking biometric input. Using the health kit, P provides biometric input for five vital signs of body i.e. pulse rate, body temperature, respiration rate, blood pressure and blood glucose. After necessary processing and filtering, the health kit sends vital signs data to the app. At the same time, P inputs clinical factors (e.g. age, gender etc.) and additional symptoms (e.g. headache, bleeding etc.) within a scale from 1-5 into the app. In the database of the app, a number of diseases with possible symptoms and clinical factors are stored. The app finds out all possible diseases by matching symptoms stored in the database with the symptoms provided by the user. The whole process can be conducted without internet connection. The system architecture for checking health status is shown in Fig. 1.

Multiple symptoms and clinical factors contribute to a disease to different extents. The contribution factor of a particular symptom S_i is defined as $\beta_i = ln\ (\mathrm{OR}_i)$, where OR_i is the *odds ratio* of S_i. Odds ratio denotes the amount to which a particular symptom contributes to a disease. In a particular group of individuals, *odds* is the ratio of instance of the disease to that of its non-instance. Hence, *odds ratio* is the ratio of *odds* in that group of individuals having a symptom to that of those who do not possess it. If we consider a group of 10 people

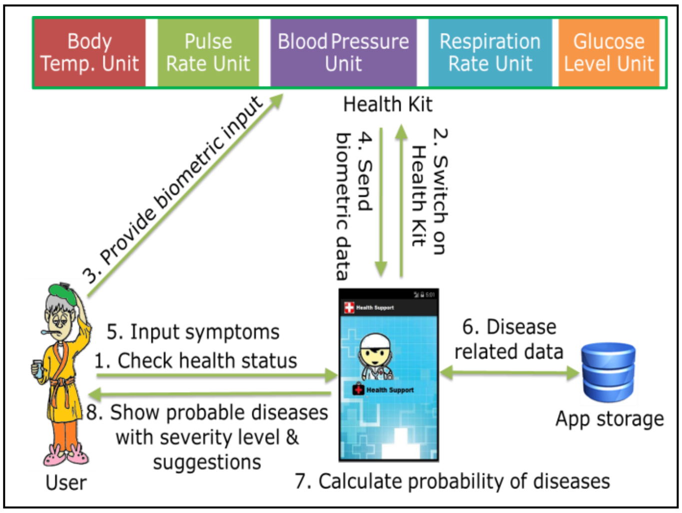

Fig. 1. System architecture for health status checking

affected by a disease X, among whom 6 are showing a particular symptom y and the rest are not, then odds of disease X for the individuals with symptom y is 6/4, i.e., 1.5. Similarly, in a group of 10 people without disease X (2 with symptom y and 8 without symptom y, *odds* of disease X for the individuals not showing symptom y is 2/8 i.e., 0.25. Thus, *odds ratio* associated with symptom y for disease X is 1.5/0.25 i.e., 5. Odds ratio of different symptoms and clinical factors corresponding to a particular disease can be found from the results of various medical studies. For example, odds ratio of the symptoms of cardiovascular disease can be found in [20].

Contribution factors i.e., β values are stored in the app database along with the symptoms and clinical data related to the diseases. We use a logistic regression model to calculate the accurate probability of a particular disease by weighted averaging these β values of the symptoms according to the following equation [21].

$$R = \ln\left(\frac{Pr}{1-Pr}\right) = \sum_{i=1}^{\lambda} \beta_i \times n_i \quad (1)$$

In this equation, R is the regression coefficient, Pr is the probability of disease X, λ is the total number of symptoms and clinical factors associated with disease X, β_i is the contribution factor of the i[th] symptom, and n_i is the value of the i[th] symptom. For simplicity, we let $n_i \in \{0, 1\}$.

For example, let n_i denote smoking behavior. Thus, if the patient is a smoker, $n_i = 1$ and $n_i = 0$, if she is not. Similarly, if the clinical factors are the results provided by health kit (glucose level) or demographic data (age etc.), those attributes can also be converted to binary form. For example, we can represent age of the patient in a binary form depending on whether it is greater than 40 or not.

Finally, Pr, the probability of disease X, is computed as below, which follows directly from (1).

$$Pr = \frac{e^R}{1-e^R} \quad (2)$$

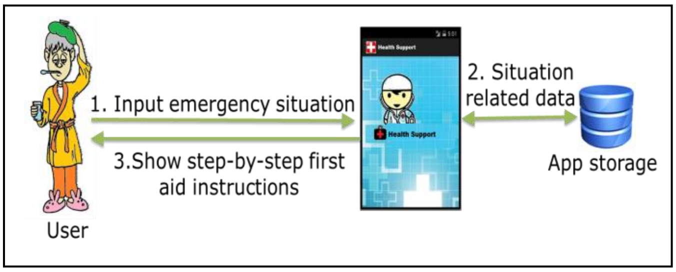

Fig. 2. System architecture for first aid

The final list of all possible diseases is shown to user P along with their respective probability or severity levels. Additionally, suggestions and supplementary health tips (e.g., necessary food habit, exercises etc.) are shown to improve the conditions. Depending on the severity of the disease/condition, the app suggests medication or consultation to specialists. It also shows nearby hospitals and specialists suited for the particular disease. For this, the app automatically sets the user's current location using GPS co-ordinates. User can also change their current location to any virtual location and see which hospital is nearby. We use Google Maps Android API to embed the map in our app. We note that internet connection is needed for finding nearby hospitals.

For regular checking of health status, users can create profile in the app with username and password to save their individual biometric data in the app database. In this way, they can regularly monitor if there is any significant change in their biometric data. This might be extremely useful for patients with chronic diseases like hypertension etc. For example, the normal blood pressure for an adult (age > 20) is 120/80 mm Hg. However, the regular level of blood pressure may be 140/90 mm Hg for a patient of hypertension. Thus, if his blood pressure ranges between 120/80 and 140/90 mm Hg, it will be normal for him, but not for another person possibly not having hypertension. If the patient's blood pressure rises over 140/90 mm Hg, then the app will show him necessary precautionary measures to avoid the risk of stroke. Thus, maintaining individual profile provides a convenient way towards personalized diagnosis and treatment of diseases.

Apart from searching for all possible diseases, user can also select a particular disease/condition to learn its basic symptoms and check whether he/she has chances to develop that particular disease by providing symptoms and biometric inputs. This is another helpful option for patients with severe chronic diseases like hypertension, diabetes etc.

B. *First Aid*

In this subsystem, a user can look for first aid instructions in case of emergency situations. Our app storage contains a list of first aid guidelines for common troublesome conditions like burning to various degrees, bleeding, snake biting, broken bones etc. If any such emergency occurs, user can select that condition in our app, and necessary first aid measures will be shown step-by-step with proper figures. It has also option to show the guidelines visually. A number of videos for most common emergency situations are embedded within the app. More videos can be streamed from our system website if internet connection is enabled. All the videos are not embedded within the app in order to minimize the storage overhead. The system architecture for first aid help is shown in Fig. 2.

IV. Description of The Health Kit Device

In this section, we describe the methodology of the health kit device which is designed to measure five vital bio-metric data e.g. body temperature, pulse rate, blood pressure, blood sugar level, and respiratory rate. At first, these biometric data are accumulated from the user through the health kit and then transferred to the mobile application for detection of possible diseases or health troubles the user might be suffering with. The complete procedure is described in three units: biometric data measurement unit, data processing unit and data transmission unit.

A. Biometric Data Measurement Unit

In this unit, we measure five vital signs of body i.e., blood pressure, body temperature, blood glucose/sugar level, respiration rate, and pulse rate.

1) Blood pressure measurment unit: In order to measure blood pressure of a person, we design a unit with an inflatable cuff, mini air pump, bleed valve, and a pressure sensor. The inflatable cuff is used to restrict blood flow when fitted on the wrist (elevated to heart height) or the upper arm of a user. Initially, the cuff is inflated by an electrically operated mini air pump to a pressure in excess of the systolic arterial pressure. Then the cuff is deflated by a bleed valve to reduce the pressure below diastolic pressure. The MPXV5050GP pressure sensor is connected to the cuff for measuring the cuff pressure every moment. Oscillometric method is used to interpret blood pressure value from the sensor output [22]. When blood flow is null (cuff pressure exceeding systolic pressure) or unimpeded (cuff pressure below diastolic pressure), cuff pressure will be essentially constant. On the contrary, when blood flow is present, but restricted, the cuff pressure will vary periodically in synchrony with the cyclic expansion and contraction of the brachial artery. The output from the sensor is passed to a data processing unit through a high pass filter for neccsary filtering. The procedure of blood pressure measurement is shown using a schematic diagram in Fig. 3.

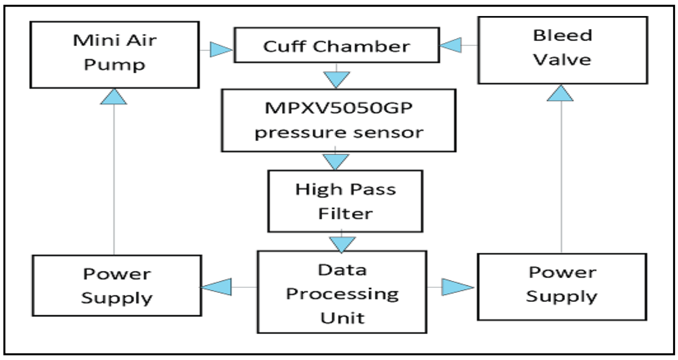

Fig. 4. Schematic diagram of blood glucose level measurement unit

The values of systolic and diastolic pressure are computed from the filtered data using analysis algorithm.

2) Body temperature measurement unit: For body temperature measurement, we use LM35 among several sensors (e.g., LM35, TMP36, Thermistor etc.) for its higher accuracy and wider range. The LM35 series developed by Texas Instrument are precision integrated-circuit temperature sensors [23]. Its output voltage (V_{out}) is linearly scalable to temperature, which is 10mV per 1° Celsius (Centigrade). So, mathematically, temperature in °C = (V_{out} in mV) / 10

For this reason, the LM35 sensor has an advantage over other linear temperature sensors, calibrated in °Kelvin, because the user do not need to subtract a large constant voltage from the sensor output to obtain convenient celsius scaling. The LM35 sensor can provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full -55 to +150°C temperature range without any external calibration or trimming. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. Thus, the interfacing to readout or control circuitry using LM35 is very simple and easy for its low output impedance, linear output, and precise inherent calibration.

3) Blood glucose level measurement unit: This unit measures the approximate concentration of glucose in blood. A small drop of blood, obtained by pricking the skin with a lancet, is placed on a disposable test strip. The test strip converts the glucose concentration in blood into a voltage signal [24]. It forms an electric circuit with a platinum and a silver electrode where hydrogen peroxide is electrolyzed. The hydrogen peroxide is produced as a result of the oxidation of glucose on a glucose oxide membrane. The current through the circuit provides a measurement of the concentration of hydrogen peroxide, giving the glucose concentration. Current produced in this way cannot be utilized unless it is changed to voltage for processing. We use trans-impedance amplifier and instrumentation amplifier for this conversion. The output voltage signal is sent to the data processing unit after necessary filtering. Finally, ADC (Analog to Digital Conversion) unit of the data processing unit analyses the voltage signal and infers blood sugar level from it. The schematic diagram in Fig. 4 shows the procedure of blood glucose level measurement.

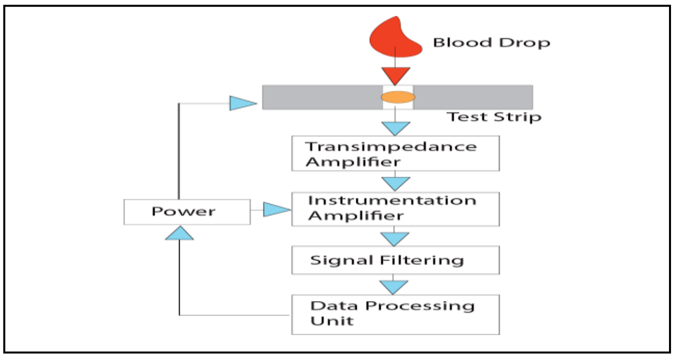

Fig. 4. Schematic diagram of blood glucose level measurement unit

4) Respiration rate measurement unit: A person's respiration rate is the number of breaths he takes per minute. The normal respiration rate for an adult at rest is 12 to 20 breaths per minute. Respiration rate can be measured by analyzing the level of oxygen in blood using an Oximeter. However, in 2014, the 'Child and Family Research Institute' of University of British Columbia launched an Android based mobile application named 'Rrate' that calculates the respiration rate using a simple interactive method [25]. In our system, we use an infrared sensor based device that incorporates the basic concept of this application. The user have to touch the designed switch while breathing and the data pin from the sensor combined with the comparator circuit gives 5V each time it receives a pulse. The pulse is transmitted to the controller for counting and further analyzing.

5) Pulse rate measurement unit: Heart rate, also known as pulse, is the number of times a person's heart beats per minute. We use the basic concept of pulse oximetry to design infrared (IR) sensor based device to measure the pulse rate of a user [26]. In this device, a clip is prepared with IR emitting diode which is attached to a reasonably translucent measuring site in the body with good blood flow, e.g., earlobe or fingertip etc. Opposite the emitter is a photodetector that receives the light that passes through the measuring site. At the measuring site, constant light absorbers such as, skin, tissue, blood etc. are always present. However, the heart contracts with each heart beat and there is a surge of arterial blood which momentarily increases arterial blood volume across the measuring site. This results in more light absorption during the surge. Light signals received at the photodetector are measured to find the peaks with each heartbeat and troughs between heartbeats. The amount of light absorption at the trough (which includes all the constant absorbers) is subtracted from the light absorption at the peak. The resultants are the absorption characteristics due to added volume of arterial blood only. Since peaks occur with each heartbeat or pulse, the number of pulse per minute can be detected from the received data which is then transmitted to the controller of the data processing unit.

B. Data Processing Unit

In our system, a multistoried data acquisition and pre-processor shield is designed to capture signals from data measurment sensors. Additionally, this sheild filters and amplifies the output of the data measurement sensors, if necessary and feeds it to the central data processing unit. For data processing, multiple hardware choices are available; e.g. Arduino, Raspberry Pi, Intel Galileo etc. However, we are currently using Arduino Mega 2560, as it is cost effective, most flexible & easy-to-use hardware with an embedded software platform.

C. Data Transmission Unit

Main challenge of our system is to integrate the biometric data collector unit (health kit device) with the Android operated mobile device. The integration between Arduino and

(a) (b) (c)

Fig. 5. Implementation of the proposed system, (a) biometric data input from the health kit, (b) symptoms input from the user, (c) diagnosis of disease with probability and suggestions.

Android is easier to achieve with the use of Google ADK. However, to make the device wireless, we used Bluetooth as the communication protocol in our system for receiving command from the mobile app to operate the health kit and transmitting biometric input data from the health kit to the mobile app. It was convenient for our system as Bluetooth is now available in every Android device. The Bluetooth Module Breakout, HC-05 is used as a wireless serial (Tx/Rx) cable.

V. PERFORMANCE EVALUATION

Android 4.4 - API Level 19 is used to build the prototype of the application. We conducted the experiments on Sony Xperia L. In Fig. 5, we illustrate three screenshots from our prototype implementation in which we show the steps of health status checking and diagnosis of a disease based on the biometric data of five vital signs taken from the health kit and input symptoms along with probability or severity level of the disease and necessary suggestions.

We evaluated our health support system in two parts. Firstly, we checked the accuracy of the five biometric data collection unit – blood pressure, body temperature, blood glucose level, respiration rate, and pulse rate. We took 40 trials for each of the five units and compared the output of our system with manually obtained results using separate devices widely used to measure these vital signs. Secondly, we analyzed the accuracy of our system to diagnose any disease with respect to the input symptoms and the biometric data inputs from the health kit. For each of the 40 trials, the disease and its probability diagnosed by our system is compared with the diagnosis of medical professionals and other symptom checker applications. The result of our experiments are summarized in Table I.

TABLE I. PERFORMANCE EVALUATION OF HEALTH SUPPORT SYSTEM

Name of the test	Success rate
	80% (32 times)
Respiration rate measurement	60% (24 times)
Pulse rate measurement	52.5% (21 times)
Diagnosis of disease	
	72.5% (29 times)

We note that our prototype health kit device showed nearly accurate results in measuring body temperature, blood pressure and blood glucose level. The slightly increased error percentage in pulse rate is due to the fact that pulse rate depends on whether the person is sitting or moving, air temperature, and even emotions [27]. Moreover, if a user is aware that his/her respiration rate is measured, its value may also fluctuate significantly [28].

Additionally, a usability test was conducted among 20 people to evaluate the usefulness of our health support system. One of the participants was a doctor while the rest had no/marginal medical knowledge. Six of them were going through some chronic health issues like hypertension, diabetes etc. At the end, we supplied a questionnaire (on Lickert scale 1 to 5, where 5 is excellent) to each participant to receive their overall feedback. The test result is showed in Table II.

TABLE II. USABILITY TEST RESULTS

Criteria Scale	Health Kit	Health Status Checking	First Aid	Understandability
Poor	0	0	0	0
Moderate	0	0	0	1
Good	3	2	1	4
Very good	8	10	3	13
Excellent	9	8	16	2

In response to the question whether the app could successfully predict the disease/condition based on symptoms provided, 40% rated 5/5 (accurate prediction), while another 50% gave 4/5 (nearly accurate). 53% of the testers indicated that they were highly satisfied (5/5) with the suggestions the app came up with, while another 35% told that suggestions were quite satisfactory (4/5). 30% participants have used other health apps before and 86% of them rated our system much better (4/5) compared to those apps. 75% of the participants with no prior medical knowledge commented that the instructions of the app were quite easily understandable (4/5) to them, while 87% of them told that the interface of the app was highly supportive (5/5). Moreover, 80% participants showed remarkable interest (4/5) to use the app if launched in the market. In response to whether our biometric data collector supporting device was helpful, all of the participants came up with a positive answer (5/5). Thus, the usability test results show that our health support system has significant potential for practical use and further improvement.

VI. CONCLUSION AND FUTURE WORK

In this paper, we present the design and implementation of an efficient, cost-effective and user-friendly health support system, especially for people of underdeveloped countries with low-to-mid level income. Our proposed system correctly diagnoses various diseases with respect to the input symptoms and conditions given by the user, predicts the probability or severity level of the diagnosed disease with near perfection and provides necessary suggestions along with nearby hospital locations, if needed. Additionally, for regular health status checking, our system comes with a compact health kit device to measure the vital signs of body using biometric inputs from the user. Moreover, health tips and first aid suggestions in case of emergency situations are also provided by our system.

In future, we intend to provide personalized health tips and regular prompting for timely check-up. As an improvement of the health kit device, we aim to provide options for electrocardiography (ECG). We also intend to include audio-based health tips and voice recognition system for taking vocal input from the users to improve understandability and effectiveness of the system.

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