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Smart healthcare support for remote patient monitoring during covid-19 quarantine

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A R T I C L E I N F O

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A B S T R A C T

Social distancing and quarantining are now standard practices which are implemented worldwide since the outbreak of the novel coronavirus (COVID-19) disease pandemic in 2019. Due to the full acceptance of the above control practices, frequent hospital contact visits are being discouraged. However, there are people whose physiological vital needs still require routine monitoring for improved healthy living. Interestingly, with the recent technological advancements in the areas of Internet of Things (IoT) technology, smart home automation, and healthcare systems, contact-based hospital visits are now regarded as non-obligatory. To this end, a remote smart home healthcare support system (ShHeS) is proposed for monitoring patients' health status and receiving doctors' prescriptions while staying at home. Besides this, doctors can also carry out the diagnosis of ailments using the data collected remotely from the patient. An Android based mobile application that interfaces with a web-based application is implemented for efficient patients-doctors dual real-time communication. Sensors are incorporated in the system for automatic capturing of physiological health parameters of patients. Also, a hyperspace analogue to context (HAC) was incorporated into the current monitoring framework for service discovery and context change in the home environment towards accurate readings of the physiological parameters and improved system performance. With the proposed system, patients can be remotely monitored from their homes, and can also live a more comfortable life through the use of some features of smart home automation devices on their phones. Therefore, one main significant contribution of this study is that patients in self-isolation or self-quarantine can use the new platform to send daily health symptoms and challenges to doctors via their mobile phones. Thus, improved healthy living and a comfortable lifestyle can still be achieved even during such a problematic period of the 2019 COVID-19 pandemic that has already recorded 20,026,186 million cases so far with 734,020 thousand deaths globally.

1. Introduction

Independent and convenient, healthy living is the aim of any human being no matter their age, gender, location or health status. However, there are limitations due to age, illness, medication, hospitalization, epidemic, pandemic and other circumstances. Health monitoring systems have evolved to assist convenient healthy living, more accessible communication between healthcare givers and patients for close monitoring, measurement of vital health parameters, routine consultation and overall healthy living. Moreover, with the recent advances in information and communication technologies (ICT) through the adoption of Internet of Things (IoT) technology, smart health monitoring and support systems now have a higher edge of development and acceptability for enhanced healthy living.

The study conducted by Zikali [1], revealed that with the rapid increase in the population of older or senior citizens, patients who require health monitoring have also increased exponentially. The same study predicts that by the year 2045 the number of senior citizens who are considered the most vulnerable in society will exceed the number of children and young adults as a recent population census shows an increase in older people. However, a shortage of home health helpers, nursing assistants and home healthcare givers is looming worldwide, which makes care for the elderly expensive. Therefore, a health monitoring system can play a vital role in lessening physical contact,

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hospitalization, consultation time, queuing list and overall health cost for a patient while also reducing workload, burden and stress on medical staff [2]. Advancements in information and communication technologies for connectivity anywhere and anytime make a valuable contribution to the development of the modern healthcare system utilized in telemedicine solutions and other portable medical platforms.

The advent of smart home technologies proposes healthy living and improved quality of healthcare support services for the elderly and handicapped for independent and comfortable lifestyles while at home, instead of nursing homes, hospitals or other confinement facilities. The healthcare module, as a part of the smart home automation system, will improve healthcare facilities for patients while at home or in remote locations outside the hospitals. Thus, there is a reduction in depression that arises from loneliness in the hospital wards for patients. The doctors can monitor patients from their office, prescribe medication and view measured vital health parameters for a remote diagnosis. Also, the rapid improvement of software and hardware technologies in the smart home healthcare system, makes it possible for patients, especially the elderly or disabled, to control certain home appliances with ease from devices such as smartphones, tablets, laptops, internet, etc.

A smart home healthcare environment comprises of numerous computing devices acting proactively on behalf of users, thereby making such an environment pervasive. Therefore, for decision making in a smart home healthcare environment, user context and preferences are some of the vital features to be considered for the user to make any choice of interest among available resources and services in any given situation [3]. Also, the context-aware paradigm gives an insight into some factors within the home that influence the output of physiological readings. These factors are explained in this paper. The user context refers to any information that could be used to describe the situation of an entity (person) concerning their physiological medical status or needs.

In this paper, we propose a mobile application-based prototype smart home healthcare system for efficient and effective health monitoring for the elderly and disabled for their convenient and independent living while at home. A section of the proposed system allows the patient to remotely upload or capture essential health symptoms information during an era of a pandemic such as the ongoing COVID-19 disease for their doctor's assisted diagnosis. The new healthcare support system measures and records specific health parameters such as weight, pulse, blood pressure, glucose level and body temperature. Also, it assists with the control of a few home appliances for the conducive home living of the user. This system is also designed to send a reminder to patients on the use of certain medications with input supplied by the user. An algorithm was developed based on Hyperspace Analogue Context (HAC) for a pervasive environment, to address the need for choice for the user among numerous devices placed in the smart home healthcare system.

The technical contributions of this paper are as follows:

- A proposal for a smart health support system for remote patients monitoring during quarantines.
- Implementation of IoT based smart home healthcare support framework capable of reducing unnecessary burdens on the hospitals due to disease outbreak. Mainly, the new system which is also able to provide essential comforts using the IoTs enabled home appliances only, encourages patients with severe and critical conditions to utilize hospital facilities.
- Extraction and interpretation of patient's health data from wearable, built-in, and mobile sensors for medical diagnoses and prescriptions.

The remainder of this paper is organized as follows: Section 2 provides the review of related works and overview of health monitoring support systems, Section 3 discusses the proposed system motivation, conceptualization, and design methodology, while in Section 4, the details of the new smart healthcare support system implementation are discussed. Finally, Section 5 provides concluding remarks, recommendations, and future directions.

2. Related works

Advances in the development of smart home automation technologies and e-healthcare systems allow people to enjoy in-home medical services without staying in hospitals. Remote health monitoring of patients through home health care technologies assists healthcare givers, medical personnel and physicians to reach out to patients without physical contact or presence of patients at clinics or hospitals. Health care technologies also save cost, expenditure and stress for patients as they do not need to travel before seeing their healthcare givers or medical personnel. There have been many published articles in the area of smart health care system, e-health and remote healthcare. Authors in Ref. [4] proposed an e-health care system for monitoring patients' vital physiological parameters by doctors from any location. The proposed system is capable of collecting the required data from the patient and making it available and visible to the doctor for action. The web application is a feature of the system that allows the doctor to record the patient's information, input notes for advice, prescription and dosage of drugs while also allowing the patient to key in measured psychological parameter values and display of information received from the doctor. Smart TV application was used for reminding patients daily about their activities, medications and other events. Lastly, the system has the feature of a mobile application with the same functionality as the web application but with an added advantage of access from anywhere and at any time.

Sparsh and Agarwal [5] described a remote health monitoring system for the collection of blood pressure values from patients through mobile phones. Values recorded on mobile phones are supplied and displayed to doctors or caregivers through the web interface in the system. Doctors can monitor and manage the patient's condition through the system and provide feedback to the patient remotely. A secure IoT based modern healthcare system using Body Sensor Network (BSN) referred to as BSN-Care was proposed by authors in Ref. [6]. The proposed system measures and monitors physiological parameters such as blood pressure, electrocardiogram (ECG), and electroencephalography conditions in the body through wearable sensors. The values of measured parameters are collected and sent to the Local Processing Unit, which is also the coordinator of the system. Data received by the BSN-Care server from the body of the patient are fed into the database for analysis. Based on the analysis and degree of abnormality in the values, the system alerts either the family member, local physician or emergency unit contact of the patient. The system is secured using a lightweight anonymous authentication protocol, which confirms the identity of anyone using the BSN-Care server. For privacy, data integrity and data freshness, the Offset Codebook (OCB) authentication encryption scheme was used.

Minh Pham et al. [7] presented a cloud-based smart home environment named CoSHE for a home healthcare wearable unit, a private cloud and robot assistant. The CoSHE system collects physiological, motion and audio signals from residents thorough non-invasive wearable sensors and thus provides information about the daily activities and location of residents in the home. Comprehensive health data are provided to caregivers and caretakers through a web application built on the cloud server of the system. The system also has a hydration monitoring application for continuous monitoring of water consumption levels and daily fluid requirements of the patient. Hydration monitoring is achieved by the use of acoustic data collected from microphones and body activity context derived from a smartwatch accelerometer in the system.

A smart home integrated system that runs on an Android operating system, for ambient assisted living for people living with dementia, was presented by Eren Demir [8]. The design of the system allows the collection, recording and transmission of data through cloud application. The system involves seven types of sensors to detect a person's position, whether standing or sitting, flame detection and use of specified appliances in the home. Also, the sensors remind or alert the patient if he or she forgets to carry out specific tasks in time. A switch is also installed in the system to detect if the light is on or off. The system is also designed to identify the activities of patients and send information to the doctor or caregiver. Data are retrieved from different sensors placed in specific locations in the home for processing.

Bilal and Khaled [9] proposed a wireless remote-control home automation system for the elderly, handicapped, decrepit and disabled persons. The system was designed for easy movement, control and monitoring of essential home appliances for people with locomotion difficulty. Users of the system can control or monitor appliances through a remote control device that sends orders wirelessly using XBee trans-receivers. Features of the remote control are control buttons for different appliances and LCD for message notifications. The proposed system was implemented using a wooden prototype version.

Min Chen et al. [10] proposed an E-healthcare management system based on a second-generation RFID system. The system for monitoring the medical condition of the patient, communication between the patient and the doctor or health caregiver as the case may be is through video conferencing calls via the internet. The system is also capable of information collection and transformation for medical emergencies handling. Physiological signals such as temperature, blood rate and heart rate are obtained from the patient through a body sensor attached to a particular part of the patient's body. The system also maintains a healthcare database of the user's profile and medical history.

Andrea et al. [11] proposed a smart sensing technique based on an integrated sensor network for monitoring the user's home and environment in order to derive information about the user's health status and behaviour. The authors' proposed platform includes sensors that are biomedical, wearable and unobtrusive for monitoring physiological parameters such as ECG, heart rate, breathing waveform, breathing rate, blood pressure and so on. An application on a smart device such as a tablet was proposed for the user's interaction with the sensors. Data collected through the application are further sent to the cloud for storage and data analytics towards services for the elderly. Moreover, Abdelsalam et al. [12] designed a smart home-based software architecture for assisted monitoring of diabetic patients. The system is intended to monitor activity, diet and exercise compliance of patients and evaluates the effect of alternative medicine and regimen through personal connected devices and smart home technologies. Wearable devices are used as connectivity to technology in the architecture.

An Android smartphone application for elderly, assisted independent living at home was developed by Muhammad et al. [13]. The application tracks and monitors the daily activities of the user and serves as a reminder for the scheduled activities of the patient. The system also gives alerts in case of incomplete, critical and overlooked scheduled activities. Other functions and actions performed by the system include tracking of environmental conditions (humidity, temperature, location and gas leakage), giving details of the patient's activity list and reminders to family members and healthcare givers.

Hossain [14] proposed a smart home healthcare system to fulfil the needs of older adults for continued care. The patient's health condition is monitored through the use of multimodal inputs (speech and video) in the proposed system. Videos and speeches of the patient are captured continuously through sensors from video cameras, and microphones installed in the home, transmitted to a dedicated cloud for processing, and classification scores are produced. Doctors prescribe and render services through audio or video messages depending on the outcome of the classification score, whether normal, tensed or in pain.

Saiteja et al. [15] proposed a smart home health monitoring system for remote monitoring of diabetes and blood pressure in patients. The system assists in analysing the patient's blood pressure and glucose readings from home, sending a notification to the caregiver or healthcare provider if an abnormality is detected and also predicting the status of hypertension and diabetes in patients by training results obtained from the readings. For the model training, support vector machine classification was employed to provide effective and efficient training task. Also, the system is capable of sending alerts and real-time notifications from home about the patient's health to a registered physician or clinic.

Kashif et al. [16] developed a smart home system based on Information and Communication Technologies (ICT) for the elderly, using an Android platform. The system was developed to improve the quality of life for elderly persons, prevent electricity wastage and preserve human energy simultaneously through remote access. The system also controls environmental parameters according to the health status and living needs of the elderly and triggers alerts in the case of intrusion and home invasion.

3. Motivation and conceptualization

The provision of services through assisted means enables a comfortable and convenient lifestyle. The primary role of any smart home automation system is to assist users in remotely controlling and monitoring appliances. With this in mind, we are motivated to develop a system that not only controls and monitors the home but also supports an improved healthy lifestyle of users. Smart home automation as an emerging area of IoT has been applied in various areas such as: easy and assisted daily living especially for the provision of support to humans [17], remote control of home appliances [18,19], detection of movement in the house [20], energy management in the home [21] and security [22], and provision of healthcare services to out-patients, disabled and elderly persons [10,23,24]. However, the design of a system for both health monitoring and home control is yet to be fully explored. Considering this, we look at a scenario whereby John has just been discharged from the hospital but still needs his physiological vitals monitored closely by his doctor, and he is advised to bed-rest at home. For John to enjoy being at home, he needs some convenience, such as putting on the television while lying on the bed, and controlling a fan or light while still in bed. We decided to aid people in John's condition by proposing a smart home-healthcare automation system. The proposed system monitors and records physiological parameters in a module, sends recorded parameters to the doctor and controls the home as well.

The second motivation comes from the pandemic currently ravaging the globe. Social distancing, less physical contact and staying at home orders are issued by the government to control the spread of the virus. People who have been in contact with positively tested individuals, but who are not showing symptoms, are also counselled to self-isolate or self-quarantine for some days. Positive patients with mild symptoms are advised to observe quarantine. The self-isolation or quarantine can be observed from home while the affected person sends signs or symptoms of any ailment observed to the doctor at regular intervals. To this end, we are motivated to broaden the scope of the smart home healthcare system to accommodate the upload of symptoms affected by COVID-19 from the comfort of their respective homes.

There may be some instances whereby the user might need to change his position in the house, increase or decrease the home temperature, and other environmental factors that might affect the physiological parameters recorded. To address the external factors that influence the values of the physiological readings, we build on the discovery approach used by authors in Refs. [25]. The approach is based on Hyperspace Analogue to Context (HAC) in a pervasive environment. The HAC concept implemented for the current study is discussed below.

3.1. Hyperspace Analogue to Context (HAC)

In smart home-healthcare, HAC is a formal model to define the multidimensional context in space [25] (*in our work, space refers to a domain where entities have dependencies. For instance, in the space of checking John's vitals, time, location and medication taken by John have relations that can influence the values of his physiological vitals*). There are basic definitions of HAC related to operations. These are further explained in the next subsection using smart home healthcare context types.

3.1.1. Smart home-healthcare context types

Healthcare in a smart home comprises different elements such as the user, location of the user, his activities, environmental conditions and other related parameters. To adequately understand the correlation between the user and his activities, context is required. According to Refs. [26], context is any information that can be used to describe the situation of an entity. Dimensions for HAC are formed based on specific context types. Due to the complexity of a pervasive environment, the number of dimensions may be large [3]. For our work, the significant fractions of applicable dimensions are used, as indicated in most context descriptions. The major context used to describe the situation of the user are location, time, physiological condition, activity and atmospheric and environmental conditions.

3.1.2. Position

To get an accurate value of a specific physiological parameter such as blood pressure, the position of the patient is of significant consideration. For instance, it is not recommended to take the readings of blood pressure while standing. Position influences the values obtained either on the systolic or diastolic value. Therefore, the recommended position is sitting straight up or lying down comfortably [27]. Location can also be added to the position to effectively record the range of the value.

3.1.3. Time

Time influences the results and conclusions of doctors for prescription of medications. Time describes activity happening and surrounding. Some medications or prescriptions are recommended to be taken with breakfast and others at night. If a patient misses the right time for taking a specific dosage, it may trigger some health conditions which the doctor will need to consider before concluding the patient's health condition.

3.1.4. Environmental condition

Weather and indoor environmental conditions, for example, absolute humidity and temperature influence physiological conditions of the patient in so many ways. A patient might have a high fever yet his body temperature has a reading that falls within the normal range during the winter season. At the same time, a patient without a high fever might have a high trigger in his body temperature when readings are taken in a hot environment or a closed room with a heater on. Therefore, atmospheric conditions must be taken into consideration for a better summary of the health of a patient. Subsequently, we now present some significant definition of terminologies used in this study concerning service discovery and context change relative to the HAC.

3.2. Basic definitions

Definition 1. (n-dimensional HAC): A n-dimensional HAC is a space $\mathbb{S} = < \mathbb{D}_1, \mathbb{D}_2, \cdots, \mathbb{D}_n >$ where $\mathbb{D}_i$ represents each dimension as a type of context. Dimension in HAC refers to an informative label used to describe other data in the space alongside their type and value set for a specific context. Examples are time, physiological condition, location and position. The values of a dimension can be continuous or discrete, depending on the data type [25]. This work will take into consideration blood pressure with a normal value range between 110/70 mH g and 140/90 mH g, and normal sugar level values between 70 and 100 mg/dl.

Definition 2. (Context Point): The context point of an object γ in space $\mathbb{S}$ is $C^{\gamma} = < d_1 d_2, \cdots d_n >$ where $d_i \in \mathbb{D}_i$. The context of a device or appliance in the home is described as a point in HAC. In our work, the context of John may be $< d_{position} = \textit{lying down}, d_{BP} = \textit{normal} >$, where *BP* denotes blood pressure; when the BP value is not within an expected range, it can be put as $< d_{position} = \textit{standing}, d_{BP} = \textit{abnormal} >$.

Definition 3. (Context Scope): A context scope $\mathscr{C}$ is a subspace in $\mathbb{S}$, $\mathscr{C} = < \mathscr{D}_1, \mathscr{D}_2, \cdots \mathscr{D}_n >$, where $\mathscr{D}_i \subseteq \mathbb{D}_i$. A context scope limits the value sets for the dimensions. It is mostly used to describe a condition. For example $< \mathscr{D}_{\mathscr{BPS}} = [110, 111, \cdots, 140], \mathscr{D}_{\mathscr{BPD}} = [70, 71, \cdots, 90] >$, where $\mathscr{D}_{\mathscr{BPS}}$ describes the systolic value for normal blood pressure and $\mathscr{D}_{\mathscr{BPD}}$ describes the normal diastolic value of blood pressure readings. Blood pressure has both upper and lower bound values measured in units of millimetres of mercury (mmHg). The readings are always given in pairs with the upper bound (systolic) value first, followed by the lower bound (diastolic) value.

Definition 4. (Context Change): Movement of a patient must be taken into consideration in addition to monitoring and measurement of physiological parameters. Important information about a patient's health condition can also be derived by monitoring the walking pattern [28]. To denote the movement operation of a patient in the home concerning health influencing factors, context change is required.

The context change is an operation to change a context point. It is defined as $\times \Delta c = < \Delta d_1, \Delta d_2, \cdots, d_n >$, Δd_i denotes the new value for a dimension, $d_i^{'} = d_i \times \Delta d_i$. If d_i does not change, $\Delta d_i = \varnothing$.

The above definitions are applied to our ShHes environment for detecting the factors that can influence the output of measured physiological parameters. For instance, if the indoor temperature of the home is high, it might affect the body temperature of the patient. Likewise, if a patient is in a standing position while blood pressure is being measured, the corresponding value of the measured blood pressure might be high either on the systolic or diastolic readings. To further apply the HAC contexts in our work, an algorithm (Algorithm 1) was developed on steps to consider these factors in order to get actual readings and for diagnosis by the doctor.

3.3. Overview of the proposed system

With the advent of the IoT, remote health monitoring, consultations and prescription have been made a reality while patients are at home. IoT technologies have made medical equipment smart; examples are sensors, actuators, microcontrollers and boards that have made it easier for doctors to have the patient's data and oversee their health without a visit to the hospital. On the patients' side, it has greatly assisted in stress reduction as patients do not need to waste time in queues in hospitals, and again, they can send and receive information from their doctors through IoT enabled systems for health monitoring. Furthermore, the physiological parameters of patients can be measured and transmitted to the database for a doctor's perusal towards clinical diagnosis and advice on treatment.

In this COVID-19 era experienced globally, infected patients and people in contact with the infected patients are counselled to self-isolate or quarantine depending on the level of infection. We propose a Smart Home Health Monitoring System referred to as ShHes in this paper. The proposed system described in our work is intended to perform a dual function of controlling home appliances as well as monitoring and recording the patient's physiological data such as blood pressure, body temperature, pulse rate, body weight and sugar level and other symptoms related to a specific virus. The values of measured physiological parameters are keyed into the system wirelessly through sensors or manually by the caregiver for transmission to the doctor. The main aim of the system is to assist out-patients and patients in prescribed isolation to live a comfortable life at home and reduce the stress of visiting hospitals often before consultation with their doctors.

Disabled and older adults are also factored into consideration of our system as the system is designed for comfortable daily living in the home. In our proposed system, the home is remotely controlled through a developed mobile application installed on a smartphone, and the user can also communicate with his doctor through another module in the same application. Medical conditions, such as chronic hypertension and diabetes, were used as the focus of our design. The system takes into consideration the role of family member or caregiver who will be

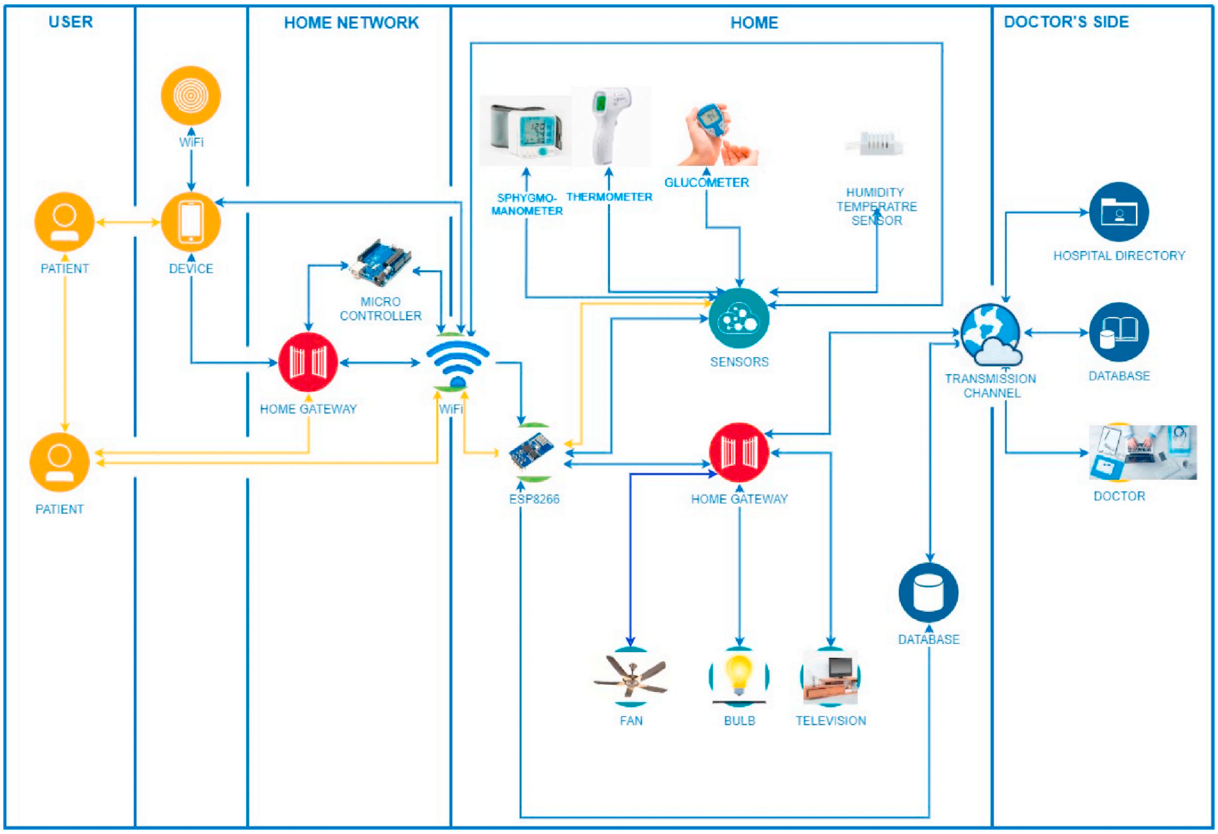

Fig. 1. System architecture.

responsible for helping the patient while at home. Hence, the proposed system has three major users: patient, doctor and home caregiver. In the proposed system, patients can upload values of physiological health parameters, chat with doctors, leave a message and book an appointment.

3.4. System Architecture

Fig. 1 shows the architecture of the proposed system design. The architecture includes the home appliances, smartphone, sensors, actuators, Wi-Fi module, and an Arduino board, which serves as the microcontroller. In the system, sensors are installed for measurement of the indoor temperature or humidity levels, and detection of motion and smoke. In our work, communication between the user and the home is wireless. The Arduino microcontroller collects data from various sensors, home appliances and physiological devices through the ESP8266 wireless module and transmits it over the internet to the user. The user receives and sends commands to the home through the developed Android mobile application to the microcontroller for necessary actions.

3.4.1. Home control scenario

The selected controlled area for the work is a room in the house. Features to be controlled by the application are the temperature, cooling system and other basic home appliances like the light switch and television. For temperature control of the home, the desired temperature is entered by the user through the developed mobile application and saved in the memory unit of the Arduino microcontroller. The temperature is measured using the DHT11 humidity and temperature sensor. The Arduino continuously reads the temperature and compares it with the value inserted by the user; if the value measured by the system is lower than the desired value given as input by the user, a notification is sent to the user, and the system automatically puts on the heater to make the area warm. If the measured value is higher than the user's desired value, the fan is automatically turned on, and a notification is also sent to the user via the mobile application. For control of other appliances in the home, the user selects the desired appliance he wants to control on the mobile application and a signal is sent to the Arduino microcontroller for necessary action on the appliance. The communication between the user, the devices and appliances is wireless using the ESP8266 Wi-Fi module.

3.4.2. Home health monitoring scenario

The user's physiological parameters are measured manually using conventional equipment such as a sphygmomanometer for blood pressure, a thermometer for body temperature and a glucometer for sugar level, with the assistance of the healthcare or family member caregiver at home. The values of the measured parameters and symptoms of the virus are sent to the doctor via the internet. The values are stored in the created database for the developed system and the doctor views the parameters and other information from the patient such as message, chat and complaints through the developed web application. On the other hand, the physiological body parameters can be obtained through the use of body sensors and the values are received wirelessly by the microcontroller. If the measured parameters received are not within the normal specified range as discussed earlier, our algorithm 1 is used to perform basic checks using the HAC context types. The microcontroller sends the received values to the database and the values are then transmitted over the internet to the doctor for further diagnosis. The doctor communicates with the patient via the mobile application by placing a call, leaving a message or using the chat box option on the platform.

Several devices are involved in IoT systems, thus the need for a gateway that serves as a means of integration between the devices in the system and communication modules. Home appliances are connected to the Arduino board for control through relay pins on the board. Also, data generated from the smart sensors used for measuring physiological

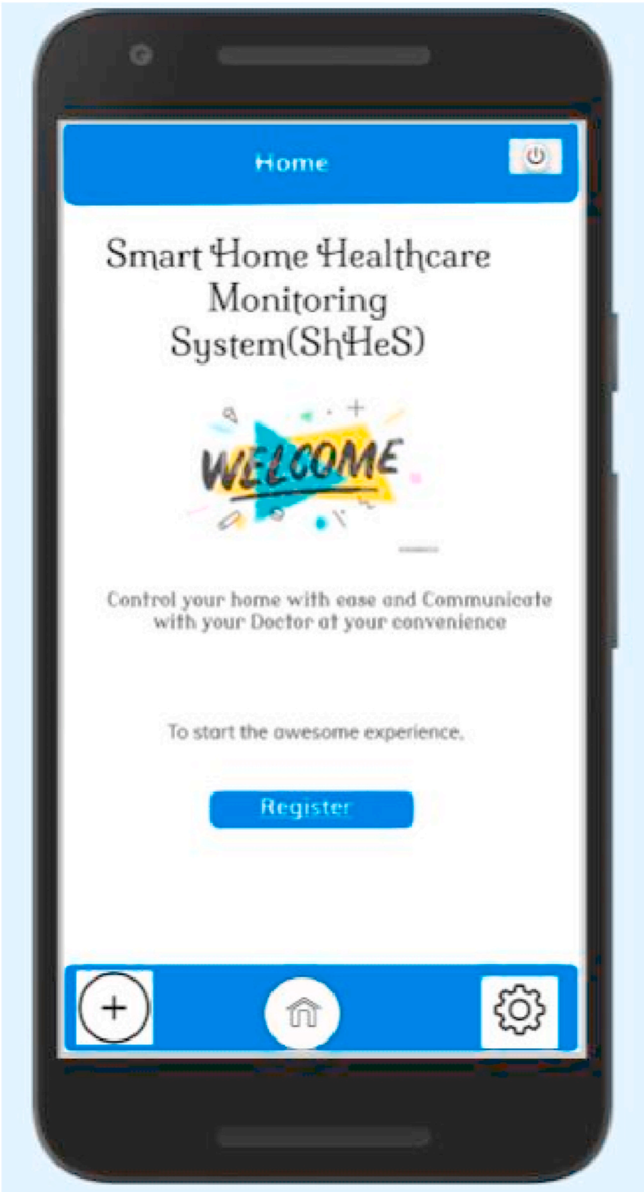

Fig. 2. Home page.

parameters of the patient are sent to the database and from there transmitted over the internet to the doctor for action. The doctor also communicates with the patient by sending information through the internet. Steps involved in the operations of the smart home healthcare system are stated in algorithm 1. The algorithm works based on the HAC definitions to perform necessary actions for accurate readings. If the readings do not fall within the expected range, context change, position and other factors in the HAC are put into consideration for subsequent readings. The following terminologies are used:

- HA stands for home appliances.
- N_c stands for network connectivity
- HC stands for home control
- PD stands for physiological devices
- PD1 stands for blood pressure devices with the range as $< \mathscr{D}_{\mathscr{BPS}} = [110, 111, \cdots 140], \mathscr{D}_{\mathscr{BPD}} = [70, 71, \cdots 90] >$.
- PD2 stands for sugar level device with the range between 70 and 100 mg/dl

Fig. 3. Login page.

- PD3 stands for temperature device with the range between 36.1°C and 37.2°C

Algorithm 1: HAC based Smart home health care system

1: ***Begin***
2: Initialize HA
3: Evaluate the initial state of HA
4: ***If*** $HA = n$(where n = number of configured home appliances)
5: Start N_c
6: Else, go to step 3
7: ***If*** $N_c = 1; \forall HA \in N_C$
8: Start HC
9: ***Else***, repeat step 4
10: ***While*** N_c && $HC = 1$; continue action till the desired state is reached
11: Switch on PD_1
12: Record value of measured PD_1
13: ***If*** PD_1 of $D_{BPS} \in \{110, 111, \cdots 140\}$ && $D_{BPD} \in \{70, 71, \cdots 90\}$
14: Record value
15: ***Else***, apply $X\Delta C$ and repeat steps 11 to 14
16: ***End If***
17: Switch on PD_2

(*continued on next page*)

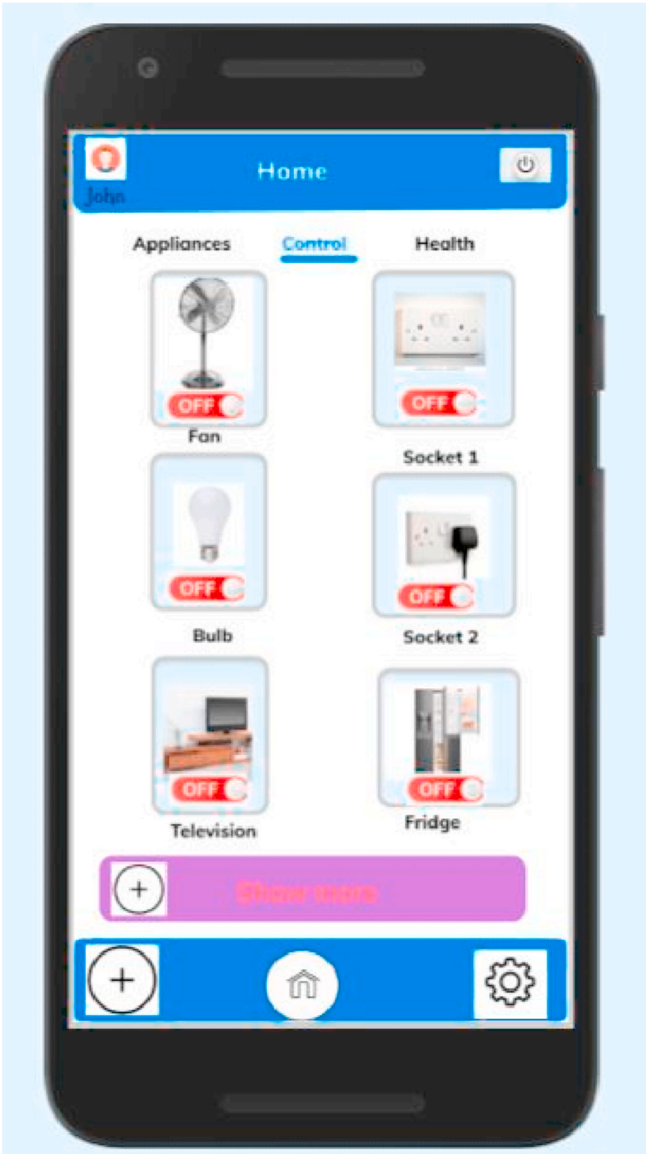

Fig. 4. Appliances control.

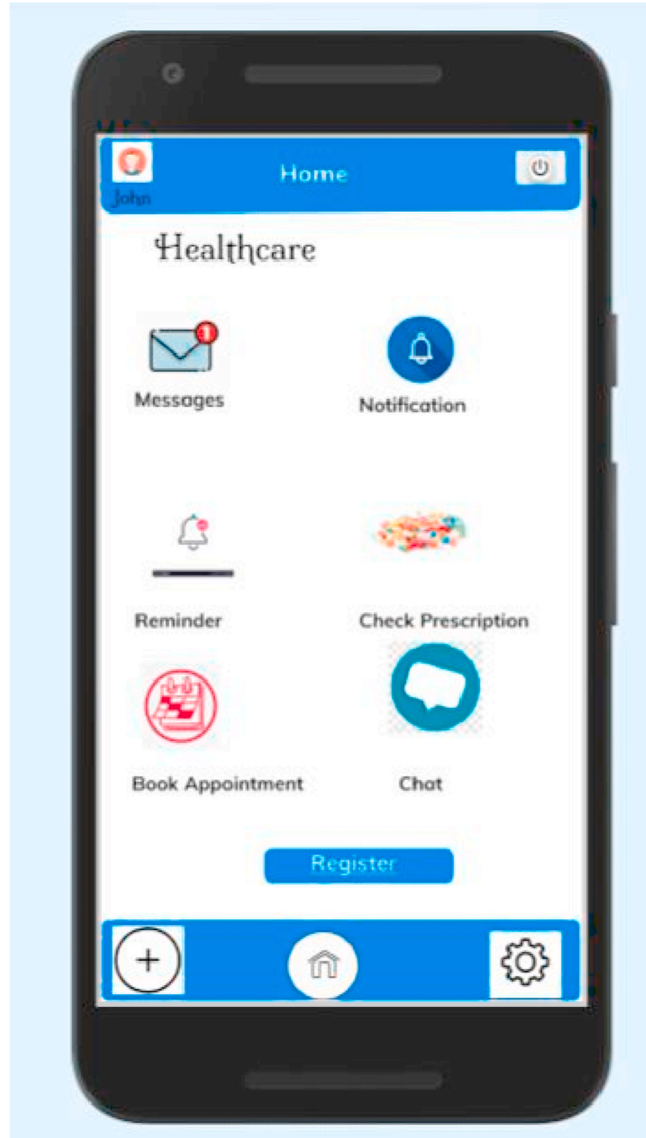

Fig. 5. Communication with the doctor.

(continued)

Algorithm 1: HAC based Smart home health care system	
18:	Record value of measured PD_2
19:	***If*** $PD_2 \in \{70, 71, \cdots, 100\}$
20:	Record value
21:	***Else*** repeat after 1 h
22:	Switch on PD_3
23:	Record value of measured PD_3
24:	*If* $PD_3 \in \{36.1,\ 36.2,\ \cdots,\ 37.2\}$
25:	Record value
26:	***Else***, apply $X\Delta C$ and repeat steps 21 to 23
27:	Send all initial and final values of PD_1 , PD_2 *and* PD_3 to doctor
28:	***End***

4. Results and discussion

As presented in the architecture, the proposed smart home health-care system has both user's and doctor's sides. At the user side, two main parties are involved: registered user and the family member responsible for overseeing and taking care of the patient at home. The user (patient) can perform the following basic functions on the system after successful registration:

- Control home devices
- Check for medication and prescription
- Send symptoms of the virus to the doctor while under isolation
- Chat with the doctor or leave a message
- Enter physiological values of measured parameters manually
- Book appointment with the doctor
- View medical data.

The role of the family member in the system is to assist the patient with uploading and retrieval of information when necessary, communication with the doctor on behalf of the patient, and also use the application for home control. The doctor, after successful registration and login, can communicate with the patient either by chats or message, view messages from patients, prescribe medications, diagnose any ailment from the received physiological vitals and provide other medical consultations.

Hardware components of the system include the following:

***Sensors*:** Body temperature sensor, blood pressure sensor, pulse rate sensor, etc. are used in the system for collection of data from the

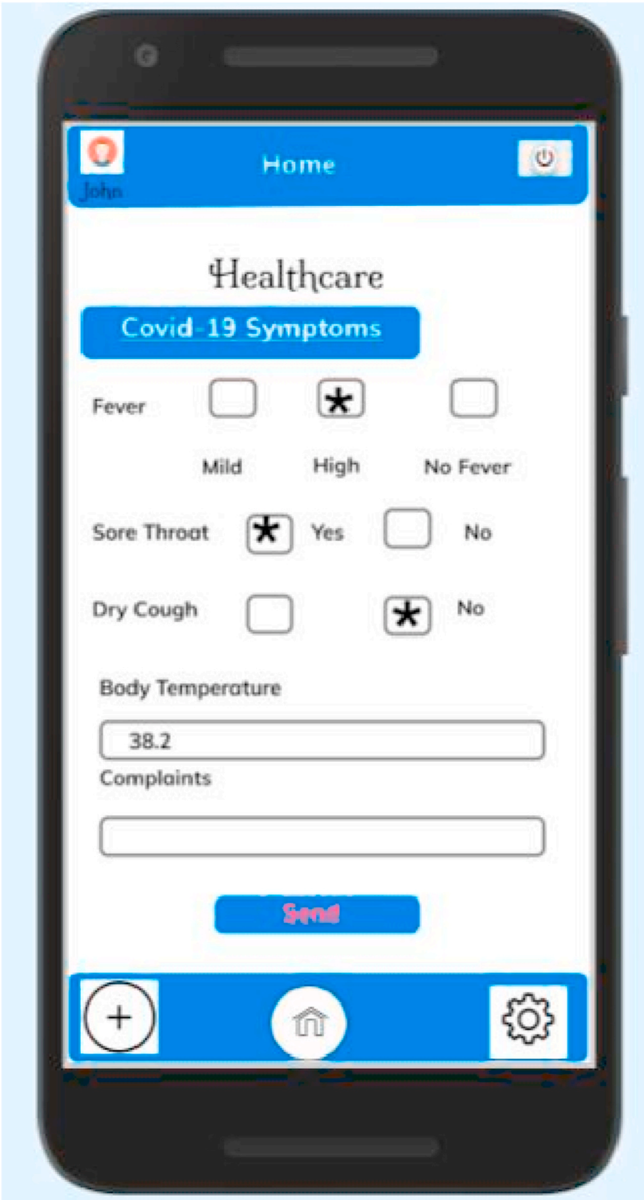

Fig. 6. COVID-19 page.

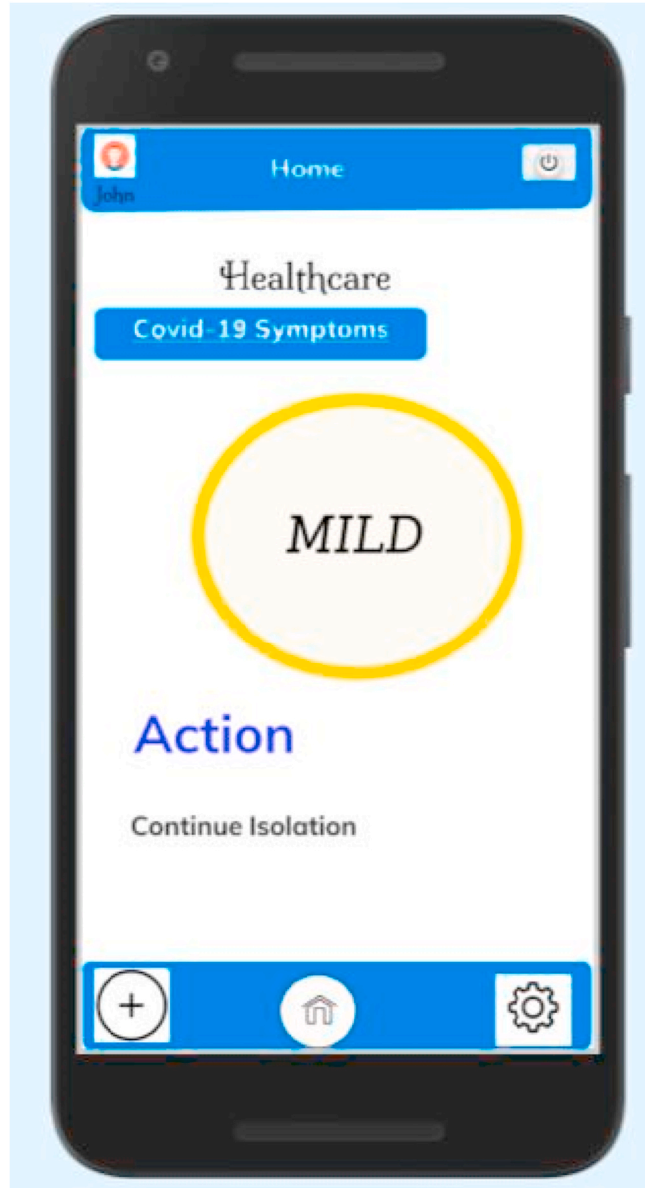

Fig. 7. COVID-19 response.

patient's body and transmitted wirelessly to the microcontroller via the home network gateway for storage in the database and forwarding to the doctor over the internet. The body sensors are used to ease the stress of manual input.

Arduino Board: Microcontroller oversees the functionality of the system. IoT appliances and devices are connected to the Arduino board for collection and transmission of data within the system and also to the mobile application for home control. With the digital pins present in boards, home appliances settings are relayed and hence controlled. The functionality of home appliances is highly dependent on boards.

Gateway: Several IoT devices are involved in this system. To this end, we decided to use a gateway to unify the communication of devices. The gateway serves as an intermediary between the home appliances, the microcontroller and the internet. The major role of the gateway is the unification of network connection from various devices.

The proposed system is to be used through the mobile application and the web-based application. Patients connect with home appliance and doctor through the mobile application to carry out the functions previously highlighted. The patient's physiological parameters are sent to the doctor automatically with the aid of body sensors deployed for capturing the values or are sent via manual input of values on the mobile application platform. With the help of service discovery explained through HAC earlier, the performance of services in the home are displayed, changes can be discovered and results reflected in the system.

The android studio integrated development environment was used for designing and developing the Android mobile application for the control of home appliances, health devices and communication with the doctor from home. Fig. 2 shows the home page of the designed mobile application. The user can gain access to the mobile application by registering on the application; after successful registration, access can be gained to login (Fig. 3) and then directed to the desired page either as patient or family member depending on the information submitted. The user registers home appliances to be controlled, and there is an option to add more appliances for future purposes. After the registration of devices, home appliances that can be controlled are displayed (Fig. 4). The application is designed to allow manual input data in case the sensors irritate the patient's body, and automatic measurement of physiological conditions is not possible. For automatic capturing of health data, the

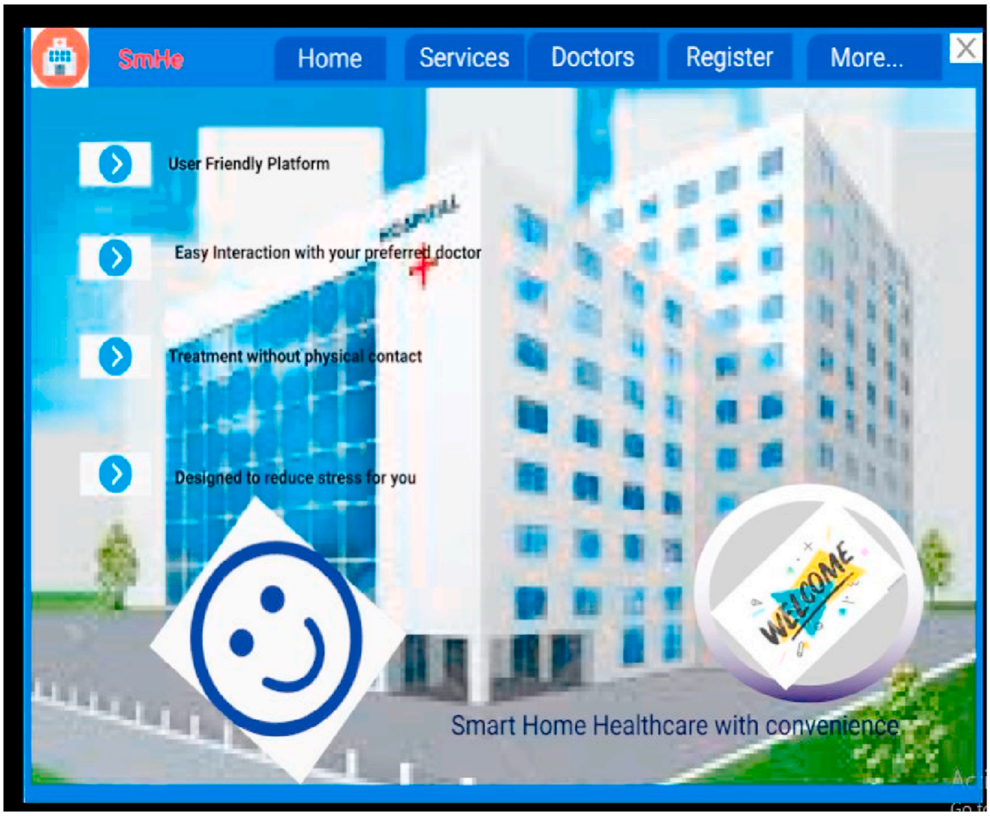

Fig. 8. Home page.

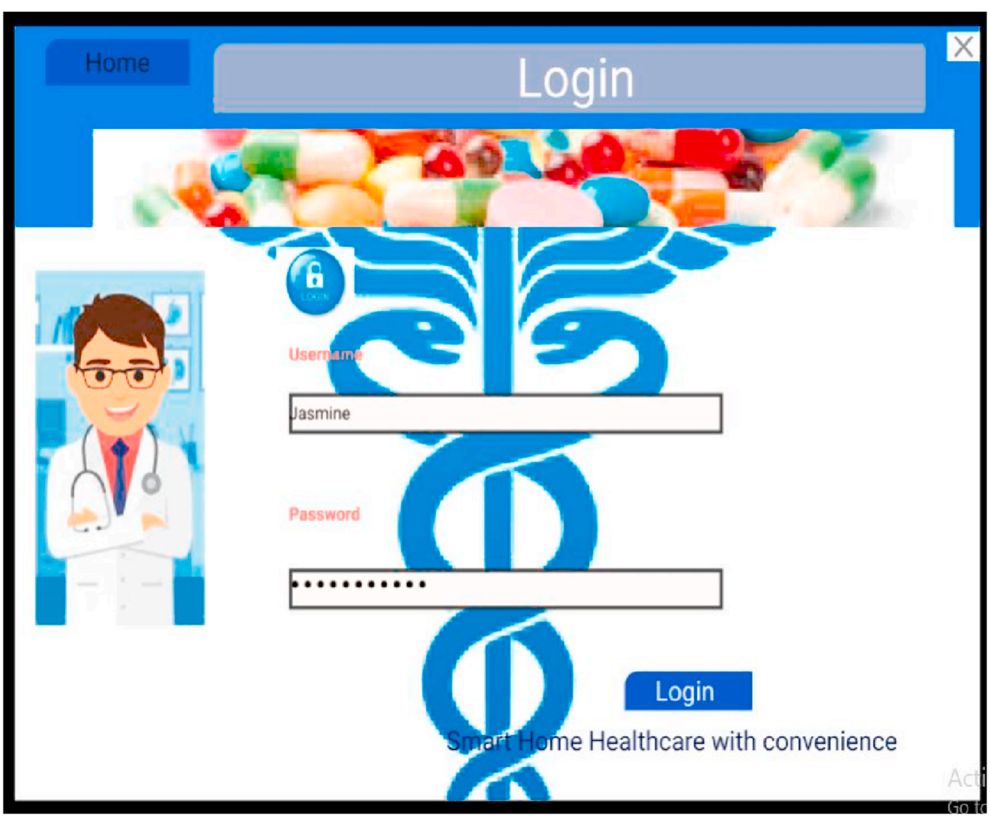

Fig. 9. Doctor's login page.

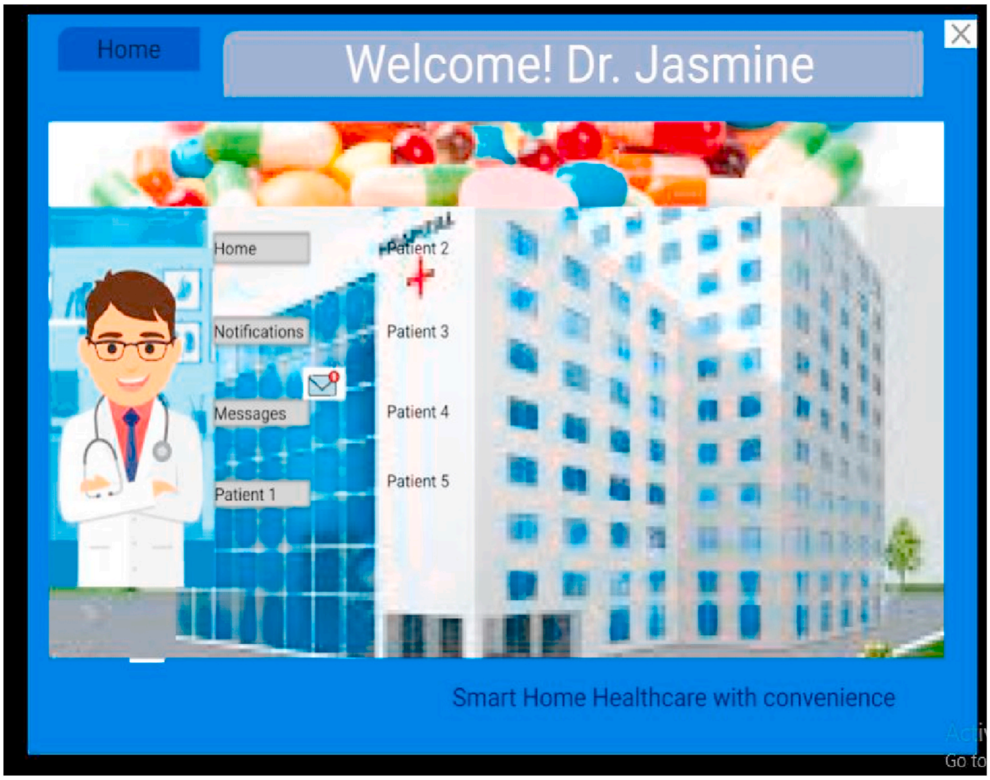

Fig. 10. Doctor's page.

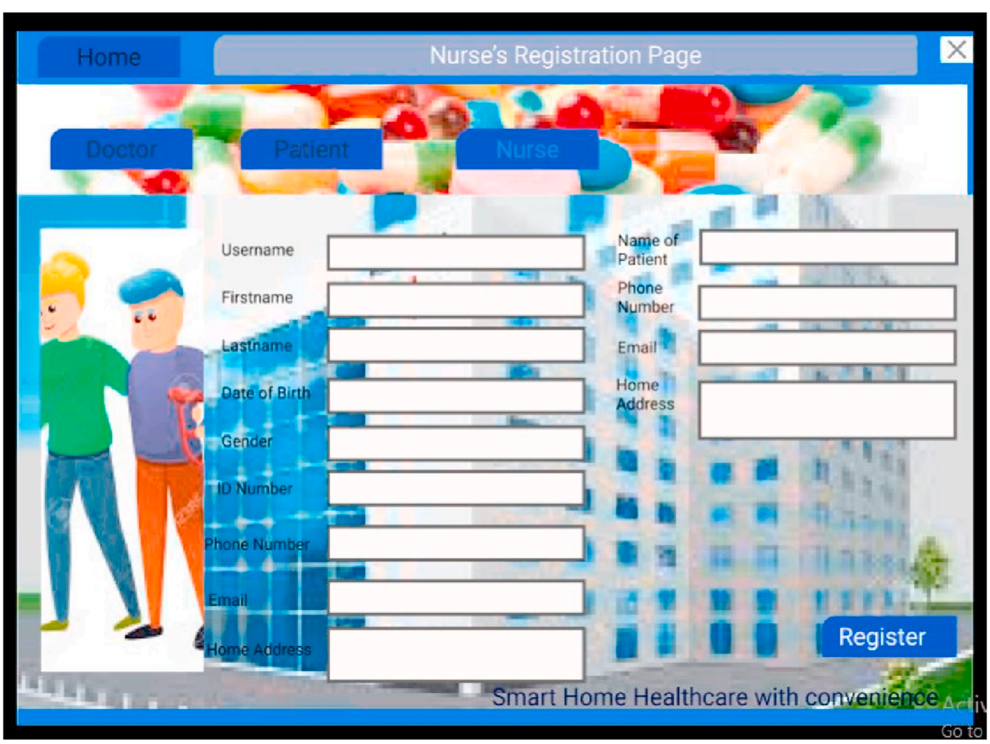

Fig. 11. Family Member's registration page.

user will click on the parameter to send while on the health parameter page. The health interface of the mobile application allows the user to perform functions like chatting, leave a message or check the prescription of previous medication from the doctor (Fig. 5). Also, the mobile application can be used to communicate with the doctor concerning COVID-19 diagnoses, especially when the patient is observing self-isolation at home or government obligatory quarantine. Specific symptoms are monitored and checked at intervals and sent to the doctor with the range of the readings (Fig. 6). A response is received after the patient has successfully keyed-in the values and responses for the COVID-19 symptoms. The application is designed to analyse the input received and give a response for the next action to be taken by the patient. Colour code red means the patient should report to the nearest hospital or COVID-19 treatment facility with immediate effect, an orange colour indicates that the patient is exhibiting above 80% of COVID-19 symptoms and should be screened and further tested as soon as possible, a yellow colour indicates that the patient is exhibiting very mild symptoms of the virus and hence should continue to self-isolate and avoid contact with people while the green colour indicates that the patient is not showing any symptoms at all. Based on the input received in Figs. 6 and 7 shows a mild indication and the necessary action to be taken by the patient. The doctor will further advise and prescribe necessary medications based on the parameters received at the doctor's end.

From the doctor's side, a web-based application was designed which can be managed by an administrator. Users and family members are to register with the doctor to have their data in the database similar to the hospital filing system. The doctor and administrator are the major users of the web application. It is designed for monitoring patients' health, delivery of services such as consultations, prescriptions, evaluation of physiological values for diagnosis, treatment or further directive on medical tests required. The system is designed for the doctor to manage as many patients that are registered on the platform. For the creation of a portal for the user, user supply information such as ID number, sex, blood group, genotype and other vital details are recorded on the system. The interfaces for the web application are shown in the Figures below. Fig. 8 shows the interface of the web application giving an overview of what the application is all about. After successful registration, the login page of the doctor is displayed in Fig. 9, while Fig. 10 shows the doctor's page in the application. A family member taking care of the patient from home also needs to register with the doctor and have their records in the database since he or she has the assigned role of communicating with the doctor on the patient's behalf (Fig. 11).

In summary, the main goal of the developed hybrid smart healthcare based Android mobile web application framework discussed in this paper serves the vast purpose of enabling remote monitoring of patients concerning those diseases that might require constant visits to the hospitals even though such diseases can be diagnosed and treated remotely by doctors. The proposed mobile application similarly offers features that can monitor the patient's condition in real-time, which can help reduce hospital costs and most importantly protect the hospital against any further exposure of patients to highly contagious diseases, especially during a pandemic like the COVID-19 where most hospitals are grappling with high numbers of patients.

5. Conclusion and future direction

The application of Internet of Things in smart home automation has led to a great deal of improvement in convenient living, remote access to home appliances, mobile health care and improved social lifestyle primarily for senior citizens. Combining home automation with the healthcare system helps alleviate stress, reduces the cost of living and gives room for remote communication between doctors and patients. In this work, we have proposed a smart home health care system for the sick, elderly and handicapped. The current work was focused mainly on making life more convenient for those with health challenges who need to visit the hospital regularly. The new system has been developed in order to reduce the number of hospital visits, queues in the hospital and reduction in the cost of taking care of the sick. The system performs a dual role of both health monitoring and control of essential home appliances; with this, users can enjoy social life and still have their health managed and monitored especially during an era of the pandemic. The proposed method will have a great impact on the quality of life by reducing the transmission rate of communicable diseases. Patients diagnosed and under treatment for a disease such as COVID-19 will not have any cause to move about frequently and thus, quality of life is ensured and transmission rate is reduced. The on-going phase of the current system is its physical deployment with IoT devices, a testing phase of the mobile application using the real-world scenario and documentation of feedbacks for improvement.

It is recommended that after rigorous testing and evaluation, the proposed system can be deployed in hospitals for use in various units. The designed mobile and web application, once fully developed, can be plugged into existing web domains of hospitals as a portal and can be launched as a fresh application for hospitals without existing domains. It is also recommended that new features such as a physiological data capturing device be incorporated into the current system.

As a future direction, we plan to extend our application beyond Android platform to other IOS platforms for wide adaptability. With the efficient technique presented in this paper, it is believed that this research can be extended to other areas of IoT such as agriculture for monitoring of livestock and consultation of farmers with veterinary doctors towards diagnosis, prescription and treatment of diseases in livestock in farms. Also, the new system can be extended for use in the pharmaceutical sector. The doctors can send prescriptions to the pharmacist for recommendation of dosage and possible dispensing of medications to patients. Finally, it will be of interest to carry out an evaluation of the overall performance of the proposed system using different mathematical and statistical evaluation tools.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Not Applicable.

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