DigiHealth-Asia

Deliverable D1.1: Literature review on digital health care and monitoring technologies and its status/vision in EU and Asia

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Authors	Timo De Waele (UGent), Adnan Shahid (UGent), Ingrid Moerman (UGent), Nauman Aslam (UNN), Xiaomin Chen (UNN), Qasim Zeeshan Ahmed (UoH), Maryam Hafeez (UoH), Chantal Bonner Cherifi (ULL), Yacine Ouzrou (ULL), Aicha Sekhari (ULL), Hamza Bin Waheed (CUST), Marriam Bakhtiar (CUST), Amir Qayyum (CUST), Rafia Mumtaz (NUST), Pradorn Sureephong (CMU), Faranaaz Moolajee (CMU), Suwit Wongsila (CMU), Punnarumol Temdee (MFU), Worasak Rueangsirarak (MFU), Surapong Uttama (MFU), Ariuntuul Garidkhuu (MNUMS), Amarsaikhan Bazar (MNUMS), Tselmuun Chinzorig (MNUMS), Mend-Amar Majig (NUM)
Reviewers	Xiaomin Chen (UNN)

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Executive Summary

This deliverable is related to 'WP1 – Preparation' and 'Task 1.1 Literature review of digital health care technologies and its adoptions in EU and Asia'. It presents the importance of Internet of Medical Things (IoMT) in healthcare. It includes detailed literature review on the three pilot cases (cardiovascular monitoring, mobility disorder monitoring, and remote patient consultation) in Europe and Asia. The literature review includes 1) key available technologies, 2) their system components, and 3) use of Artificial Intelligence (AI)/Machine Learning (ML) for the pilot cases in Europe and Asia. The literature review shows the need and importance of the pilot cases in the Asian countries. This one hand can have a significant reduction in hospital bills, but on the other hand provide efficient and effective healthcare services. The information in the deliverable will be helpful in defining the pilot cases in the Asian countries (Pakistan, Thailand, and Mongolia).

1. Introduction

The healthcare industry is dealing with an enormous pressure. The reason being that the global population is ageing and the number of noncommunicable diseases (NCDs) is on a rise. Due to this, the cost of healthcare provision is increasing sharply in all nations across the world. For example, in the US, healthcare spending grew 4.6% in 2019 and thus, reaching $3.8 trillion per person. This accounts for 17.7% of the nation's Gross Domestic Product [1].

Advancement in Information and Communication technologies is expected to provide effective and efficient healthcare services to ageing patients or patients with NCDs. In this regard, several phenomena have emerged such as ambient assisted living (AAL) [2], ubiquitous healthcare, and Internet of Things (IoT) for healthcare (Internet of Medical Things - IoMT) [3]. These three terms differ from each other but somehow, they are related. The technology cannot stop ageing and NCDs, but it can make the healthcare easier on a pocket and in terms of accessibility. Before such technological advancements, the patient's interaction with doctors was limited to physical visits to hospitals or private clinics, tele and text communications. It was not possible at that time that doctors or hospitals could monitor patients continuously and make recommendations accordingly.

IoT refers to the billions of physical devices including sensors, smart devices, cyber sensors, etc. around the world that are connected to the Internet and used for the collecting and sharing of data. The IoMT mean is a connected infrastructure of medical devices (sensors, wearable or implantable), software applications as well as health systems and services. It provides accurate and cost-effective personalized healthcare services [4]. In other words, IoT-enabled devices have made remote monitoring possible in the healthcare sector. This remote patient monitoring has increased patient satisfaction because the interactions with doctors have become easier and more efficient. In addition, remote patient monitoring also helps in reducing hospital stays and prevents re-admissions. This has a major impact on reducing the healthcare costs and improving treatment outcomes as medical diagnostics consume a large amount of hospital bills. The IoMT can bring numerous advantages such as simultaneous reporting and monitoring, end-to-end connectivity, data assortment and analysis, tracking and alerts, remote medical assistance and research.

Artificial Intelligence (AI) and Machine Learning (ML) are powerful tools that can be used for extracting hidden insights from the data in IoMT. They can be used for finding hidden patterns in the bulk of data for making an optimal diagnosis, prediction, and recommendations. Since a huge amount of data is available from IoT devices attached to patients and healthy people, the data can be used for making fine-grained diagnosis possible and helping research in the medical domain.

This deliverable presents a detailed literature review on 1) key available solutions, 2) system components, and 3) use of AI/ML for the three pilot cases (cardiovascular monitoring, mobility disorder monitoring, and remote patient consultation) in Europe and Asia. This information will be helpful in defining the need for and importance of the pilot cases in the partner countries (Pakistan, Thailand, and Mongolia). The main idea of presenting different solutions in Europe is to use that knowledge to drive the design and development of the pilot cases.

2. Digital healthcare and monitoring status in Belgium w.r.t the three pilot cases

2.1. Review of key available technologies for digital health systems

Cardiovascular monitoring

Cardiovascular monitoring is one of the most technologically advanced medical fields in Belgium with several technologies already developed for both in-hospital and at-home monitoring of patients. Both the Holter ECG [5] and event recorder [6] have been specifically designed for ambulant recording of the heart rhythm to follow up patients with known cardiovascular diseases or to diagnose potential cardiovascular issues. These are both small devices that must be continuously worn by the patient over a certain period. After that the doctor can manually read out the recorded data and make a diagnosis based on the long-term measurements where the patient was performing regular day-to-day activities, potentially discovering issues that do not show up during a snapshot recording at the hospital.

Next to the wearable heart rhythm monitoring there is also the possibility to perform ambulant blood pressure monitoring [7] where the patient wears a blood pressure monitor for a certain period that will record the patient's blood pressure at fixed intervals. This allows the doctor to detect any abnormal rhythms in the patient's blood pressure as well as record the patient's blood pressure during a variety of activities, making a more informed decision about the patient's health.

The WearIT4Health research project [8] aims to develop a wearable sensor device that can be used in hospitals to monitor patients without impeding their mobility as is the case right now with most sensors relying on a fixed wired connection to the monitoring system. The project aims to incorporate body temperature sensors, ECG and O2 saturation measurements into one single device. The data collected will be sent over the air to a centralized server so doctors and nurses can have an overview of the parameters of all patients in the ward.

These three technologies do however have one major drawback. They all rely on specialized medical equipment. Luckily in recent years there has been a revolution of turning smartphones and smart watches into health trackers. With most of them already incorporating accelerometers, GPS, and barometers to track daily activities such as steps taken, flights of stairs climbed, and distance traveled. But now there even is an ongoing trend of turning these devices into medically certified monitoring devices. For instance, the Apple Watch [9] incorporates a certified ECG scanner that automatically checks for atrial fibrillation and allows the user to periodically make an ECG scan which can be shared with doctors and nurses. The Fibricheck [10] smartphone application on the other hand brings heart rhythm monitoring to millions of smartphones, relying only on a camera with flash to detect heart rhythm based on the light that is reflected through the finger of the user.

Mobility disorder monitoring

The medical field of assisting and monitoring patients with mobility disorders is far less technologically explored than cardiovascular monitoring. However, one system is already being used in practice for the monitoring of patients that are revalidating from knee or hip surgery and one system is currently being researched for use in care homes.

MoveUP [11] is a smartphone application that uses a wearable fitness tracker to provide remote monitoring of patients that are revalidating from knee or hip surgery as well as for weight loss. By using the information from the fitness tracker and the smartphone's sensors physicians can gain better insights into how the patient is progressing and provide the patient with personalized revalidation schemes that can be adjusted based on data from the application when necessary.

The Watcherr [12] project is a project that is currently under development and aims to produce a smart wearable that incorporates heart rate monitoring, accelerometers, gyroscopes, and GPS to monitor elderly people and warn nurses or doctors about any potential issues such as a fall, heart attack, or stroke. The data of this wearable will be wirelessly transmitted to a central server where caregivers can get a quick overview of the health status of all residents.

Remote consultation

Due to the COVID-19 pandemic there has been an enormous uprising in available technologies for remote consultation of patients. Standard teleconferencing tools such as Zoom, Hangouts, and Teams could be used for this purpose, but these are not ideal in a medical setting as these often lack security and privacy guarantee which is required in a patient-doctor communication setting. To this end many specialized remote consultation tools have been developed such as ClickDoc [13], Comunicare [14], Doctena [15], and FaceTalk [16]. These tools put a strong emphasis on privacy and security by using end-to-end encryption. Next to this they also incorporate methodologies for making sure that only the real patient and attending physician have access to the connection as well as providing secure access to the patients' medical records.

2.2. Monitoring system: sensor based and non-sensor based

- **Holter ECG/Event Recorder:** Wearable ECG device that uses stick-on electrodes to record heart activity over a 24-hour or longer period.
- **Apple Watch:** Starting with the 4th generation Apple Watch the device was equipped with electrodes which could be used to perform on-demand ECG recording, the software then uses this ECG to detect signs of atrial fibrillation.
- **WearIT4Health:** Wearable device that incorporates multiple sensor types such as body temperature, heart rate, ECG and O2 saturation that are used to perform continuous recording of these parameters.
- **Ambulant blood pressure:** Blood pressure monitor that is worn by the patient and measures the blood pressure at fixed intervals over a certain period.
- **Fibricheck:** Smartphone application that uses the phone's camera and light from the flash to measure changes in the amount of blood that flows through the capillaries. This can be used to calculate the hearth rhythm and detect any abnormalities in this rhythm.
- **MoveUP:** Smartphone application that makes use of a wrist mounted step counter to aid with and monitor the revalidation of patients that underwent hip or knee surgery as well as for weight loss.
- **Watcherr:** Wearable device that consists of a heart rate monitor, an ECG, a blood oxygen saturation meter, an accelerometer, a thermometer, a blood pressure monitor and both indoor and outdoor localization systems. Used to remotely monitor both patients in a hospital, recovering patients, elderly or patients with chronical issues.
- **Remote consultation:** Video calling software with a strong focus on 1-on-1 communication, security and privacy through end-to-end encryption, secure authorization to make sure only the doctor and the patient have access to the call and information, and easy access to medical records of the patient.

2.3. Data collection, data processing, transmission modules, software APIs

- **Holter ECG/Event Recorder:** Manual data extraction at the end of monitoring period by the doctor via a wired connection.
- **Apple Watch:** Export the full ECG to a PDF file or extract the data for processing in an app via the HealthKit SDK and API.
- **WearIT4Health:** Tight integration with existing monitoring software and databases already used in hospitals, continuous uploading of the recorded parameters to this software either to edge storage or cloud storage, this is achieved through a wireless link, for example Wi-Fi or Bluetooth.
- **Ambulant blood pressure:** Manual data extraction at the end of the monitoring period by the doctor via a wired connection.
- **Fibricheck:** Result immediately visible in the app, can be viewed by both patient and doctor.
- **MoveUP:** Information accessible in the application both locally by the patient and remotely by the doctor by uploading information wirelessly to the cloud via the phone's internet connection. Step counter synchronized to application via Bluetooth.
- **Watcherr:** Information and notifications accessible via a webapp dashboard and mobile application. Data stored in the cloud.
- **Remote consultation:** N/A

2.4. Monitoring systems using AI/ML

Most of the technologies used in Belgium for the monitoring of patients do not incorporate any AI or ML at the moment. Only the Watcherr project [12] openly advertises its use of AI but it does not go into detail about which type of AI but given its use case it will probably involve some type of anomaly detection.

The lack of any AI in Belgian healthcare currently leaves open a wide range of possibilities of improvement on existing technologies by applying state-of-the-art ML and AI.

3. Digital healthcare and monitoring status in France w.r.t the three pilot cases

3.1. Review of key available technologies for digital health systems

Telemedicine was not widely used in France so far. It turns out that COVID-19 spurred the development of new digital uses in health. Recently, R&D efforts have been made to make telemedicine more effective and accessible, accelerate the spread of health apps, wearable devices, connected care systems, and maximize the use of routinely collected data.

<u>Remote monitoring of cardiovascular patients</u>

In France, more than 1 million of people are suffering from heart failure. Every year, it represents 120 000 additional patients, and more than 210 000 hospitalizations of 10 days duration in average. Basically, remote monitoring of cardiovascular patients is done by telephone support performed by dedicated staff like nurses trained in heart failure. Nevertheless, today in France, connected tools are available for remote monitoring, ranging from non-invasive devices (balance, blood pressure monitor, pulse oximeter, electrocardiogram) to invasive devices (pacemaker and defibrillator (for therapeutic purposes)), and dedicated devices (continuous measurement of pulmonary pressure using a sensor placed by catheterization in the pulmonary artery). While remote monitoring for heart diseases is not widely spread out across the country, trials show its advantages. OSICAT (*Optimisation de la Surveillance ambulatoire des Insuffisants CArdiaques par Télécardiologie* - Optimization by telecardiology of outpatient monitoring with insufficient heart disease) is a trial launched in 2013 and coordinated by the CHU (*Centre Hospitalier Universitaire* - University Hospital) of Toulouse. For two years, 937 patients have been equipped with a balance and a communicating box. Data was transmitted to the healthcare practitioner and phone calls by dedicated nurses allowed a daily monitoring [17]. More recently, a second trial conducted at Hôpital Marie Lannelongue Paris [18] aims at showing if a remote monitoring associated with a heart failure biomarker could reduce hospitalizations. Those French trials are accompanied by a real-time experiment. The ETAPES (*Expérimentations de Télémédecine pour l'Amélioration des Parcours en Santé* - Telemedicine experiments for the improvement of health care paths) protocol was launched in 2018 by the French Ministry of Solidarity and Health [19]. The protocol currently includes more than 2000 patients, which shows the interest of cardiologists for this type of remote monitoring. The ministry hence encourages and financially supports the deployment of remote monitoring projects across the country validating the fact that telemonitoring opens enormous potential for the future management of heart failure.
There are several providers in the market. Among them, Air Liquide-CDM e-Health provides a connected technical solution called Chronic Care Connect (CCC) [20]. It offers a technical solution that is simple, flexible, and easy to use. It provides connected tools, tablet and balance, and trains the patients for their use. A website providing information on their pathology is available to patients. CCC ensures remote monitoring of patients by the Monitoring Center or medical platform. A decision-making algorithm sorts efficient alerts. CCC manages the active queue of patients, their medical record, hospitalizations and prescriptions. Renewals of prescription are made by the TLS doctor every 6 months. The clinical data is collected daily by CCC on a secure site. Healthcare practitioners can connect at any time to process an alert, which is sent to them by e-mail. Comarch CardioVest is a solution dedicated to preventive examinations, diagnosis and monitoring of patients with heart disease using technology allowing safe, reliable and long-term ECG signal recording.

<u>Remote monitoring of mobility disorder patients</u>

Kiwatch is a smart monitoring solution to help the elderly staying at home [21]. The system is composed by smart cameras with night vision, built-in microphone and speaker. The data is accessible from a smartphone. Arkéa Assistance remote alarm [22] is a remote monitoring solution for elderly people or people with loss of autonomy and difficulty performing everyday actions on their own. The alarm can be triggered and warn someone. Both are commercial kits.
In [23], the authors propose inertial wearable sensors leveraging unsupervised approach for human activity recognition from raw acceleration data measured.

Remote consultation of patients

The number of remote consultations has recently increased in France. In 2020, from around 100 000 in week 13, it reached a maximum of around 1 million for weeks 14 to 17. Those consultations are mainly performed by phone and video. For video consultations, we notice the use of software like Skype, Whatsapp, Facetime, which are more dedicated to general public. Comparing with phone remote consultations, video consultations should ensure data protection and privacy by leveraging professional software [24]. To that end, a body of digital telemedicine solutions proposed by software publishers have been identified by the French Ministry of Solidarity and Health. The lastest version of the list, published on April 1st, includes 186 solutions. The solutions are analyzed according to 8 criteria: Geographical coverage (Mainland France, Overseas France), Video transmission, Documents sharing from healthcare practitioners to patient, Documents sharing from patient to healthcare practitioner, Possibility of making an appointment, Possibility of payment, Possibility of directly invoicing health insurance, Security). Security is a score taking into account General Data Protection Regulation (Règlement Général sur la Protection des Données RGPD) compliance, Health Data Host (Hébergeur des Données de Santé HDS) certification, history of acts traceability, video or data streams security (TLS encryption), patient identification, reinforced patient identification, healthcare practitioner identification, reinforced healthcare practitioner identification [25]. Nevertheless, the use of phone or video may not be efficient enough in general, and especially for patients with complex or serious health problems. To improve remote consultation, supporting devices like oximeters for example could be used by patients to provide additional health information [24].

3.2. Monitoring system: sensor based and non-sensor based

Some of the devices that were already mentioned and studied before such as Apple Watch, Ambulant blood pressure or Holter EEG are not repeated here.

- CAPRI [26]: CAPRI is a remote patient monitoring system for cancer patients. It contains features such as patient monitoring, helping with care protocols or video calling for medical advice.
- BePatient [27] is a French company that provides services for patients, including remote monitoring via connected devices.
- Minimed: MiniMed is a continuous glucose monitor manufactured by MADTRONIC that streams measurements from its sensor to a transmitter, reducing the need for blood testing for diabetes patients. It is the first system of this kind covered by the French Social Security.

3.3. Data collection, data processing, transmission modules, software APIs

Medical data collection sources can be summarized as following:

- Electronic Health Records / Electronic Medical Records
- Genome and Research databases
- Case studies

- IoT sensors
- Wearable: Tracking heart rate, BP, weight, activity levels, stress levels
- Apps: Track a user's regimen and intensity
- Medical devices and sensors
- Insurance Providers
- Other Clinical data
- Social Media
- Usage data
- Web Knowledge
- Interviews

Data processing types

- Batch Processing: large volume of data processed all at once.
- Real-Time/ Stream Data Processing: achieve real-time analysis of data
- Time-Sharing: single CPU used and different time slots are allocated to each user to perform individual tasks and operations
- Multiprocessing: uses multiple CPUs to perform tasks or operations
- Online Processing: automatically update the data across the entire network

Transmission modules

- Wi-Fi,
- Bluetooth,
- ZigBee,
- Bluetooth Low Energy,
- LoRaWAN

Software APIs

Several APIs published in RapidAPI [28]. As example, we can list:

- Symptom Checker
- EndlessMedicalAPI
- MyHealthbox

3.4. Monitoring systems using AI/ML

The rise of Telemedicine has shown the possible rise in demand for AI. The ability to monitor patients using AI can allow information to be communicated to doctors if the presence of disease is detected. The use of a wearable device can allow constant monitoring of the patient and detect changes that are difficult to detect. In France, medical applications of AI are emerging, mainly in the French radiology community [29]. From a monitoring system perspective, the radiology community is beginning to use Machine Learning and Deep Learning algorithms to detect lung nodules using computed tomography. The aim is to predict whether nodules are present or not. Some research is beginning to focus on predicting the malignancy of nodules.

From a monitoring point of view, an example of an e-Care platform based on ontologies and Machine learning is used to experiment with home monitoring, using non-intrusive sensors, of patients with NYHA stage III heart failure [30]. It assists the medical profession by automating the processing of information from these sensors in order to detect and report risk situations at an early stage, thereby avoiding hospitalization.

Teams from the Laboratory of Medical Informatics and Knowledge Engineering in e-Health (LIMICS, Inserm unit 1142) and from the Assistance Publique - Hôpitaux de Paris, are taking part in a European project, Desiree, which uses the AI and symbolic approach to help clinicians in the treatment and monitoring of patients with breast cancer. These very complex diseases often require adaptations to classic protocols.

France has one of the largest health databases in the world [31]: its national medico-administrative data system, SNIIRAM (for Système national d'information inter-régimes de l'Assurance Maladie). This database stores all drug prescriptions, disease descriptions and hospital procedures. It is, however, difficult to use because the database was created for the economic analysis of health services but not for medical analysis. For example, a person hospitalized for a respiratory problem will be treated for this problem without necessarily mentioning the cancer that affects him/her. In some cases, there are 30% errors in the description of pathologies associated with patients. Correcting these errors requires cross-referencing data with other sources, such as those corresponding to the drugs administered. Research work using AI and ML is underway to help analyze this data and extract knowledge for patient monitoring.

4. Digital healthcare and monitoring status in UK w.r.t the three pilot cases

4.1. Review of key available technologies for digital health systems

UK has a number of available technologies that are offered both in partnership with NHS as well as private vendors. Through research a number of such systems and products are found that are in service in the sector, however, only a set of few examples is chosen to provide an overview of the landscape in the area.

- The CareLink network service is a remote monitoring system for people with a Medtronic implantable cardiac device [32] [33]. The service uses the MyCareLink monitor or MyCareLink Smart (for smartphones or tablets) to collect data remotely from the device. These data are transferred to the patient's clinician through the CareLink network with the aim of reducing the need for face-to-face follow-up visits. The main component of the system, the LATITUDE Communicator, typically costs up to £500 (excluding VAT) per patient. The LATITUDE NXT Heart Failure Management System, which includes the Communicator, weighing scales and a blood pressure monitor, typically costs up to £1,200 (excluding VAT).
- Another remote patient monitoring solution is Huma's Remote Patient Monitoring (RPM) [34] which supports Healthcare organisations by providing greater access to care outside of a conventional setting and empowers patients to better manage their own health. The modular solution tracks symptoms and vital signs, flags deterioration, incorporates telemedicine functionality, and is integrable with medical devices. This solution is for a range of conditions that include both cardiovascular as well as Musculoskeletal.
- TechHealth Solutions [35]: This remote monitoring healthcare solution allows vital sign data to be sent from a patient remotely to a clinician who will case manage the patient. It also offers a variety of services aimed at various applications. Relevant to the current context are Diabetes Monitoring service and HomePod.
- Smart Blood Glucose Monitoring using a compact device that interfaces with phone via an app [36].
- There are a number of companies in UK such as baywater [37], which have simply peripheral devices that interface with Mobile Phone or Tablet through an App and then used for remote monitoring.
- For remote consultation, many practices moved rapidly at the start of the pandemic to set up video-conferencing facilities. Wide variety of applications such as Skype, Zoom, WebEx and custom-built tools. This means that an increasing number of appointments with doctors and nurses will be carried out at a distance. Some surgeries are restricting video appointments to those who have already been assessed over the phone.

4.2. Monitoring system: sensor based and non-sensor based

- **Holter Monitor/Event Recorder/Ambulatory Monitor:** A wearable external monitor that continuously measures and records the heart's activity for different periods of time.
- **ZIO by iRHYTHM** [38]**:** A commercial ambulatory cardiac monitoring solution, including a wearable heart monitor to collect ECG data, deep learning algorithm to detect and classify 10 arrhythmias with expert-level accuracy, and comprehensive patient report to provide a clinically actionable view of a patient's cardiac activity.
- **Implantable monitoring device** [39]: An innovative Bluetooth device developed by Medtronic is paired to a mobile phone enabling doctors to monitor a person's heart round the clock. The

size is of a small paperclip or one third the size of a AAA battery. It was implanted in the chest of a patient in the UK for the first time in Sep 2020. The cardiology team is also among the first in Europe to offer the state-of-the-art LINQ II system to patients who need long-term monitoring because they suffer unexplained palpitations, fainting episodes or blackouts.

- **Spirit Digital** [40]: Commercial kits to record accurate clinical measurements such as temperature, heart rate, oxygen levels, blood pressure and weight using Bluetooth devices. Patients answer clinically validated questions to track symptoms such as shortness of breath, chest pain, tiredness and fluid retention. Clinical teams view patient lists that are prioritized with red/amber/green status, making it easy to triage and see the right patients at the right time.
- **AliveCor KardiaMobile** [41]**:** Commercial kits to capture FDA-cleared personal ECG data to detect Atrial Fibrillation, Bradycardia or Tachycardia. Users wear it on the finger (no wire, no patch, no gel) to collect a medical-grade ECG in 30 seconds and get an instant analysis right on theirsmartphone. It can email ECG data to the doctor or save it locally on the phone.
- **Rheumatoid arthritis remote monitoring service in South East London** [42]**:** The proposition was based upon two-way SMS communication with users through the exchange of patient-reported outcome measures (PROMs). An SMS user interface (UI) and a remote monitoring platform, with rudimentary data displays with the ability to send, receive, remind and display messages as well as show trends in PROM data, were ready to be deployed. Design features such as automated reminders, graphical feedback on scores, a red flag system to alert to changes and an SMS template library have supported personalized care for disease flare, emotional wellbeing and appointment deferment, accelerated in uptake by COVID-19.
- **Docobo's DOC@HOME** [43]**:** DOC@HOME is an advanced digital remote patient monitoring and case management system. It enables clinicians and carers to deliver better care, helps patients to be more aware of their condition and improves self-management. DOC@HOME is used across the NHS to enable overstretched clinicians to provide better care to more patients. For instance, one of the case studies in East London NHS Foundation Trust (ELFT) uses a combination of education and remote monitoring tools to support people living at home with lung conditions, heart failure or diabetes. The app- and web- version software can be downloaded onto the patient's own Android or Apple iOS phone/tablet or PC. AHP and nurses at ELFT manage a digital health hub to monitor patients' observations which consist of vital signs and symptoms. Patients routinely answer questions configured for their particular condition. This approach enables clinical teams to observe remotely and intervene early.

4.3. Data collection, data processing, transmission modules, software APIs

Data Collection:

The UK has some of the richest health and research datasets and assets world-wide. Some of these are well organised, but only a fraction of all NHS and research data is accessible [44]. Access to health data is necessarily complex as it requires safeguards, high levels of security and data minimisation to mitigate the risk of re-identification, and clear controls to ensure it is used only for appropriate purposes. A Data Framework has been developed by the UK Health Data Research Alliance which will enable the use of health data in a trustworthy and ethical way for research and innovation [45].

Data processing:

Depending upon the medical requirements, different data processing methods and techniques have been proposed. The following are two use cases:

Case-I- **Implantable monitoring device**: The Reveal LINQ™ Mobile Manager is an innovative, app-based device management system for Reveal LINQ™ insertable cardiac monitor (ICM). The device is paired to the patients' mobile phone or tablet using Bluetooth and an app constantly records and shares second-by-second ECG data with their healthcare team, including any rhythm abnormality when it occurs. It can also be used for stroke patients when the cause is unknown. Cardiologists will also be able to change settings on the device remotely, enabling them to monitor a specific area like a patient's fast heartbeat at certain times of the day without having to bring them in to hospital.

Case II- **ZIO by iRHYTHM:**

Has the ability to monitor the ECG for up to 14 days. The patient can carry out daily activities such as showering and exercising. However, the way data is collected and processed is not known.

However, recently cloud-based databases are also gaining importance as they have the ability to share huge volume of data. Furthermore, they can now include comprehensive tracking and audit logs to easily manage data governance.

Transmission Modules:

Generally, low powered and energy efficient transmission modules are preferred, and Bluetooth is the preferred interaction between the device and the patient. However, other standards such as WiFi, ZigBEE, and LoRaWAN has also been used.

APIs:

As the health care facility in UK comes under NHS a range of healthcare APIs can be found in [46].

4.4. Monitoring systems using AI/ML

UK and its National Health Service (NHS) are leading the world in the use of AI technology in hospitals for diagnosis, monitoring and treatment. In 2019, UK introduced NHSX [44], which is a new unit responsible for setting policy and best practice around the use of digital technologies in healthcare in England. As a part of this initiative, an AI Lab with £250m of funding was also created to support the development and deployment of AI technologies in the NHS and care system. The NHS AI Lab's activities include the AI in Health and Care Award, awarding £140m of funding to support the testing and evaluation of promising AI technologies.

For cardiovascular disease diagnosis, treatment and monitoring, NHS is using AI powered diagnostic technology from HeartFlow Inc.. Coronary Heart Disease (CHD) is the leading cause of death in the UK. NHS England has mandated the adoption of AI-powered HeartFlow FFRCT Analysis test. The mandate has recently begun in April 2021.

HeartFlow Analysis is a non-invasive technique that takes data from a coronary CT angiography (CTA) scan and uses deep learning technology and highly trained analysts to create a personalized, digital 3D model of the patient's coronary arteries as shown in Figure 1. The AI algorithm simulates blood flow in a patient's arteries to help clinicians assess the functional impact of any blockages. HeartFlow based solution is expected to cut the costs by a quarter [47]. However, exact details of the deep learning technique are not publicly available.

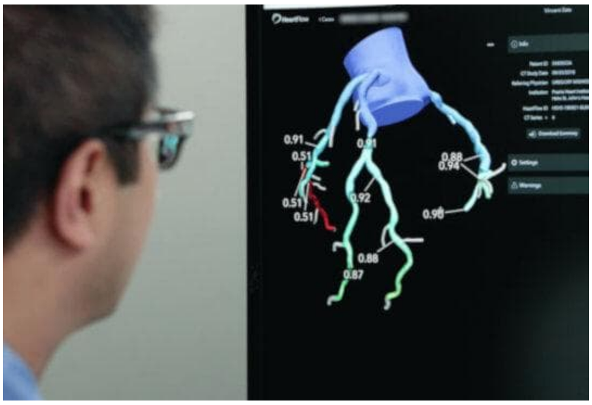

Figure 1: HeartFlow Analysis empowered 3D heart model [38].

According to [48] Kardia Mobile and Kardia Band are also two AI-enabled platforms that provide accelerated diagnosis of potentially fatal heart rhythm condition. NHS-wide rollout of Kardia products is also expected in near future.

Currently there are no official NHS trials that used AI platforms for remote patient consultation or monitoring of patients with mobility disorders.

5. Digital healthcare and monitoring status in Pakistan w.r.t the three pilot cases

Healthcare is an indispensable part of human life. Chronic illnesses like cardiovascular diseases have a deep negative impact on the healthcare sector. There are not enough resources to manage the ever-growing population of patients, especially chronic patients, at hospitals. Therefore, there is an urgent need for periodic monitoring of vital parameters and apposite treatment based on medical data and health status. Digital health has evolved the medical field due to the considerable progress of radio and wireless technologies which enables remote as well as on-site monitoring of patients' health status. Apropos of this, this study focuses mainly on monitoring technologies developed in Pakistan for Cardiovascular diseases. Cardiovascular diseases represent the major causes of death in Asia, the mortality rate being higher among women and patients with a low socio-economic status.

There is a vast gap between efficient and quality medical resources and their availability to the general population in Pakistan. While people living in major cities such as Islamabad, Lahore or Karachi have access to healthcare facilities, such as government or private medical institutions, most of these institutions lack state of the art medical technology. It can be inferred from their systems that the concept of digital healthcare may be alien to them. It has been a never-ending outcry of people located in remote areas to be given access to medical resources. Due to geographical constraints, people must travel great distances in order to receive medical help, and in doing so their health degrades further [49].

<u>Cardiovascular</u>

There are many available technologies in the field of remote monitoring cardiovascular diseases like ECG holters, blood pressure monitoring kits, heart rate and pulse monitoring and other related devices and systems. There are various parameters like hypertension, hypo tension, heart attack, pains, mood swing and uneven condition of patient. Many projects are done to monitor these parameters and evolve systems that help medical industry and patients in the continuous monitoring of these important parameters.

These parameters can be monitored by sensor enabled devices that are wrapped over the body in the desired mentioned locations and send their data through wired and wireless medium for their protected and reliable delivery to the hospitals and doctors. The devices also consist of IoT and non-IoT based solutions. Non IoT based solutions can monitor patients locally and then trafer the data c to desirable locations where the team of doctors can analyze the cardiovascular diseases parameters and after analysis recommend the desired solution.

Google glasses are the one of the available technology that has been used by doctors for angioplasty. Moreover, the others system for monitoring heart diseases are vital sign monitoring that have systems such as , vital sign camera by Phillips and Skin micro-blush. which is used for observe the change in capillary filling to measure heart rate and chest movement, through which respiratory rate can also be monitored [50]. There are many other devices and systems that are already used for cardiovascular diseases such as Scanadu, Zephyr ,Hexoskin ,OMsignal and cardio care boz. Scanadu is the device that me [51]. Zephyr is an Adhesive patch transmits wirelessly pulse, R-R interval, respiratory rate, activity, respirations, ECG, position and posture [52]. Hexoskin is shirt which is refered to as wearable Body Metrics, this Shirt measures HR, HRV, respiratory rate and volume, activity and estimates VO2 max [53]. OMsignal is also another washable shirt that monitors 3-lead ECG, respirations, stress, temperature [54]. Cardio Care box is the product of cognitive health care in Pakistan. The sensors made by cognitive health care, that are used in cardio care box have 80 - 85 percent efficiency. The only issue with cardio care box at this time is the error between readings of cardio care box sensors, otherwise overall application and communication system is much better. Shimmer sensors also provide the wide range of sensor to monitor Blood pressure, ECG and other health related parameters.

These all technologies are good to their purpose of usage but needs improvements in the precise and accurate values of all the vital signs. Moreover prediction systems for different diseases are missing in them.

Mobility disorder monitoring

Like the monitoring systems in other fields, there are also some advancements in the field of mobility disorder monitoring. Many of the systems and technologies have been made through which we can improve and measure the mobility disorder problems. Some of the literature is mentioned here. In research paper, successfully quantifies tremor severity and distinguishes between resting and postural tremors, the sensor used was accelerometer [55]. Another method for the detection of dyskinesia in PD patients is introduced in 2015, where activity classification is done prior to the detection of dyskinesia in order to enhance the accuracy of the system. The sensor used were Shimmer IMUs [56] [57]. Accelerometer data was used to estimate clinical scores of bradykinesias and showed good correlation with limb-specific scores [58]Evaluation of rehabilitation programs for patients with Knee Osteoarthritis was done with the help of accelerometers [59].

Remote consultation

Remote consultation is also emerging concept in the field of medical science, especially due to covid 19. Many hospitals have launched their consultation platforms, through which patients can interact with doctors and other paramedical staff for acute and mild diseases. Many applications have also been developed in this regard to bridge the gap between doctors and patients. The current literature has the systems like CHI doc and CHI buddy that enable user to interact with doctors. Moreover, the systems involve MDlive, Live health online mobile, Plush Care, Doctor on Demand, Amwell, Teladoc, oladoc, and many other systems to provide remote consultations and also suggest suitable medicine. The research gap is to improve the system for its autonomous response and related parameters.

5.1. Review of key available technologies for digital health systems

The COVID-19 pandemic has emphasized the importance of implementing smarter medical technologies. This pandemic caused a great deal of havoc on the medical institutions of Pakistan. As a result, hospitals and their medical staff have realized the necessity of digital healthcare systems and have now ventured into the era of digitalization. The author of [60] mentions a joint venture between Pakistan and United States in telemedicine. A center was established for training medical professionals in telemedicine/E-health, in which about fifty doctors as well as the nurses were trained for telemedicine services.

5.2. Monitoring system: sensor based and non-sensor based

Non-Sensor Based Technologies

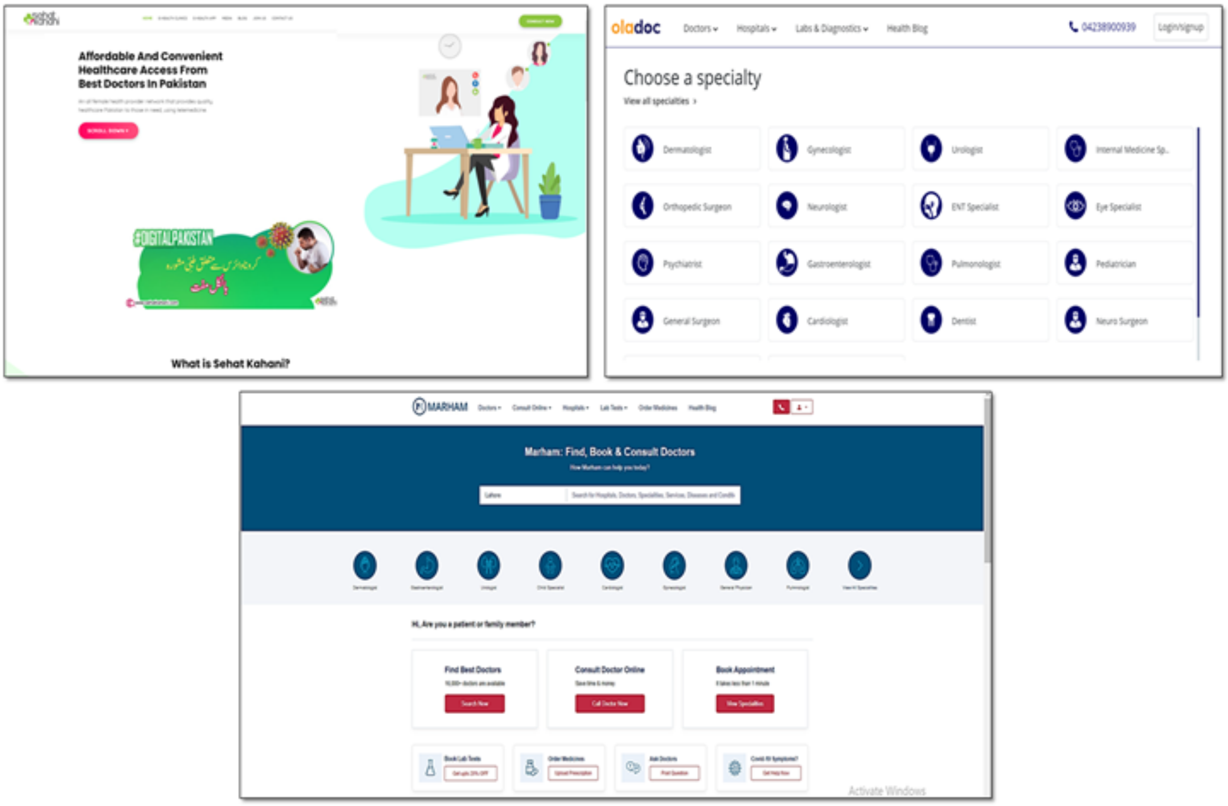

Figure 2: Online consultation panels of various health care services in Pakistan.

During this recent growth of the digital healthcare sector in Pakistan, most of the solutions or establishments that have emerged are based on online consultation services. The most notableservices are **marham.pk, emeds.pk, Sehat Kahani, oladoc,** etc. [61]. Some of these online consultation services offer video conferencing between the doctor and the patient, while others have voice chats between the two concerned parties. These online consultations can serve an important purpose in helping patients with cardiovascular diseases. Chronic heart failure is a common diagnosis but carries a poor prognosis. Affected patients are mostly major consumers of healthcare resources. The study carried out in [62] explores and reviews the effectiveness of tele monitoring for patients with chronic heart diseases. In this study, it was concluded that remote monitoring should not be seen as a replacement for specialist care, however, it may be of particular benefit to patients who have difficulty accessing specialized care because of constraints pertaining to geography, transport, or infirmity. In the truest spirit of CVD prevention, health care providers can utilize telehealth platforms to discern alarming symptoms and to counsel patients on the risks of delaying medical care as shown in Figure 2.

Another major digital healthcare provider in Pakistan is the **Shifa International Hospital in Islamabad**. They offer various tele-health services like tele-clinics, home vaccinations etc. which are shown in Figure 3. A home-monitoring service is also available but only to COVID-19 patients who are suffering mild to moderate symptoms and do not need to be hospitalized. Although, the only service relevant to cardiovascular patients is the tele-clinic which is essentially a virtual consultation system. Patients can book online appointments with medical professionals, and even opt for home visits in case they are housebound and need special medical attention.

Figure 3: Eshifa online medical services [63].

In [64] the researchers propose a fundamentally smart solution to bridge the gap between people located in remote areas who suffer from inaccessibility of medical care, and non-practicing lady doctors. Statistically 80% of the female students pursue medicine as a major in Pakistan, among which only 10-15% join the medical field as professionals. The proposed system (Figure 4) is based on virtual clinics which are accessible either through Internet (website) or cellular services (SMS). Although the proposed architecture is based on telemedicine, the authors mention that patients will, in fact, physically visit these “virtual clinics” to get their vital data registered with the nursing staff. This data will then be sent to a doctor for diagnosis based. The design or specifications of this proposed facility are not mentioned in this paper. However, improvement on this novel idea could prove vital for patients administering their cardiovascular health with the help of this telehealth service.

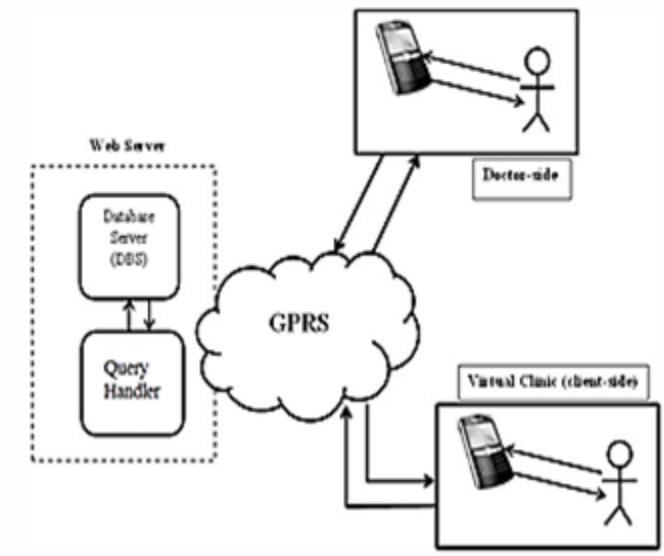

Figure 4: Proposed system model.

Another hospital in Pakistan, The Agha Khan University Hospital, provides home health care [65]. Similar to the previously discussed services, this hospital also provides services like online consultation, doctor and nurse visits, physiotherapy and palliative care. However, again these services are general and not specific to CVD patients; the only service relevant to cardiac patients is the tele-consultation service. The authors of [66] mention that this well reputed medical university in Pakistan, The Aga Khan University, is actively involved in innovating and developing digital healthcare services in Pakistan. This center envisions the "next generation hospital ward" by simulating a futuristic 8-bed virtual ward, with the latest patient monitoring, networking, and teleconferencing facilities. Digital health solutions are in the process of development in Pakistan. Pharmevo (Pvt.) Limited is the first pharmaceutical company in Pakistan to adopt new technological trends in healthcare, and they have developed a telemedicine platform known as Evotelemedicine [67]. This technology is a cloud-based telemedicine software designed to create a virtual clinic destination for patients. The main aim of this service is to help patients get rid of unnecessary wait times and the hassle in accessing qualified doctors in time. This platform gives them access to remote monitoring facilities. Their website where they offer a wide range of their telehealth services is shown in Figure 5. Their medical care through technology program offers a wide range of services, such as electronic media records (EMR), medical devices to monitor patients, live video consultation between patient and doctor etc.

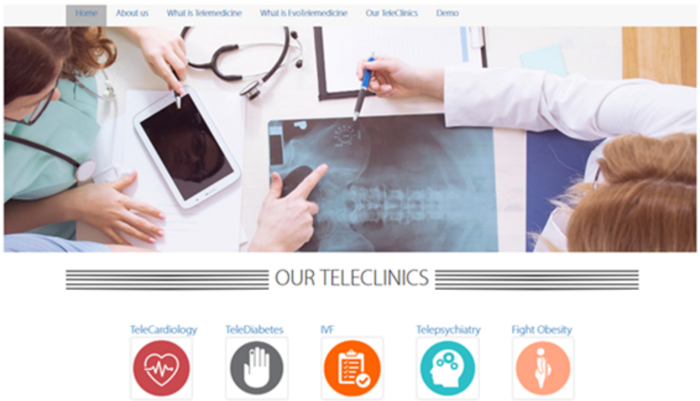

Figure 5: Evotelemedicine website.

Pakistan is facing a dual burden of both communicable and non-communicable diseases. This particular shift in disease-related paradigm has additional implications for health care service delivery capacities and resource allocation. A few estimates about the common illness among Pakistani adult population include 41% hypertension, 21% tobacco use, 17.3% high cholesterol, 21% obesity, 10% diabetes mellitus (DM), and dyslipidemia (males, 34%; females, 49%), and 2.8% stroke [68] [63]. These estimates are on the rise in this country, and healthcare technology is of utmost importance in this time to meet the supply and demand curve of this basic and crucial resource. This is where telehealth plays a vital role. While most of the telehealth platforms in Pakistan are based on online consultations, there exists a dire need to develop systems capable of delivering remote healthcare to far flung areas with easy and hassle free wearable sensors for continuous monitoring of patients. Integration of this system with AI could boost the healthcare industry in Pakistan by delivering timely responses for emergencies and saving precious lives.

Considering the alarming statistics that highlight the mortality rate of chronic patients, there is a sense of emergency to come up with solutions for it. Addressing this sense of emergency is crucial to saving human lives. This is where digital healthcare and monitoring technologies play a vital role. Evolution of AI in the medical sector has contributed massively to classify and predict health status of patients based on their physiological parameters. These parameters may be extracted through different sensing devices [69] Furthermore, computational intelligence on health data enables us to foresee and predict the possibility of heart diseases. The Internet of Things (IoT) has further revolutionized the IT sector and has had a direct effect on the medical sector. It has allowed researchers to develop mobile health monitoring devices that record vital health parameters on a configured basis. Such systems allow medical providers to remotely monitor their patients and oversee their treatment. The IoT technology has eliminated geographical distances and constraints between doctors and patients. It has also allowed the providence of state-of-art medical services to patients who are located in remote areas and are generally deprived of such luxuries. The following sections will discuss the senor-based technologies, data collection, processing, transmission and analysis methods.

Sensor Based Technologies

Monitoring system:

1. **Bpro Watch:** Measures Blood pressure 24 hours. Wrist band that sends data to android software from where it can be readable.
2. **VitalSigns Camera**: Used to monitor vital sign through camera invented by Philips
3. **Bio patch**: Adhesive patch transmits wirelessly pulse, R-R interval, respiratory rate, activity, respirations, ECG, position and posture.
4. **Hexoskin Wearable Body Metrics**: Shirt measures HR, HRV, respiratory rate and volume, activity and estimates VO2 max.
5. **OMSignal**: Washable shirt that monitors 3-lead ECG, respirations, stress, temperature.
6. **Perminova:** Heart rate, respiratory rate, fluid levels
7. **Cardio care box:** provides wearable devices that monitors all the sign and symptoms of Cardiac diseases.
8. **Rigas 2012**: postural activities monitoring
9. **Shimmer IMUs**: Simple daily life activities
10. **CHI doc**: Provide the android application for patients to communicates with doctors.

5.3. Data collection, data processing, transmission modules, software APIs

1. **Bpro Watch:** Connected to application software mainly database.
2. **VitalSigns Camera**: Onboard processing.
3. **Bio patch**: Wireless transmission of data to database and where actual processing done
4. **Hexoskin Wearable Body Metrics**: Wireless transmission.
   i. Open Data API allows to download raw data and use your own analytics software for health monitoring
   ii. Analog 256Hz ECG data
   iii. Analog dual-channel 128Hz breathing sensors
   iv. Analog 3D 64Hz acceleration
   v. Hexoskin SDK License for Android Available
5. **OMSignal:** Wireless transmission of data with android.
6. **Perminova:** Heart rate, respiratory rate, fluid levels
7. **Cardio care box:** provides wearable devices that monitors all the sign and symptoms of Cardiac diseases.
8. **Rigas 2012**: postural activities monitoring
9. **Shimmer IMUs**: Shimmer processor and wireless sensors.
10. **CHI doc**: Provide the android application for patients to communicates with doctors.

In [69] [70], the importance of healthcare monitoring systems for cardiovascular disease has been highlighted and the need of sharing the bioinformatics with medical professionals, of patients living in rural areas who are alienated or face scarcity of medical resources is discussed. This paper describes the implementation and design of a wearable ECG monitor, interfaced with Arduino. The system architecture (as shown in Figure 6) involves bio-sensing modules, a cloud (Google firebase) to store the real time data of patients, and the web interface for medical professionals to view the data and offer timely diagnosis and treatment of any incurring cardiovascular disease. The major outcome of this study is the design of a low-cost, portable and complete real-time ECG acquisition, transmission, storage, and visualization system. This real-time data can be visualized by medical professionals for offering diagnosis of cardiac diseases.

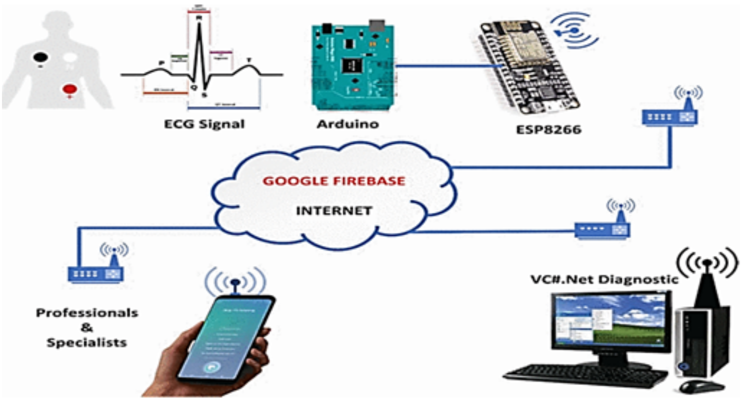

Figure 6: Proposed system [70].

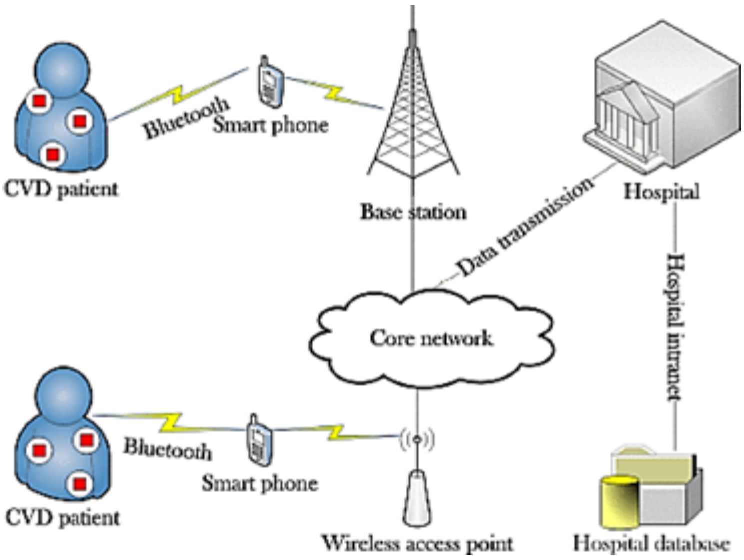

Figure 7: Proposed architecture of healthcare using IoT concept [65].

A similar approach has been taken in [71] in which the authors highlight the importance of ECG signals of cardiovascular patients. They present an IoT based health monitoring system which uses a statistical model, the Hidden Markov Model, to observe the underlying characteristics of ECG signals recorded via a sensor. This scheme aims to facilitate improved monitoring and timely intervention for CVD patients thereby enhancing medical services for such patients. The system implementation (as shown in Figure 7) employs a patient path estimator, patient table and alert management schemes within the hospital to facilitate the localization and timely intervention for the treatment of CVD patients. ECG signal is classified based on amplitude R peaks, and the time between each RR peaks. These altogether are used for detection of common and important rhythm disorder peaks. Based on comparison data of 50 normal patients and 50 CVD patients, the thresholds of ΔRR > 150 ms and t period > 60 ms are set, resultantly offering a high positive prediction of CVD.

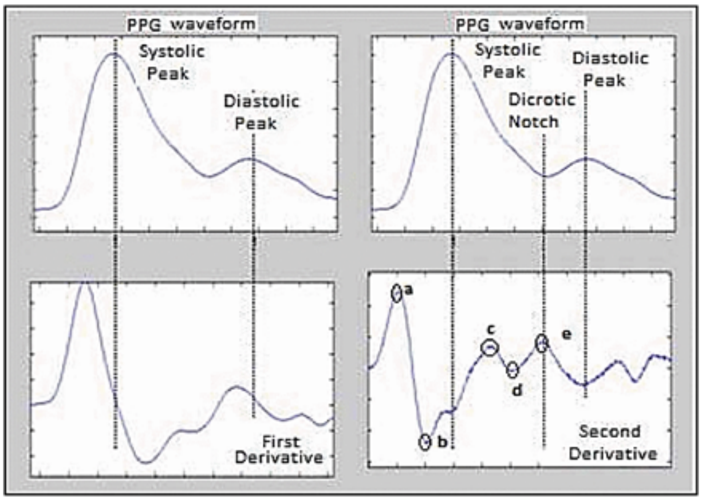

Figure 8: Feature extraction using the derivatives of the DVP [72].

Another paper highlights the limited accessibility to devices which offer advanced feature extraction for cardiovascular diagnosis [72]. This work investigates a noninvasive and continuous monitoring system using photoplethysmography (PPG), which is a simple, low-cost, popular choice for wearable devices. Features other than pulse rate and blood pressure can be extracted from acquired PPG signals. The investigations outlined in this paper advance work in automated feature extraction for cardiovascular diagnosis, demonstrated through identification of the 'a', 'b' and 'e' waves derived from the second derivative of the PPG waveform, followed by calculation of indices associated with patient arterial stiffness using these waves. The features extracted from a PPG signal are a, b, c, d, e (as shown in Figure 8) by taking a double derivative of the signal. Ratio of these features are used together to determine different attributes, i.e., b/a ratio indicates arterial stiffness. Similarly, (b - e)/a indicates vascular aging index for arteriosclerotic diseases. Prior to collecting PPG data from each subject, the heart rates were recorded in addition to metadata such as the gender, age, weight and height for each test subject. These were important as they not only provided the basis for the calculation of common metrics used for fitness (e.g., BMI), but also for validation of the trends observed through the data analyzed using the diagnostic system. The sensor was placed to collect the PPG from the wrist, which was ascertained using an oscilloscope. Percentage errors were drawn by using ratios of the features. It was found that the 'e' wave contributed the most to the inaccuracy of arterial stiffness parameter and vascular aging index. So an error in determining 'e' wave could lead to degradation of results recorded.

5.4. Systems based on Machine Learning and Artificial Intelligence:

Machine Learning techniques are revolutionizing the digital healthcare sector. AI plays a vital role in IoT-based monitoring systems for disease diagnosis and prevention. In order to maintain the health of cardiovascular patients, it is of utmost importance that their diseases are diagnosed as soon as possible. Moreover, in the IoT environment, a large amount of data is generated by sensors. This data has invaluable healthcare information and hence it is important to analyze it. Machine learning can be applied for efficient data analysis of this healthcare data.

AI and ML show that computers have the ability to accomplish tasks that are normally completed by intelligent beings such as humans and animals. Among current AI applications, ML is a tool that combines computer science with statistics for generating advanced algorithms capable of identifying the complex relationships within large datasets. At present, some of the greatest successes of machine learning have been in the field of vision and neural language understanding. Many tasks such as object classification, detection, and segmentation have demonstrated superhuman performances.

Medicine and healthcare, even from the early time of intelligence system research, has been one of the most promising and inspiring domains for the application of automatic decision-making approaches. On the other hand, it has been one of the most challenging areas for effective adoption. AI is transforming healthcare in various domains such as oncology, dermatology, ophthalmology, and radiology. Medical imaging modalities like EEG, ECG, PCG, X-ray, magnetic resonance imaging, computerized tomography, single-photon emission computed tomography, positron emission tomography (PET), and fundus and ultrasound images have provided valuable information from various body parts for diagnosis, prognosis, and treatment. Biosensor, which integrates biology, chemistry, physics, information science, and technology, is an active branch in the field of science and technology. It has a broad application prospect in disease detection, environmental pollution monitoring, immune analysis, drug screening, and other areas.

Artificial intelligence and IoT have taken the healthcare industry by a storm, with bringing state of the art care even to people located in far flung areas. A smart system based on IoT and AI is developed by a recent startup in Pakistan, Cognitive Healthcare International [55]. They are working on a proposition to help alleviate some of the pressures – bed occupancy and in-hospital expense – by integrating IoT technology with artificial intelligence in order to develop and implement a proactive diagnosis framework. Their proposed framework will monitor real-time vitals of chronically ill patients in order to provide comprehensive healthcare services outside a typical hospital and in the familiar environment of one’s home. This data will be available to the responsible physicians in order to provide timely and pertinent medical advice, thereby decreasing the average hospital stay of these patients. These services can later be expanded to cover chronic care and long-term rehab of cardiovascular patients.

In [73], the researchers are of the view that the evolution in the machine learning technologies has made it possible for early disease detection and diagnosis. This is especially useful in cases of chronic illnesses particularly heart diseases. This paper proposes a custom machine learning algorithm for the prediction of the possibility of heart disease in the next ten years and its workflow is shown in Figure 9. They have named their algorithm as Hard Voting (HV) classifier. HV has been made with the well-known Logistic Regression, Random Forest, Multilayer Perceptron, and Gaussian Naïve Bayes classifiers. The classifier takes multiples risk factors (e.g. age, sex, smoking, systolic blood pressure etc.) as inputs. The four classifiers are used, and the best prediction is considered by taking a vote. The authors used a publicly available dataset on Kaggle which comprises 3751 patients’ data. The authors used RobustScaler to scale the data to eliminate any outliers. The dataset was divided into two parts of ratio 80%-20% for training and testing purposes. The design of this meta-classifier algorithm was successful. The authors achieved an accuracy of 88.42% accuracy on the test with a precision value of 1.0.

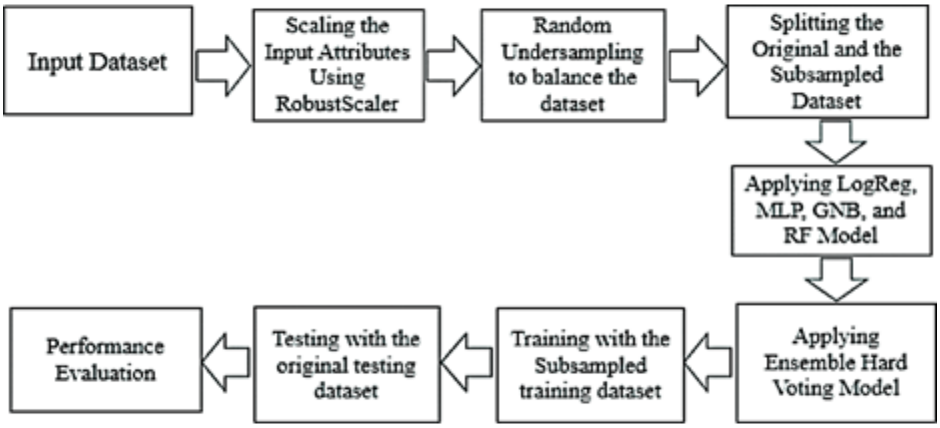

Figure 9: Workflow of the overall procedure for the heart disease prediction [73].

In [74], the researchers address the issue of remote monitoring by proposing a system that is based on IoT and machine learning techniques and is shown in Figure 10. It implements an IoT based sensor network, particularly pulse sensor, interfaced with Arduino. This system also employs ML classification techniques on the data recorded for heart illness classification. The algorithms tested in this study are the Decision Tree algorithm, Random Backwoods classifier, and Support Vector Machine (SVM). The authors collected a sample data of 40 patients and trained the afore-mentioned algorithms. It was observed that SVM shows a higher accuracy in terms of exactness of identifying a heart illness (an accuracy of 86%). The proposed hardware as well as software system helps patients to predict heart disease in early stages.

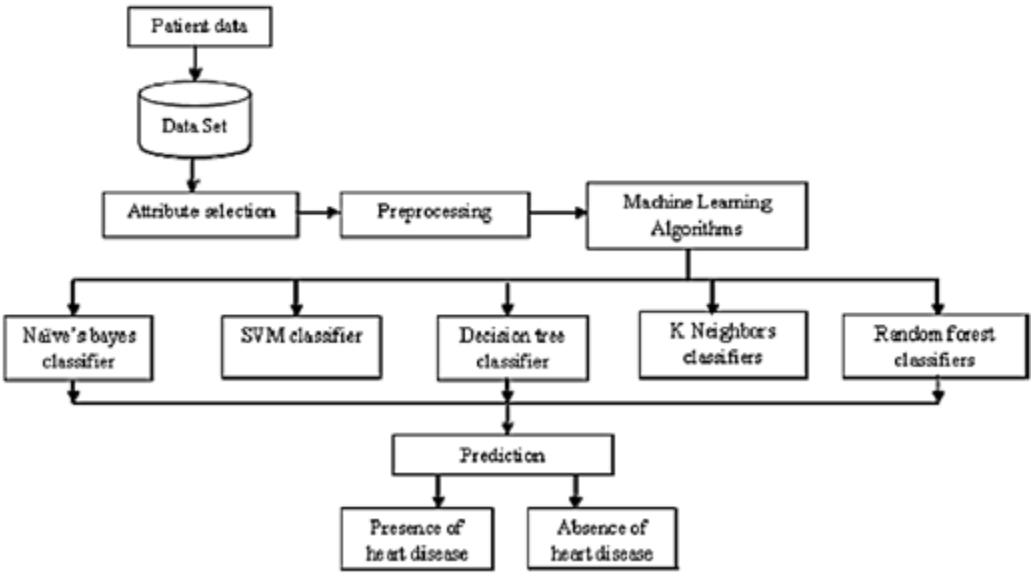

Figure 10: A smart intelligent system framework predicting heart disease [74].

ECG Signal Processing:

ECG features are unique information extracted from ECG signals and are used to represent the state of the heart. Analysis and interpretation of the ECG signal is often performed by medical professionals, who are experts in this field. However, this process can be cumbersome even for experts becausethey cannot extract enough information from the ECG signals when compared to a computational model designed to extract the components of the ECG signal. To their dismay the advancement of algorithms and physical hardware technology, automated diagnostic systems are playing an increasingly important role in the diagnosis of heart diseases. These algorithms can extract and classify the different heart related diseases transitioning from selecting potentially effective lesion features from the ECG signal thereby, aid the doctors for decision making regarding the cardiac health of the patient. In addition to morphological features that can be observed, features such as wavelet features and statistical features have also been proven to be effective in diagnosis. The features commonly applied to ECG diagnosis include P-QRS-T features, statistical features, morphological features, frequency-domain features, and other more complex parameters. Advanced algorithms extract features according to the needs of the task and automatically selects specific features to achieve precise diagnosis [75].

Let us understand the Normal ECG waveform, which consists of P-wave, QRS complex, T-wave and sometimes U waves, evident from Figure 11. Morphological features of ECG signal include different peak amplitudes, peak intervals and QRS complex, etc. The most common parameters taken into accord for heart disease diagnosis are:

- P-R interval which corresponds with the spread of the electrical conduction in atrioventricular junction. A prolonged P-R interval reflects impaired atrial conduction, and maybe an indicator of ischemic strokes [76].
- The QRS complex represents the spread of a stimulus through the ventricles. A complete QRS complex consists of Q-, R- and S-wave. Heart rate is usually measured by recording the number of QRS complexes in a minute.
- The T wave which forms due to repolarization of the ventricles and is always positive. It is useful for the diagnosis of certain cardiovascular diseases, such as an abnormal T wave, which corresponds to an inverted T wave, indicates pulmonary embolism [29].
- R wave is long and narrow, representing the depolarization of the left ventricle.

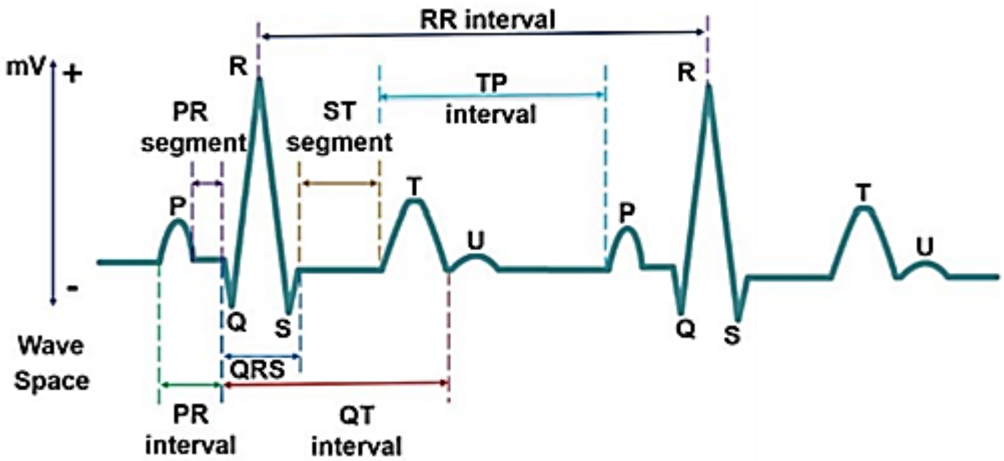

Figure 11: ECG Signal.

Among the wide variety of signal processing tools available, the most powerful tool used for feature extraction is the Fast Fourier Transform (FFT), since it reduces the times of multiplication required for computing the discrete Fourier transform and significantly improves the processing speed. Frequency domain analysis can be used to locate feature points for ECG signal analysis.

Table 1 shows the comparative overview of various digital health systems in Pakistan and neighboring regions along with the features offered by them.

Table 1: Comparative overview of various digital health systems in Pakistan and neighboring regions.

System	Region	Bio-sensors	Machine Learning/AI	Cloud Computing	Fog/edge computing	Web/mobile app
marham.pk [77]	Pakistan					✓
emeds.pk [78]	Pakistan					✓
Sehat Kehani [79]	Pakistan					✓
oladoc [80]	Pakistan					✓
eshifa [81]	Pakistan					✓
Virtual clinic [82]	Pakistan	✓				✓
Evotelemedicine [83]	Pakistan			✓		✓
eHealth Management System [71]	India	✓		✓		✓
Cognitive Healthcare International [84]	Pakistan	✓	✓			
Ensemble Hard Voting Model [69]	Bangladesh		✓			

6. Digital healthcare and monitoring status in Thailand w.r.t the three pilot cases

6.1. Review of key available technologies for digital health systems

- Research and development of a revolutionary UHMWPE (Ultra high molecular weight Polyethylene) resin with properties of a plastic resin that is extremely solid, resistant to abrasion, has good impact tolerance, and is light weight for people with paraplegia as shown in Figure 12.

Figure 12: Walking robot.

- The Space Walker is a walking aid that provides partial weight support as shown in Figure 13. For those with walking mobility issues, this can aid in walking practice, avoid trips, and improve the patient's chances of returning to regular walking.

Figure 13: Space Walker.

- Duo Seat is a bath chair designed to make it safer for the elderly to use the bathroom as shown in Figure 14. Anti-slip and fall security for the elderly can be placed on the wall in the bathroom and has no zoning, wet and dry areas. The first-floor functions as a bath seat. After a shower, another floor opens a dry seat where a user can change clothes.

Figure 14: Duo Seat.

- Sit and slip-on or a back-supporting device, is a device that aids people who are suffering from back pain or injuries as shown in Figure 15. The bottom may be dressed independently.

Figure 15: Sit and slip on.

- Developing ‘Smart Caregiving’ Application to Support Caregivers of Persons with Mobility Disability (Figure 16)

  The ‘Smart Caregiving' application was created using React JavaScript technology (ReactJS) to support caregivers of people with mobility disabilities. Caregivers and users can access the system through browsers on mobile and computers to allow caregivers and users to easily use the system and get the most benefit from providing care to people with mobility disabilities.

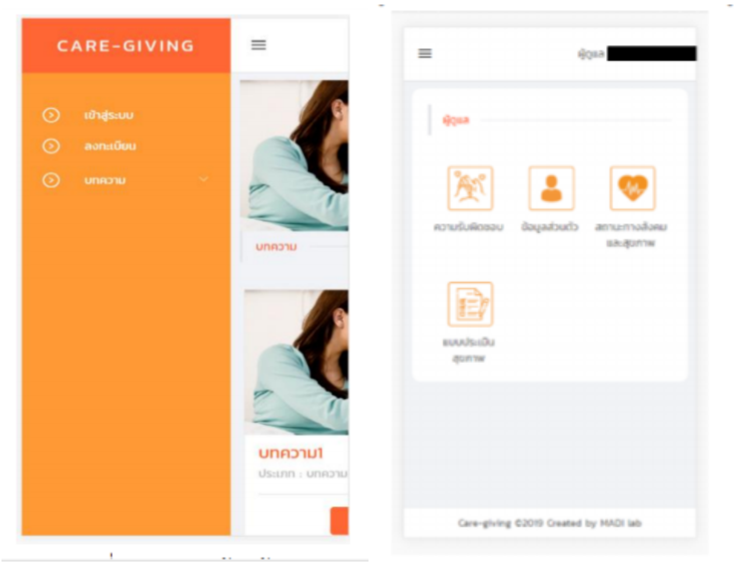

Figure 16: Smart Caregiving Application.

- The 3D Sole Innovation will improve walking comfort as shown in Figure 17. The polymer formula is intended to be an anatomically specific shoe insole with 3D Printing (FDM) technique that improves the foot's contact area.

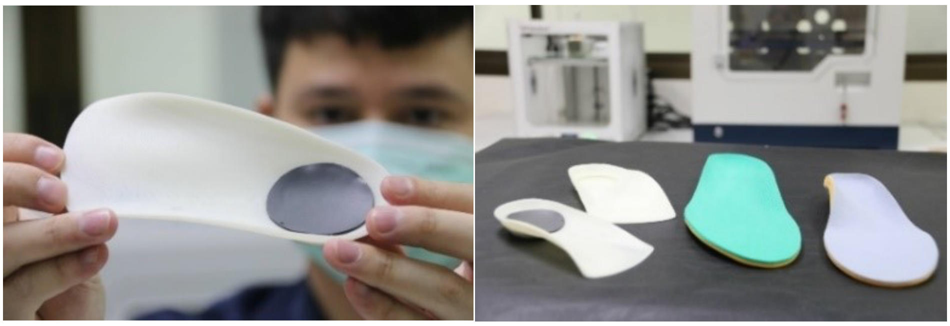

Figure 17: 3D Sole.

- A device that converts a regular cart into an electric wheelchair as shown in Figure 18. It is made up of a mobility control unit (left-right), a power unit (2 motors), and a power source unit (battery), which expands the possibilities for average wheelchair users such as an elderly or disabled person with a strong upper body.

Figure 18: M-Wheel.

6.2. Monitoring system: sensor based and non-sensor based

- The Dinsow Mini is a small elderly care robot that can be placed on a tabletop as shown in Figure 19. Sensors on the robot detect falls and motions. When an accident occurs, the robot can send a signal to family members or an elderly caregiver. It can also serve as a reminder to the elderly to take their medications at the appropriate times.

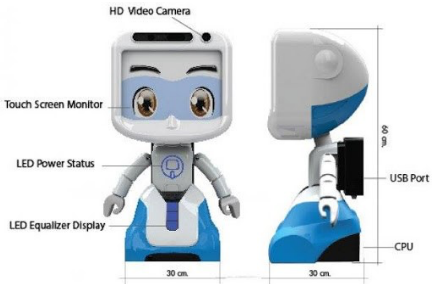

Figure 19: Dinsow Mini.

- In the event of an emergency, if no user responds within 5 minutes of receiving the notification, home8 will send an SMS message to emergency contacts (Figure 20).

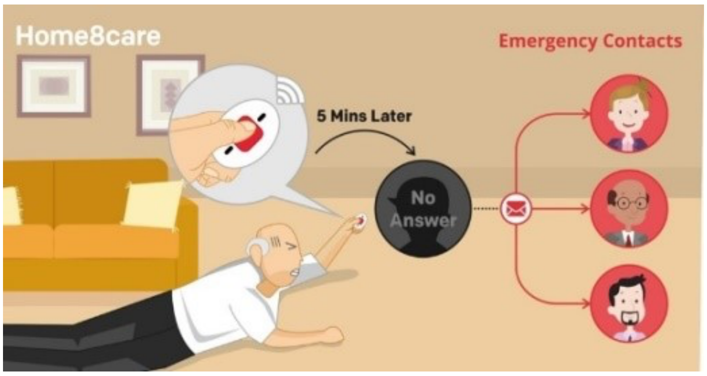

Figure 20: Fall detecting device, model FDS1300, Home8 brand.

- A smart sensor system to aid in the treatment of the elderly and sick is being developed as shown in Figure 21. It's a small sensor that monitors the elderly and hospital patients' bodies in different areas, including the ears and legs. The processing display will be alerted every 1 second by the device. To claim that the patient is getting out of bed or going out of the room in order for nurses or caregivers to take care of it before the accident, or for those people who need to be cautious with pressure ulcers. The length of time the patient has been in the same role would be known to the caregivers.

Figure 21: Intelligent sensor system, innovation for the aging society.

- Developing a 2D fall detection system with Bluetooth accelerometer sensor, the software will capture falling data and provide warning sound and text warnings on the falling victim's smartphone for assistance from those who are nearby with a text message indicating the severity of the fall and the direction of the fall to the set emergency contact phone number for quick fall rescue (Figure 22).

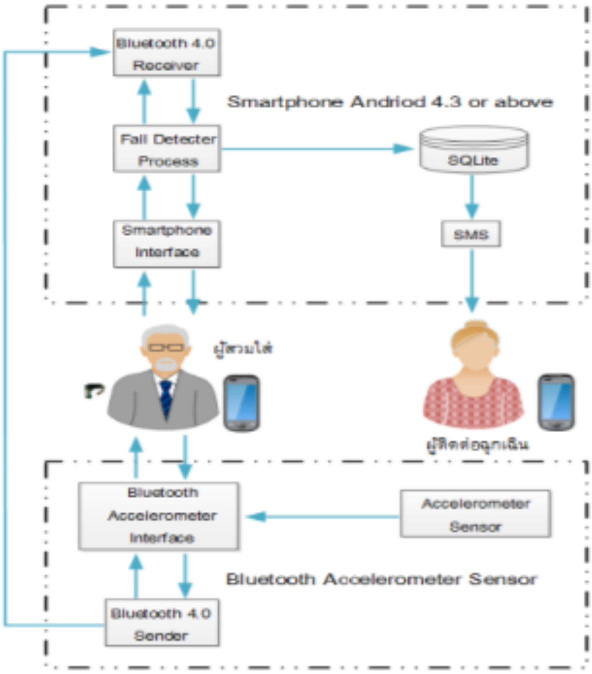

Figure 22: Bluetooth Accelerometer Sensor.

- The laser walking cane uses a light as a trigger and a switch on the ground at the end of the walking stick as shown in Figure 23. When the switch is switched on, the patient simply pushes the tip of the cane against the floor, a laser beam appears in front of it, and the resulting light encourages the patient to walk more effectively. A laser light-producing sensor is located at the end of the stick. When a patient has difficulty walking, they place their weight on the stick, which causes the sensor to fire a laser beam across the front of their face, stimulating their eyesight and enabling them to walk over.

Figure 23: The laser walking cane.

- Fall detectors for the elderly and patients with walking difficulties use a waist belt attached to the waist that tracks and processes movement posture to systematically request assistance when the elderly fall as shown in Figure 24. When the body collapses, the computer will signal an alarm and send a message for assistance to the phone, allowing the workers or assistants who have been called to locate the fallen individual.

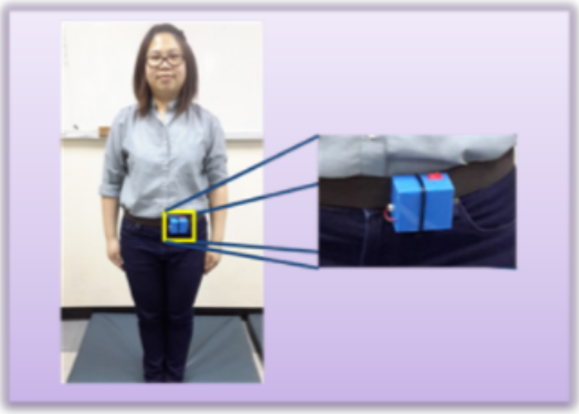

Figure 24: Fall detector for the elderly and patients with gait problems.

- Sensor system is used to monitor bedsores in patients who are confined to their beds as shown in Figure 25. The system will monitor the elderly or long-term patients' progress, such as how much slower their bodies are or how much they sit. This system indicates how much of the body's movement is slowing down. And the machine will know how fast the user is going; this is detailed to the point of saying a decimal point.

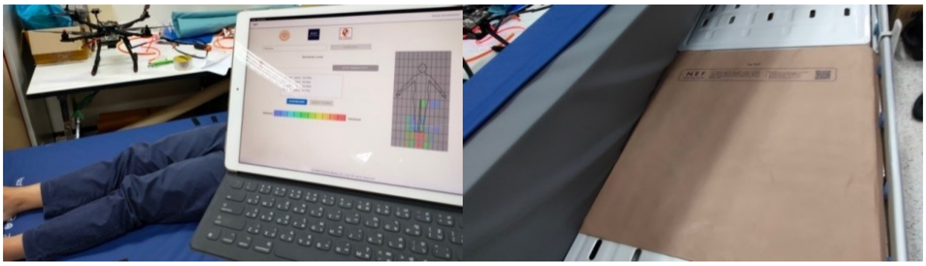

Figure 25: Sensor system for monitoring bed-stuck patients from bedsores.

- Surasole is a smart sole that allows doctors, physical therapists, and balance physiotherapists to monitor the progress of physical therapy without having to go to the hospital as shown in Figure 26. SuraSole can transfer posture training data to hospitals, physicians, and physical therapists via mobile phone or computer.

Figure 26: SuraSole smart insole for patients with osteoarthritis (OA) of the knee.

6.3. Data collection, data processing, transmission modules, software APIs

- The current Thai health information system

  The current health information system is stored in several systems, which provides Thailand with some level of essential health information; however, there are several issues that need to be addressed. Various topics, such as

  1) Lack of mechanisms and resources to support ongoing operations.

  2) Lack of quality incomplete and redundant health information system.

  3) Lack of an effective information management system

  4) Lack of a systematic data utilization mechanism

- Khon Kaen Province, one of the developing Smart Cities, has chosen to use technology, including block chain technology, to develop and improve the quality of life of its residents as shown in Figure 27. This would be used in hospitals to link data with the population in order to provide better medical services and reduce the number of patients in outpatient departments (OPD). One doctor may be required to examine up to 200 patients in less than 3 hours. As a result, using technology to help coordinate the structure is a form of long-term growth. The aim is to reduce the number of end-stage chronic disease cases caused by poor chronic disease management, such as inadequate high blood pressure or diabetes, lowering the government's healthcare costs for this community of patients.

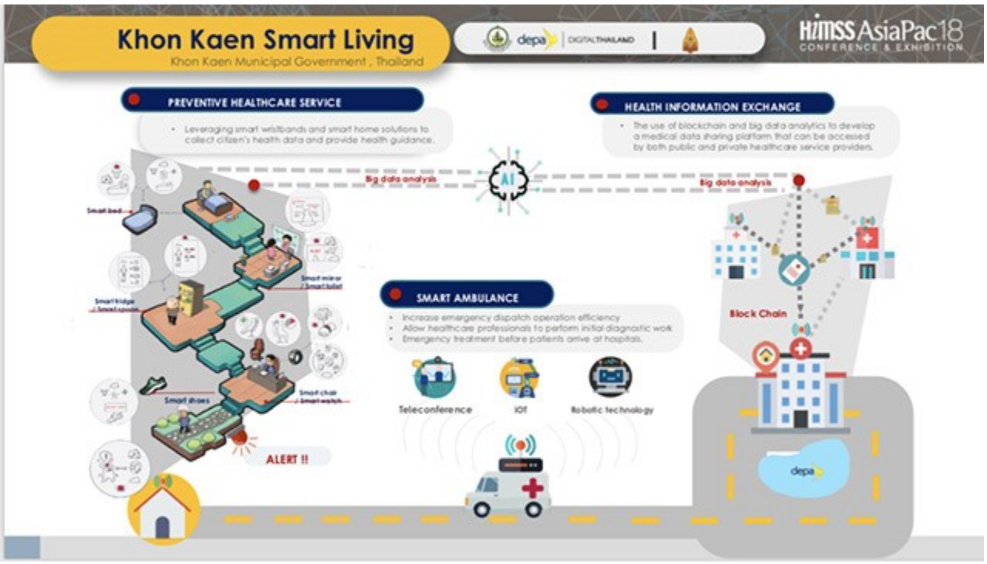

Figure 27: Health Blockchain.

- Google Cloud Healthcare API

  Google's Healthcare API (as shown in Figure 28) is an effective instrument for ingesting and storing medical data, as well as analyzing it in Google Cloud. Healthcare API is a fully managed service that is scalable, stable, and compliant with industry-specific regulations. Google has made the API really simple to use and has successfully managed to abstract away the majority of the complexities that a user would typically encounter when working with healthcare data.

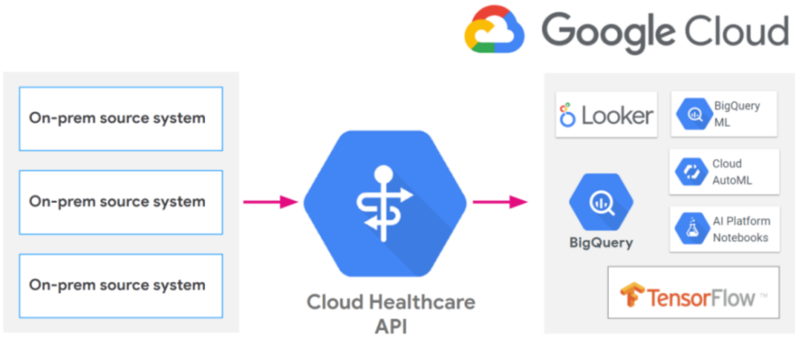

Figure 28: Connecting healthcare data to the cloud.

- The Healthcare API (Figure 29) supports a variety of data formats that are not only limited to human medicine; modern veterinary science depends on MRI and other medical imaging, and thus could benefit from this service as well.

Figure 29: Med Care Application.

- Big data with Healthcare Thailand

"Doctor Knows You Application" allows people to communicate, request services and consultation from medical personnel closely, having health information for better self-care. In case of emergency, assistance can be linked to the 1669 system.

6.4 Monitoring systems using AI/ML

- A walking robot's job entails focusing on leg movement. This gives the patient hope and allows them to learn by walking and manipulating their muscles in repeated patterns as shown in Figure 30. Physical therapy and robot walking preparation are being combined. It is more likely than physical therapy alone to help stroke survivors return to walking and regain their balance.

Figure 30: Walking robot technology to help paralyzed patients.

- GYRO GO is a hand vibration device. Which helps patients have a good quality of life and live a normal life to help themselves more and send a signal to the doctor or hospital via Bluetooth for diagnosis as shown in Figure 31.

Figure 31: GYRO GO Parkinson's hand-shake relief device.

- Asian Institute of Technology (AIT) developed the Elder Care Project which uses AI technology to act as the family's eyes and ears. Take care of your children to assist them in a timely manner, reducing the severity and loss of accidents.

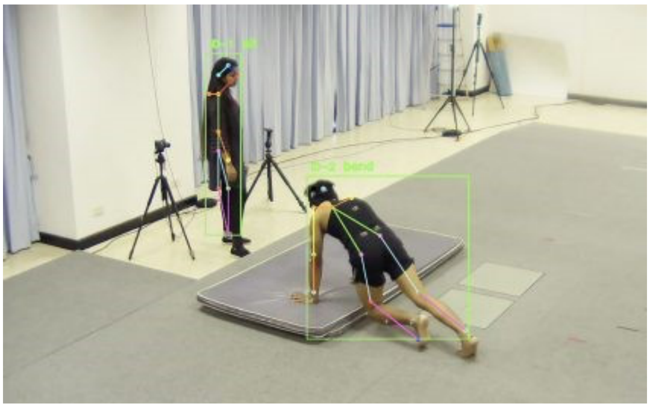

Figure 32: AI observes the movement of the elderly.

- The laser-guided walking system is built on the concept of visual cues and is designed to help the elderly with walking issues and unintentional falls as shown in Figure 33. It was studied on Parkinson's patients and found to be successful in addressing the issue of Parkinson's disease-related walking problems.

Figure 33: Laser-guided walking system.

- The Elderly Smart Pod is a device that can be used to assist Alzheimer's and Parkinson's patients as shown in Figure 34. Patients will be able to obtain assistance while still being conscious. It is also possible to track the patient's location as they leave the designated area, as well as control the patient's symptoms of tremors, spasms, or falls, thus enhancing the patient's and caregiver's quality of life.

Figure 34: Elderly Smart Pod for Alzheimer's and Parkinson's Patient.

Information technology and data communication are applied in conjunction with the remote medical system (Telemedicine) to increase access to care and medical information, enabling the remote valid exchange of information in the diagnosis, treatment, prevention and evaluation of the available evidence-based data processing system. Its use to recommend health care for bed-mounted patients (Figure 35).

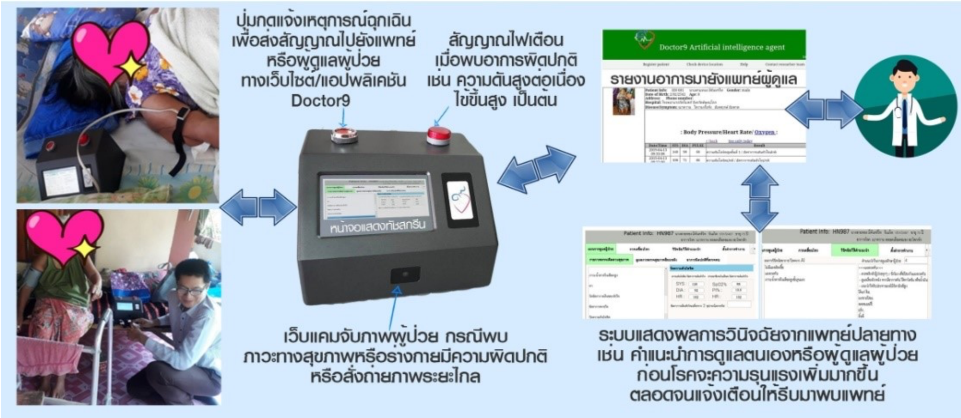

Figure 35: Intelligent telemedicine technology to monitor chronic patient care in bed.

- "3D system" medical intelligence for people with mobility disabilities

  Sirindhorn Center for Rehabilitation National medical performance has adopted a 3D motion analysis system for the development of rehabilitation medicine. The system can analyze body movement, muscle and power of various joints. While moving, such as walking, sitting, exercise, and will display the results of the analysis of the data in the form of graphs and reports through a computer monitor. In real time and processed by 3D printer, the cause of the abnormal movement of the patient can be realized.

7. Digital healthcare and monitoring status in Mongolia w.r.t the three pilot cases

Academic search platforms showed absence of published articles (in English and Mongolian) related to the topics concerned, using keywords (digital health, monitoring, remote consultation, mobility disorder, cardiovascular disease, Ulaanbaatar, Mongolia). We have collected information based on google search in Mongolian and found the following information from websites of Hospitals and organizations, official news sites and pages on current situation in Mongolia.

Mongolia is the seventh largest country in Asia with a population of above three million making it the least densely populated country in the world. Medical services including hospitals are found in the province towns, but medical specialists are available practically only in the capital Ulaanbaatar. Though the Mongolian health system is well structured, the large distance between provinces and Ulaanbaatar hospitals and the poor road infrastructure limit adequate medical services [85].

Since late 2016, the Government of Mongolia has through its Ministry of Health (MoH) received financing from the World Bank toward the cost of the E-Health Project and is in the process to establish the “integrated electronic database system of medical records” [86] [87] [88]. Throughout the newly introduced e-Health infrastructure, an application of information and communication technology (ICT) to enhance public health education, and the use of telemedicine tools for treatment, diagnosis, and monitoring is less accessible in rural areas. The use of ICT technology is very promising in Mongolia to overcome the difficulties of the patients in the rural areas to get access to the health care without travelling (walking) for days and saving a good deal of money and lives.

7.1. Review of key available technologies for digital health systems:

Cardiovascular patient monitoring:

1) The Cardiology unit at the Intermed Private Hospital uses the latest technology and equipment to provide high quality services such as cardiac coronary CT, cardiac MRI, Holter ECG monitoring, 24-hour BP measurement, stress tests and echocardiography [89].

2) In order to develop remote diagnosis and treatment, telemedicine equipment was fully installed in one of the western countryside provinces of Mongolia in 2016. At the Arkhangai aimag’s general hospital distance learning, tele-meetings, remote diagnosis and treatment consultations were conducted and regularized [90].

Within the Luxembourg government's Heart Center project, the Arkhangai General Hospital and the Shastin State Clinical Hospital in Ulaanbaatar capital city provided cardiovascular remote counseling to 28 participants, by five trained clinicians. Also, 820 cardiac ultrasound scans, and 2,884 heart recordings were done. Out of the total number of participants six cases were detected with cardiovascular disorders [90].

The electronic form of registration and information was introduced as well.

Mobility disorder monitoring:

In recent years, Yuan Run Hospital has been intensifying its cooperation with Mongolia. For example, in late January of 2021, Taiwan, in cooperation with the National Center for Trauma and Orthopedics of Mongolia, organized a conference on remote video diagnostics, treatment and exchange of experiences using 5G smart glasses [91]. Yuan Run Hospital in Taiwan, in partnership with the

National Center for Trauma and Orthopedics of Mongolia, has launched a remote video diagnostic treatment for Mongolian patients using 5G smart glasses.

Remote consultation:

1) Interview with Mr. Batsuuri [92], a medical doctor at the Intermed Emergency and Emergency Diagnostic Center. According to a study, 87% of patients who received medical treatment abroad did not actually need to go abroad. Telemedicine is said to be the most effective way to solve this problem. As a result, people with undiagnosed diagnoses do not have to travel abroad.

With the development of telemedicine services, it is possible to obtain a wide range of consulting services from highly qualified foreign and domestic physicians, whether the current treatment is appropriate, and changing the treatment plan etc. This will allow the patient to receive effective treatment. Mongolians go abroad to find out if they need to be diagnosed, have surgery, or continue treatment. In some cases, going out is unnecessary and it is economically and emotionally damaging. In fact, it is rare in Mongolia to have an undiagnosed disease. In some cases, there are diseases that are difficult to treat due to equipment. In this case, using telemedicine to inquire is cost-effective and time-consuming. Another advantage is the ability to get detailed advice from foreign qualified and specialized doctors. I think it is beneficial for a country with a large area and a sparse population like Mongolia.

For the remote consultation, first, the patient or family will be interviewed, and, if necessary, referred to a specialist to determine the effectiveness of the telemedicine service. If the patient requests for telemedicine, then he/she will be sent to the specialist consultant. Once the order is confirmed, the patient's doctor sends all the necessary diagnoses, patient histories, and test results made in Mongolia to Apollo Hospital and receives a preliminary response within 7-10 days. Once the response is received, they are contacted directly by audio and video to clarify the diagnosis and receive the necessary treatment and diagnostic advice.

In the future, telemedicine can be expanded to include tele-radiology, tele-emergency care, and tele-intensive care. In Mongolian health sector, a remote diagnostic and treatment project using information technology has been implemented since 2009 and regional diagnostic and treatment centers have been connected. The Intermed hospital has launched a joint project in the field of telemedicine and tele-diagnostics. Within the framework of this project, Intermed Hospital has been cooperating with Apollo Hospital of India for half a year. Further, the hospital aims to provide health consulting and medical care through telemedicine to citizens living and working not only locally but also abroad.

2) UB Songdo Hospital is providing access to health care from anywhere through the Borderless.clinic system based on cloud technology [93]. The hospital is working with BHG to change the availability and approach to health care in Mongolia. Through this system, women's and men's health, reproductive health, chronic disease management, and cancer care can be accessed. It includes more than 20,000 pages of content prepared by the world's best doctors and specialists, and is equipped with technology that allows doctors to translate between patients, pay by blockchain, and recognize faces. The remote treatment and diagnostic devices on the market today have a disadvantage that does not appeal to doctors and specialists who use small screens, and Borderless.clinic is working to change and update it.

Dr. Wei Xiang Yu, founder of BHG, said: “This system allows hospital staff and doctors to provide a wide range of diagnostic and treatment services, prepare information and content, and build their own brand as future professionals.” Mongolian doctors and specialists are now able to work together with experts in many fields of medicine, including Singapore, Thailand, China, Europe, Hong Kong, the United States, Canada and Australia, to fight the coronavirus without language barriers. The program can provide treatment on mobile phones, tablets, computers and TV screens. Doctors and specialists of UB Songdo Hospital will hold training on this platform.

3) The Clinica (Figure 36) is a startup for creating mobile telemedicine applications helping patients seeking easily accessible and timely alternative medical service to existing in-person services [94].

Figure 36: Mobile telemedicine application by Clinica and their problem statement.

Wasting time and unnecessary medical complications are still common due to widespread attitude of self-treatment for maladies, in Mongolia. It takes about 5-7 days in public hospitals and 1-3 days in private hospitals to get an appointment with a doctor. Lower than usual level of general public awareness of available alternatives on healthcare providers and complicated health sector structure (assigning hospitals to serving certain districts and provinces in order to provide the proportionate healthcare service) and mandatory health insurance coverage lead to overall preference for public healthcare providers with long waiting time for check-ups, wasted time for timely treatment and subsequently lower trust level in medicine. Thus, the Clinica proposing an easy, approachable solution by connecting doctor-patient virtually (Figure 37).

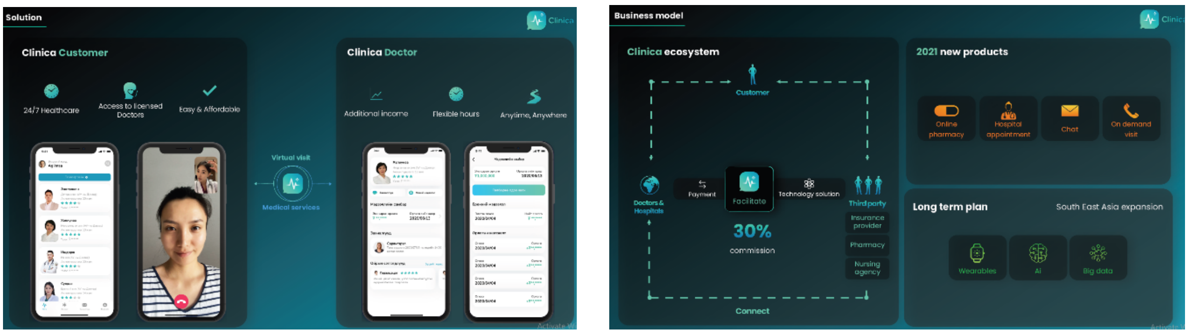

Figure 37: Problem solving statement by Clinica using mobile Medical services.

Based on existing market (Figure 38), the Clinica providing the public with basic information on the list of alternatives to public hospitals and their long waiting lists: namely info on private hospitals, paid services available for type of treatment is important for the public. Another challenge is about acquiring the service or accessing the service. With traffic jam of 2- 4 hours and parking issues in Ulaanbaatar city, it requires a significant amount of time from the patient. What is good with the mobile platform is it offers alternative choices for patients on doctors and departments with reference to practice years and public reviews. The user-friendly platform links patients short with their time and desperate for medical services with professional medical service for further quality treatment preventing life-threatening disease taking up precious human lives.

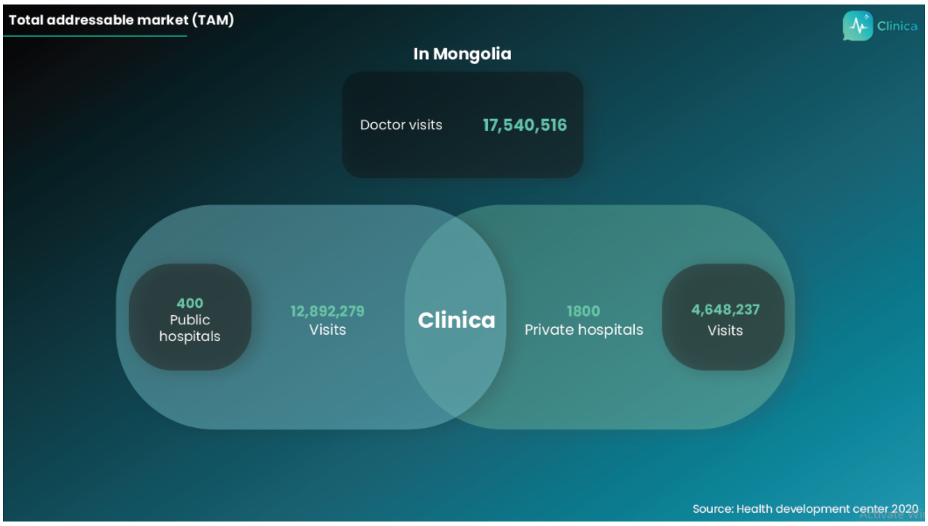

Figure 38: Total addressable market in Mongolia for the use of mobile application.

7.2. Monitoring system: sensor based and non-sensor based

- **Holter ECG/Event Recorder:** Wearable ECG device that uses stick-on electrodes to record heart activity over a 24-hour or longer period.
- **Ambulant blood pressure:** Blood pressure monitor that is worn by the patient and measures the blood pressure at fixed intervals over a certain period.
- **Apple Watch:** Starting with the 4th generation Apple Watch the device was equipped with electrodes which could be used to perform on-demand ECG recording, the software then uses this ECG to detect signs of atrial fibrillation.
- **5G smart glasses:** Enable to capture live video via the camera on the smart glasses, streaming for real-time guidance from remote staff.
- **Remote consultation:** The ASAPcare (https://clinica.mn/) [95], Borderless.clinic [96], eClinic [97] are online platforms for creating mobile and web-based telemedicine applications helping patients seeking easily accessible and timely alternative medical service to existing in-person services.

7.3. Data collection, data processing, transmission modules, software APIs

- **Holter ECG/Event Recorder:** Manual data extraction at the end of monitoring period by the doctor.
- **Ambulant blood pressure:** Manual data extraction at the end of the monitoring period by the doctor.
- **Apple Watch:** Export the full ECG to a PDF file or extract the data for processing in an app via the HealthKit SDK.
- **Remote consultation online platforms:** [98] is a government launched platform focusing on design, development, implementation and piloting of the Health Information Exchange Platform and other surrounding activities.

7.4. Monitoring systems using AI/ML

Although several AI-based doctor assistant systems such as IBM Watson Oncology, VUNO MedTrivu are used in practice, no known case is available for remote monitoring patients.

8. Analysis of the gap in digital healthcare monitoring system in partner countries

Pakistan

Modern technologies like IoT, machine learning and AI play an important role for health management of chronic patients especially cardiovascular patients. There are tons of solutions available worldwide for disease prediction & prognosis, tele-consultation, remote monitoring, and tele-rehabilitation of CVD patients. However, our detailed literature review reveals a huge research gap in the digital healthcare solutions available in Pakistan. First and foremost, there are no IoT based healthcare systems commercially available in Pakistan. Remote monitoring of CVD patients is based solely on sensor based IoT systems that can monitor the health status of a patient without any geographical constraints. However, no such systems are available to patients in Pakistan. There is also a major lack of research in Pakistan's digital healthcare sector. Furthermore, the aspect of AI and cloud computing also seems to be foreign to digital healthcare providers in Pakistan. No available e-health system employs machine learning techniques on sensor data since there are no sensor-based systems available. The only tele-health service available to CVD patients in Pakistan is the online consultation service. Some other specialized tele-health services are also available like home-based physiotherapy, but they do not apply to chronic patients directly. Some of the novel and smart solutions in Pakistan are still in the development phase and are not yet readily available to the public for use. As mentioned above, there is a dire need for digital systems in Pakistan that utilize different wearable and non-wearable sensors and employ AI techniques for efficient data processing and diagnosis. These new technologies can revolutionize the healthcare sector in Pakistan and provide much needed help to the healthcare workers. The development of the cardiovascular pilot case and commencement of specialized courses during the project will provide efficient and cost-effective medical facilities of patients in Pakistan.

Thailand

Although many researchers in many countries including Thailand have generated the systems for fall detection and prevention to increase the average life expectancy, it is still difficult to give the appropriate care for elderly people because of limitations in application settings and development processes and living alone with inappropriate care program for individuals [99]. The decline in the elderly is a major global health problem. It is found that 1 in 3 adults over 65 years old will experience a fall situation [100]. Older adults can suffer the serious consequences from fall incidences such as physical fractures and cognitive injuries. The non-trauma falls can create anxiety and fear in the elderly [101]. It also reduces situations in physical activity and social avoidance. Particularly, the fall risk assessment is a necessary step to derive individual recommendations regarding fall prevention. In addition, the practitioners might have an appropriate skill and expertise in doing fall risk screening [102] toward training and innovative tools. Preventing falls is challenged in aging [103]. The number of falls has increased as the number of elderly people increases in many countries globally. The decline is exponentially greater with age-related biological changes, which challenging to fall prevention methods [104].

It requires a new system relying on several external fall risk factors that support the environmental risk assessment process. A common system allows users and patients to develop more collaborative relationships and participation in the decision-making during the risk assessment and prevention of falls, especially for older people. To response the challenges, recommendations and future research works within this Erasmus+ project have been proposed to indicate the fall prevention methodology.

In addition, the available systems to identify and monitor the factors of falls in older people toward the physical performance parameters in Thailand are insufficient. A very reliable system likes the Optical Motion Capture system, which is the gold standard in the medical field, is too expensive for installing in all hospitals. Therefore, there are just only the medical schools and universities that can achieve this kind of equipment. Therefore, this is a huge gap for the country to provide sufficient healthcare to all populations. To shorten the issues, it is a need to design low-cost devices that can fulfill the lack of a high-end system for the practitioners and the local hospitals. These affordable devices and systems can raise the living quality to the people with a portable ability to support the practitioners for their monitoring to their clients.

Mongolia

Although the Mongolian health system is well structured, the sparse population distributed in a vast land and the poor road infrastructure limit adequate medical services [82]. The use of advancement in communication technology in healthcare is one way to help to overcome the difficulties, but our literature review shows that there is a lack of research and discussion within the country so far. There are some actions, for example, several start-up companies such as ASAPCare [92], Clinica [94] offering online medical service platforms and the Ministry of Health of Mongolia started the E-Health Project to establish the "integrated electronic database system of medical records" [83] [84], but they are at the earliest stages. These platforms are very general in terms of medical service, and their remote consultation tools are yet to be in practical application. More testing, pilot cases, and researchers from the academic side need to be involved to make them more effective and practical. So having a pilot case like ourselves will be a booster for the further development of the online platforms in healthcare, and it may become a benchmark or standard. The reason there are no scientific articles for our interest and not many researchers in AI and data analytics in general, not to mention the healthcare case, in our country, is that only a handful of universities run the programs and teach the courses. So, capacity building in higher education in those areas is essential. The commencement of the specialized courses in the degree programs and proper training programs will be another essential complement.

9. Conclusion

The use of the IoMT in the medical domain can help in providing effective and efficient healthcare services to patients with chronic diseases and ageing. Due to the incorporation of the IoMT in the medical domain, remote patient monitoring is possible which helps significantly in reducing hospitalization costs and providing home-centric medical services. With such home-centric medical services, patients are more satisfied with the treatment and interaction with the doctor.

The deliverable provides a detailed literature review on digital health monitoring systems in Europe and Asia. The literature review includes 1) key available solutions, 2) system components, and 3) use of AI/ML for the three pilot cases (cardiovascular monitoring in Pakistan, mobility disorder monitoring in Thailand, and remote patient consultation in Mongolia). In addition, the deliverable categorically identifies the gap in the available health facilities or solutions for the pilot cases in the partner countries. This information sets a ground for the needs and importance of the pilot cases in the partner countries. For increasing the sustainability impact of the pilot cases, it is planned to make prototypes and possibly commercialize such prototypes. For this, specialized and training courses will be commenced at the Higher Education Institutes in the partner countries where the goal is to train medical practitioners, medical students, medical staff, ICT staff, etc. with the pilot cases.

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