Development of Portable Multi-Functional Tele-Healthcare System

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A B S T R A C T

Medical healthcare units and the diagnostics devices are design with standard modules installation and almost every sensory device-working mode is similar with difference in mode of data fetching. However, even the working operations are standard researchers are developing different devices for different diagnostics. Typically, sensors false in digital or analog modes only hence developing generic device supporting multiple type of sensor is feasible and acceptable. For area with limitation of resources such, a multiple functional single device is in high demand. Major issues with such a device development is software and sensor value calibration or calculation as per the requirement. Body statistics includes multiple parameters where some are direct value calculated and detected by sensor itself at real-time, and few parameters are calculate based on the standard procedure of averaging with respect to time or the differential value between different processes or the values. Proposed system is design to overcome this problem and implementing a single device with multiple functional algorithms execution as and when required and demand based. Research study presented the method to handle different processes on demand and stated the multiple procedures of operations in health care devices & deployments.

1. INTRODUCTION

Hospital visits might incur high expenses, especially in rural regions, as a result of transportation costs. During the Covid-19 Pandemic, when face-to-face contact poses a risk, individuals are inclined towards telemedicine. Thankfully, the usage of telemedicine services, such as video conferencing or other virtual technology, can help decrease the number of medical visits required. Telemedicine efficiently reduces the time and expense of treatment for both patients and healthcare providers. Moreover, owing to its rapid and beneficial attributes, it has the ability to optimize the operational processes of hospitals and clinics. This innovative technique would facilitate the monitoring of patients who have been discharged and enhance the management of their recovery process. Therefore, it may be concluded that telemedicine has the potential to generate a mutually beneficial outcome.

Utilizing advanced technologies and high-quality network services allows individuals to enhance healthcare delivery and expand its accessibility to a larger population. Tele-healthcare is an advantageous technology that facilitates access to preventive therapy and promotes long-term health. This is especially applicable to individuals who encounter financial or geographical barriers to accessing high-quality healthcare. Telehealth has the capacity to enhance the effectiveness, efficiency, and accessibility of healthcare. The study in this field is now in its nascent phase, but it is progressing and growing. For instance, implementing telephone-based treatment and telemonitoring of vital signs in individuals with heart disease resulted in a reduction in the likelihood of death and hospitalization, while also improving their overall quality of life. There are multiple strong justifications for individuals to obtain a diagnosis or rehabilitation plan. This might instill patients with a sense of confidence that they are being provided with the highest caliber of medical care. Telemedicine is a highly advantageous option for addressing mental health concerns. It addresses some factors that hinder patients from accessing this essential type of therapy (Hajesmaeel-Gohari & Bahaadinbeigy, 2021; Lupton & Maslen, 2017; Wilson & Maeder, 2015).

Considering the remote or the rural area providing healthcare facilities with automated machine for diagnosis becomes the major task. Setting up critical care unit for home care patient at multiple location or setting up care unit for basic and periodic patient both have its own challenges and cost-effective issues. Portable tele-healthcare unit for first level diagnosis is better option to overcome these issues. On other hand, the problem with body parameters and statistics to monitoring is these are multiple in numbers and every parameter required different method for measurement or detection. Handling multiple machines or instruments for individual parameters needs multiple wireless connections, power supply, and standard operational procedure, which lowers the feasibility and the acceptability. With advancement in manufacturing right support and supply chain for such a device can be established but before that, it need a survey about acceptance and the usability at large scale level is essential. This research is more focused on proposing and developing the portable yet multi-functional singular medical device, which may support diagnosis of different body parameters like temperature, heartrate, ECG, oxygen, etc. individually one after another and allow user to share it to consulting hospital or the doctors for further treatment suggestions using IoT technologies. This portable device also aimed at sharing different category data for different type of data analysis authorities like, patient, doctors, health organizations, or the device manufacturers.

2. BACKGROUND

2.1 Tele-healthcare system

Telehealth refers to the utilization of technology to provide various components of health information, prevention, monitoring, and medical care through a virtual platform. Telehealth, with telemedicine as its primary component, is the most rapidly expanding sector in healthcare. Telemedicine is specifically defined as the practice of medicine using distant technological interfaces. There are variations within the implementation of telemedicine. In hospital-based health care delivery, it is common for doctors to provide care to other doctors, especially in cases when the doctors receiving care are not specialists, are located in remote areas, or are from other countries. Conversely, the demand for direct patient-to-doctor medical treatment is growing, and individuals now have the option to reach out to doctors via telemedicine using direct-to-consumer services. Telemedicine offers can be categorized into three distinct types: remote monitoring, synchronous services, and asynchronous services. Synchronous refers to the real-time dissemination of health information. This enables the provision of medical expertise in real-time conversations with the patient or healthcare provider. A Facilitated Virtual encounter (FVV) is a supplementary mode of synchronous telemedicine encounter. An instance of an assisted virtual visit can occur when a patient is present at a clinic or another conveniently accessible site equipped with diagnostic tools, while the healthcare professional is located elsewhere. In this scenario, a tele facilitator, such as a nurse, medical assistant, or other support personnel, utilizes tools such as a digital stethoscope, thermometer, pulse oximeter, etc. to gather objective data. Subsequently, the tele facilitator transmits this information to the physician. Asynchronous telemedicine, also referred to as "store-and-forward" telemedicine, involves the collection of pathology reports, pictures, and medical history by a doctor or patient. This information is then sent to a specialist for diagnosis and treatment. Remote patient monitoring is the continuous evaluation of a patient's clinical condition, either through direct video observation or study of remotely collected tests and photos. Newer technology, like as mobile applications on smartphones, enables a wider range of telehealth opportunities (Baumgärtel, Riessen, & John, 2019; Ricci-Cabello et al., 2019; Weichelt, Heimonen, Pilz, Yoder, & Bendixsen, 2019).

In order to resolve problems related to video stability and limitations on bandwidth, telehealth necessitates that participants possess reliable and strong Internet connectivity, usually in the form of a dependable broadband connection and mobile communication technology that meets at least the fourth generation (4G) or long-term evolution (LTE) standard. Due to improvements in broadband infrastructure, telehealth applications have become more widely feasible. To enhance telemedicine, healthcare practitioners often begin by doing a needs assessment to examine obstacles, such as commuting time, costs, or work absence. Technology enterprises and other partners can expedite the transition. There are four distinct domains for delivering services: synchronous live video, asynchronous store-and-forward, asynchronous remote patient monitoring, and mobile Health.(Li, Hu, & Zhang, 2017; Nduka et al., 2019; Yadav, Mittal, & Yadav, 2018; Yue, Voronova, & Voronov, 2020)

- **Capture and Transmit the Data for Future Retrieval**.

Store-and-forward telemedicine involves the collection of medical data, such as bio signals and medical photographs, which is then transmitted to a physician or medical specialist for examination at a later time. Simultaneous presence of both parties is not a prerequisite. Asynchronous telemedicine is effective in various fields such as pathology, radiology, and dermatology. The transfer should encompass a meticulously arranged medical record, preferably in digital format. The "store-and-forward" strategy eliminates the need for a physical examination, requiring the physician to depend solely on a history record and audio/video data.(Alnefaie, Cherif, & Alshehri, 2019; Deshmukh, Kumar, & Shirsath, 2019; Lakkis & Elshakankiri, 2017; MacIs et al., 2020)

- **Remote surveillance**

Medical professionals have the ability to employ a range of technical instruments to observe a patient from a distance using a method known as remote monitoring, sometimes known as self-monitoring or testing. Heart disease, diabetes mellitus, and asthma are specific ailments or chronic diseases that are most effectively controlled with this strategy. These services may offer a more cost-effective option, higher patient satisfaction rates compared to traditional in-person contacts, and produce health outcomes that are similar in quality. Two examples include enhanced collaborative management and nocturnal home dialysis.

- **Real-time interactive**

Interactive telemedicine services facilitate immediate and direct connections between patients and healthcare providers, allowing for electronic consultations. Video conferencing has been utilized in several therapeutic contexts and professions for the purposes of managing, diagnosing, counselling, and monitoring patients.

2.2 Sensory Technology in Tele-healthcare

Typically, sensory-based model works in three major stages Data extraction, Data processing, and Data presentation sequentially. We defined and presented in figure 1. These three stages as following.

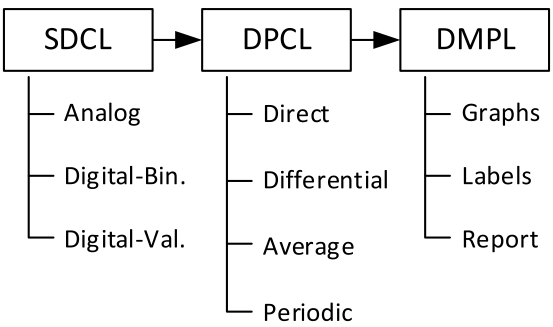

Figure 1. Sensory statistics monitoring

- **SDCL (Signal to Data Conversion Layer):** Sensors are primarily categorized in A. analog presenting variable value in pre-defined minimum and maximum ranges, B. digital binary value with true or false state in series, and C. digital unit based real-world values.
- **DPCL (Data Processing and calculation Layer):** depending upon the sensor value extracted and the working principle of medical procedure for parameter calculation or processing, methodologies are categorize in following category. A) Direct sensor extracted value as a result, B) Differential value between two or more timestamped values of pre-condition and post-conditions scenarios, C) averaging value from defined time period or defined number of samples, and D) periodic sensor value reading to monitor the progressive variations in parameters.
- **DMPL (Data Management and Presentation Layer):** presenting sensory data has globally accepted standards and methods where single instant and current values are typically present or display on labels with right visibility and readability. The series of value with relative changes and with respect to time are present in graphical patterns and finally multiple value with multiple sub-fields are present in row or column pattern known as reports.

As a part of the research and study, we studied different medical sensors and its working principle along with time sensitivity and resultant type. (Table 1) presented the comparison between selected sensors based on defined parameters. It also stated that typically medical parameters are either acceptable in interval of pre-defined time on demand or need to extract on real-time basis in critical conditions. In delayed mode, medical device could be detachable to body and connect on demand, and in real-time mode medical devices needs to connect all the time does not matter how long it took to recover. For example, patient in ICU monitored for real-time throughout the treatment time.

Table 1. Executional comparing of medical sensors

	Parameters		
	Interval	**Interval Level**	**Result type**
Temperature / Humidity	Delayed	Mid	Direct
Spo2 / Oxygen	Delayed	Low	[Avg.:Samp.] / Min
Blood Pressure	Delayed	High	Differential
Heart Rate (BPM)	Real-time	Instant	[Avg.:Samp.] / Min
ECG / EEG / EMG	Real-time	Instant	Variable Data Patterns

Different parameters are tested using supportable sensors and processing unit, to understand the acceptable frequency or interval between two readings. We also tested the need of singular direct reading or batch of reading from sensor to generate the final result. Considering the hardware design and the primary processing unit or microcontroller in such a hardware are typically single threaded program and running in an infinite loop until exiting the programs. This makes it difficult to control execution flow as it depends upon the processors clock speed and control through defined or desired delay in execution.

As medical parameter calculations has a different method of direct, averaging, or the sampling methodologies it becomes difficult to run multiple functionalities as the hardware firmware either works in continues delayed flow or continuous counter-controlled flow. For example, in direct approach, temperature sensor gives is instant resultant value. Heart rate sensor gives pulse trigger as a input which needs to calculated as number of pulse per minute so it is based on averaging. Blood pressure sensor gives resistive pressure from muscles after applying the external pressure hence real blood pressure value calculated as differential changes in pressure values. It state that sensor alone cannot give final resultant value rather it may need calculation and processing approach on sensor input. We proposed a multiple functionality with single execution at a time approach. This will enable single hardware to perform multiple operations and serves multiple functionalities on demand at different time. With this approach system, design could be singular and make it more generic to operate, transport, and maintain easily with minimum cost.

3. PROPOSED SOLUTIONS

Proposed solution is design and development of portable multi-functional medical parameters diagnosis and statistics sharing system for remote homecare patients. The overall system is combined with sensory unit, display unit, processing unit, USB wired and Bluetooth wireless communication module. Since idea is to make it portable the system is designed to run on low voltage to make it power up using DC battery power supply. Overview of the system is presented as a block in figure 2.

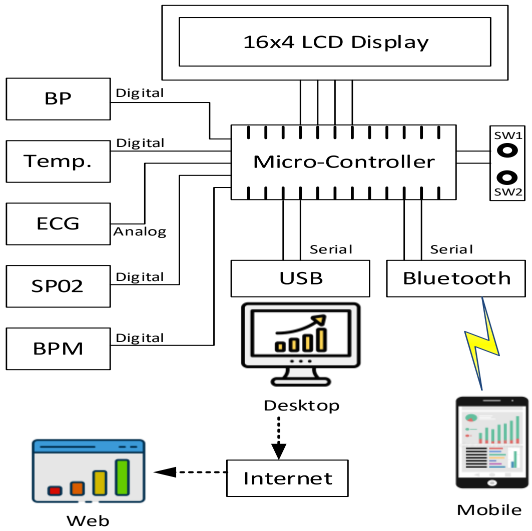

Figure 2. Multi layered proposed solution

The system utilizes the following basic sensory components. None of the modules utilized are classified as medical grade or medical devices, and they are not meant to be used as accessories for diagnosing or treating any medical disorders. These are specifically created for the purpose of conducting proof-of-concept testing in medical situations.

The MAX30102 is versatile sensor is capable of evaluating both blood oxygen saturation and heart rate, as well as accurately determining body temperature. A digital pulse oximeter and heart rate sensor is an electronic device that measures an individual's heart rate by detecting the variation in blood oxygen levels between oxygen-rich and oxygen-poor states. This device has the capability to measure both heart rate and blood oxygen levels. Analog Devices developed this sensor to detect pulse oximetry (SpO2) and heart rate (HR) data. The device consists of two light-emitting diodes (LEDs), specifically one red LED and one infrared LED, together with a photodetector, optics, and a signal processing unit that minimizes noise.

The AD8232 ECG Sensor is a cost-effective device designed to measure the electrical signals generated by the heart. Electrical activity can be measured and represented as an electrocardiogram, or ECG. The AD8232 Single Lead Heart Rate Monitor serves as an operational amplifier to efficiently acquire a clear signal from the PR and QT Intervals, which tend to be highly distorted on electrocardiograms (ECGs).

The DS18B20 is a temperature sensor. This sensor has a precision of +/-5% and is capable of measuring temperatures ranging from -67oF to +257oF (-55oC to +125oC) utilizing a single wire protocol. The data range received from the 1-wire can include between nine and twelve bits. Because this sensor follows the single wire protocol and may be operated by just one microcontroller pin.

The HX710B Blood Pressure Sensor measures the pressure exerted by the blood in the arteries as the heart pumps blood throughout the body. The heart propels blood throughout the body by contracting and propelling blood through the arteries at each beat. The arteries are subjected to pressure exerted by this force. The diastolic pressure, which corresponds to the heart's relaxation phase between beats, is combined with the systolic pressure, which represents the overall blood pressure value. The sensor module incorporates a pressure sensor with excellent linearity and a very efficient 24-bit ADC. The ADC is equipped with internal, factory-calibrated coefficients. The device offers multiple operation modes that allow the user to customize the conversion speed and current consumption. Additionally, it provides precise digital readings of pressure and temperature values with a resolution of 24 bits. The air pressure sensor module utilizes a high-precision AD sampling chip, an air pressure sensor capable of measuring pressure within the range of 0 to 40 KPa, and a 2.5 mm hose to accurately detect air pressure.

3.3 Proposed system process architecture

Proposed system work in multiple modes and in multiple scenarios where it deal with the normal workflow condition and the emergency assistance services. Figure 3 illustrates the overall architecture and the system workflow of the project.

Normal medical service mode: This mode consisting the standardization of the data travelled across the healthcare service provider entities related to individual patient. In order to preserve the data, multiple sub-entities are involved in the process those are like,

- Hospital / Clinics: These entities are responsible for generating the patient treatment and the service provided information. These includes information like patient registration, staff registration, discharge and treatment summary, prescription summary, pathology result reports, service provider profile and pharmacy and hospital inventory information.
- Government Central Server: This entity will be responsible for centrally controlling and maintaining the indexes for every hospital data. These will be responsible for sharing the data between multiple and the different healthcare service provider entities. This entity manage the individual entity information through its individual registration and profile management process. This entity primarily governed by central or state government.
- Patient health record manager application: Every time patient take the medical service form different healthcare service provider then the service provider responsible for sharing the service provided information with government central server for future references. This patient health record manager application will request central server to have a access to the patient information after specific consent. This will help patient carrying his information throughout the time and remove physical paperwork.
- Health Digital Record: This is another important and optional service for the patient where patient can maintain his medical treatment history including the report, scans, prescription and other supportable file format. These file could be accessed anytime and could be shared with doctors for further analysis and treatment planning.

Above mentioned all the entities having independent role and functionality, but the only concern of every entities is to maintain the patient information in standardized format and make it available as and when required.

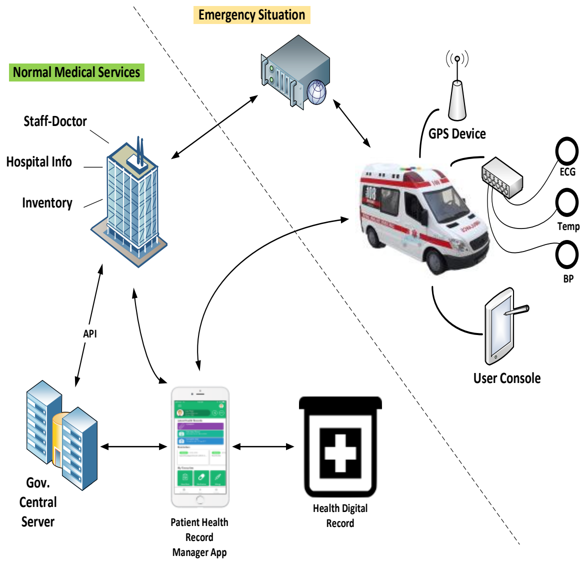

Figure 3. Proposed system architecture and process workflow.

Medical Emergency Situation Mode: In order to provide right medical service, it is important to have right information about the situation and the available resources at the treatment location. Currently in case of emergency patient taken to the pre-defined location by ambulance and after fist level of investigation decision may take place for moving patient at right location of the service availability. This may create a situation in delaying the service availability and the treatment. In this mode specially designed portable ICU inside ambulance and the centrally connected user computer console to provide patient right situation will help system to get the information about right service availability location. In this mode following are the steps involved in the process.

- Ambulance attendant first attend the patient and connect all the possible sensor to the patient and the sensor system will get the patient status by the means of defined parameter line, BP, Temperature, heartrate, etc.
- Ambulance attendants provide other patient information to the system using system console and the GUI, which cannot be taken from sensors, like loss of blood, fractures in body, etc.
- Once the system have all the information about the situation, system will connect the central server of the pre-defined first nearest service provider location and check for the inventory including the staff availability which might be required to handle the current medical situation.
- If information concluded in lacking with the resources, then system will connect to next best available service provider in the list, if it is concluded that next service provider having all the required resource to handle the current situation, then computer console in the ambulance will guide the ambulance attendant to travel to the mentioned service provider location.

3.4. Case Study for the Process

In the past years, developments in telemedicine have reached significant ground, especially in regions with inadequate health facilities. Such development would be the creation of a portable, multi-functional telehealth care system that makes the diagnostics process easier and offers a wide array of healthcare services through a single compact device. This case study demonstrates a real-world application of such a device in a rural healthcare initiative in sub-Saharan Africa, where access to quality healthcare has always been challenging due to geographical and infrastructural constraints.

The impetus of this project was provided through a coordinated effort between the World Health Organization (WHO) and the Bill & Melinda Gates Foundation, with the added specialization of one of the preeminent biomedical engineering firms entitled MedTech Solutions. It was to develop a tele-healthcare device that could support multiple diagnostics in blood pressure, heart rate, blood oxygen levels, glucose levels, and electrocardiogram, all using the same modular platform. The target was rural communities in Kenya where lack of healthcare infrastructure had left millions without reasonable access to regular medical check-ups or even emergency care.

Development of this tele-healthcare device was based on the use of standard medical modules and interoperable software that could support both analog and digital sensors. From such problems, the engineering team in MedTech Solutions realized that even though single diagnostics devices like glucometers, blood pressure monitors, or pulse oximeters are very well established on their own, there is a need for a single device able to integrate all these functionalities. Such an approach would make healthcare delivery efficient and cost-effective—especially in resource-limited settings—by eliminating the use of separate devices for each diagnostic measure.

Project initiation involved designing a device with multiple sensor inputs, all working in both analog and digital modes. Industry-standard sensors that varied from one another in terms of data acquisition were selected by the engineering team. For instance, the interface sensor for glucose monitoring operated on the principle of detecting glucose information in blood by an enzymatic reaction, transducing this information to an analog signal, and then the signal digitized for processing. On the other hand, the blood pressure module used oscillometric information detected through a digital pressure transducer. A major challenge in developing one system to process and integrate information from several sensor types was the differences in modes of data collection between different sensor types.

As such, the software architecture was designed to be modular and adaptive. It specifically was designed in such a way that it could automatically identify the type of sensor attached at any time and change its algorithms on board to suit the sensor attached. This degree of flexibility was essential to assure compatibility with data input modes as diverse as continuous, in the case of ECG monitoring, and intermittent, in the case of glucose level measurement. Such software was developed with a hybrid approach, combining real-time processing for urgent diagnostics and batch processing for parameters requiring time-averaging, such as blood glucose trends or temperature monitoring.

One of the major challenges addressed in the project was the calibration of sensors. The range of sensors in use meant that each of the different types required a calibration procedure adapted to its purpose. Here, the engineering team cooperated very closely with biomedical specialists to ensure that calibration algorithms were correct and could easily be updated/adjusted if required. For instance, the ECG sensor would require high accuracy in calibration to detect an arrhythmia, while the blood pressure sensor would need periodic recalibration to re-establish the correct relationship between pressure readings and environmental factors like altitudes.

Shortly after the prototype of the tele-healthcare device was created, there was a field test in a pilot program launched through a number of rural clinics in Kenya. One of those clinics was situated in the remote village of Oloitokitok, which became a testing ground for proving the real-world applicability of the device. The site in Oloitokitok, on the border with Tanzania and proximity to Mount Kilimanjaro, was chosen to intentionally cut off the populous urban centers, and so the access to health practitioners and facilities, was trimmed. The closest being more than one hundred kilometers from the village. This jumbled timely access to medical attention by villagers.

Local Health care workers were assembled and trained to use the device in a pilot phase. It was very user-friendly for these workers who mostly had little formal medical training, through its interface and step-by-step guide. The software enables it to be run with very minimal technical expertise, as users are guided through set-up and diagnostics. For example, in measuring a patient's blood pressure, this gadget would help a health care professional by explaining to the worker to make sure that the cuff was on the right position, that the patients was in the right position, and that the surround was quiet to avoid wrong measurements.

Of interest, in the case that this tele-healthcare system reflected was :. A man in his mid-fifties, Samuel by name, a local farmer hailing from Oloitokitok, visited the clinic because of the recent complaints of frequent dizziness and shortness of breath. An ECG had not been done on him before because of his far-off location and inability to see a cardiologist. With the newly equipped tele-healthcare device, the local healthcare worker was able to perform a full ECG scan on Samuel within minutes. The algorithm for the device flagged that the operation of the heartbeat was not functioning correctly/on some mal-functioning rhythm and symptoms related to atrial fibrillation, which could have serious implications if untreated. The ECG results of Samuel automatically reached the cardiologist in Nairobi, who confirmed the diagnosis, prescribed medication, and the possessions rushed to Samuel in days. Had the tele-healthcare device not existed, it would have involved a journey of several hours to collect an ECG of the patient, and the diagnosis could have been misplaced or delayed.

Chronic disease management such as diabetes also found it easier to manage. Patients who had previously failed to monitor their blood glucose regularly would now be able to monitor their blood glucose levels in the visiting clinic. Managing each of their blood sugar levels, the tele-healthcare system tracked them over time with data to help healthcare workers and distant doctors tailor change treatments and recommendations according to trends. Diagnosed with diabetes type 2, a young lady by the name of Aisha became one of the first patients whose life this technology managed to save. She had to manage the condition for many years without any form of glucose monitoring because she did not have access to a glucometer. Her sugar levels would now be checked and the tele-healthcare device used to compare readings, as shown by a doctor based in Nairobi, who had to adjust her treatment regime, hence cutting back the frequency of her hyperglycemic episodes.

For epidemiological research as well as for individual patient care, the pilot system was highly beneficial in data collection. Health workers could collect de-identified information on prevalent conditions in the region, such as hypertension and diabetes, for analysis by health organizations. For example, information obtained from the database revealed a high percentage of the target population suffering from the undiagnosed hypertension condition. This prompted the Kenyan Ministry of Health to run an awareness campaign on the need to check blood pressure levels regularly and with the view of raising the tele-healthcare tool to be deployed in other rural parts.

Its implementation in Oloitokitok turned out to be a great success, which further led the tele-healthcare project to further reach out to other parts of Kenya and into sub-Saharan Africa. The device is still being refined but has become a major device in bridging the gap in healthcare that exists in remote and under-served areas. Its capability to provide multiple diagnostics in a portable, user-friendly format has greatly improved the delivery of health care services in these areas by giving both patients and health care workers the tools they need to better manage a wide array of medical conditions.

The case invoked the potential of taking portable multifunctional tele-healthcare systems as transformative solutions for addressing the existing health disparities in rural communities across the world. International organizations, local healthcare workers, and engineers' work by one and the same goal together toward implementation of this innovative technology in a sustainable way that can bring about change in various problems facing healthcare access in regions with limited resources.

4. CONCLUSION

The primary goal of the proposed research is to develop a centralized command integration gateway for an improved medical aid system. The study entails creating a centralized data exchange gateway with record storage for essential healthcare support, as well as a workable portable diagnostics system. The sensors in the project will be combined to create a single sensor system for monitoring many aspects of health. The medical professional can examine the data after it has been securely moved to the cloud to provide prompt treatment. It will not only lessen the anxiety associated with repeated diagnoses, hospital visits, and medical expenditures, but it will also be able to anticipate the likelihood of serious illnesses in advance, potentially saving lives.

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