A Critical Analysis of Medical Robotic Assistive Systems for Early Diagnosis of Common Ailments in South Africa

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***Abstract*— Studies has shown that medical diagnosis of patients in most developing countries and especially in rural areas are adversely affected by lack of proper healthcare structures, poor patient to doctor ratio and sub-standard educational systems. More so, these services are not accessible due non-affordability and poor human resource allocation in public facilities. In an attempt to bridge this gap, medical Robotic assistive systems were recently introduced to enhance general healthcare access and to carry out early diagnosis of common ailments. The rapid expansion of wireless communication networks has enabled these developments. Such intelligence systems consist of wireless monitoring systems, sensor networks, medical devices, wireless communication, middleware software and software applications that help advance improvements in healthcare. This paper attempts to review the use of Medical Robotic assistive systems for early diagnosis of common ailments. Furthermore, the literature review exposes the gap in early diagnosis and some part of opportunity that have not been explored for early diagnosis of common ailments in rural areas. The study concludes that robotic systems will in fact be an important part of future interventions, but more research and clinical trials are needed.** [1]

***Index Term*—early diagnostics, wireless medical devices, sensor networks, Medical Robotic Assistive System (MRA), health tracking**

I. Introduction

In this modern era, robots perform an important role in making healthcare and medical technologies more accessible and affordable to people. Robotic healthcare systems are becoming reliable, sustainable, accurate and beneficial to people than the conventional systems [1]. However, in some areas of South Africa and the world at large, the poor patient to doctor ratio and inaccessibility to advanced healthcare systems are acute problems that the medical fraternity still faces. Robots have been tested and tried to solve these problems and the effort has been successful as robotic applications have evolved from simple day to day activities like cleaning and washing to performing critical surgeries on the heart and the brain [2]. In medical sciences, researchers are developing tele-operated robots, prostheses, and smart monitoring systems to benefit services such as medical interventions, medical studies, and medical care [3]. A major problem in public health institutions (PHIs) in some countries is the lack of adequate nursing staff required to cater for the excessive number of hospitalized patients [4]. The nurses invest substantial amounts of time updating information about each patient's health by measuring values such as body temperature, heart rate, and glucose levels. Nurses play an important role in caring for the sick, because they are in direct contact with the patients when taking vital signs. Often, these nurses and doctors record information about their patients' progress by filling out reports by hand. Hence, a smart monitoring system that could measure the patients' progress in real time is required. This will provide continuous feedback on the improvement in the health of patients who have undergone treatment or provide personal assistance which can help prevent some diseases through early diagnosis. Additionally, nurses and doctors could save valuable response time with real-time notifications. Therefore, integrating intelligent monitoring systems could improve care by providing the nurses with efficient documentation and timely access to information [5]. Wireless sensor networks (WSNs) have being used to provide feedback during monitoring processes [6]. WSNs can be used to support intelligent decisions, by providing data from many process points, thereby giving access to an overall view of conditions [7].

Other access barriers include vast distances and high travel costs, especially in rural areas; high out-of-pocket (OOP) payments for care; [8] long queues; [9] and disempowered patients [10]. Furthermore, delays in accessing healthcare are common with late-stage presentation of common ailments. The consequences of delayed or inaccessible to healthcare are lower likelihood of survival for some common ailments such as diabetes, abnormal temperature and heart diseases, leading to greater morbidity of treatment and higher costs of care, resulting in avoidable deaths and disability.

The challenge faced here, explains a need to develop a medical robotic assistive system which could be used for early diagnosis of common ailments at people's

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convenient places. The robotic system developed herein acts as a medium of communication between the patient and the doctor in case of physical absence of the doctor and also performs further medical tests that require more analysis which can be mobilized to the doctor and the patient. By employing this robotic medical assistance system, infection caused by human intervention in hospitals can be reduced considerably and more accurate measures will be used effectively.

II. Related Work

Researchers have conducted studies about early diagnostics services worldwide in an attempt to enhance healthcare access in the past years and recently, such as wireless monitoring system, sensor networks, medical devices, wireless communication, middleware software and software applications that help advance improvements in healthcare systems (see Table I). Health monitoring systems provide health status reports to actors such as people under monitoring, practitioners and coaches for several purposes.

A. *Wireless Medical Devices*

The rapid development of wireless communication has enabled the development of wireless medical devices [11, 12]. Wireless capability refers to the transmission of biomedical information obtained from sensors or fixed systems through a wireless communication channel to a remote medical station or mobile device. In the literature, many efforts have been made to advance this capability. For example, He et al. [13] have developed a wireless technique to transmit information between biometric sensors and a monitoring centre to increase the free space surrounding the patient. Additionally, the system, which is based on ZigBee technology, aims to improve the management of hospital services. The monitoring terminal can detect the patient’s body temperature, heart rate and other physiological information in real time and transmit this information to the control centre. Fensli et al. [14] presented a new concept for wireless electrocardiogram (ECG) monitoring, specially designed for arrhythmia diagnostics, and based on a smart electrode with wireless transmission capability. The system acts as a continuous event recorder that can be used to monitor patients with arrhythmia. Misra et al. [15] introduced a multi-tier telemedicine system to perform real-time analysis of sensor data. Several intelligent devices are integrated into a wireless body area network (WBAN) to create a system for health monitoring. The system performs real-time analysis of sensor data. In addition, it uses cloud storage so that data can be retrieved at any time anywhere. Table I, below shows more research on biomedicine wireless monitoring systems.

B. *Wearable Devices*

Wearable devices that monitor physiological responses and interact with robotic and computer-based systems also have the potential to promote personalized wellness regiments and facilitate early detection and continuous assessment of disorders. In this context, robotics is providing enabling technologies that interoperate with existing systems (e.g., laptop and desktop computers, wearable devices, and in-home sensors) to leverage advances across fields and produce a broad span of usable technologies toward improving quality of life. For example, smart watches such as Apple smart watches were designed to monitor glucose level and optimize fitness plans [16].

The IntelliVue MX40 from Philips Electronics attempts to simplify patient monitoring by integrating telemetry into a compact wearable patient monitor that can be used to monitor ambulatory patients and patients during transport. The device helps to save nurses’ time because it allows them to check their patients’ ECG rhythms without calling a technician at a central monitoring station [17]. Smart watch devices can provide output and connect to the Internet in various ways. Some devices enable users to monitor their own data using a mobile phone and a special website. Other devices allow data to be shared and viewed by third parties such as healthcare provider or clinicians watching for alarming trends that call for medical intervention. Although advancements in wearable glucose monitoring devices are encouraging, the formidable challenge remains in making this technology affordable and accessible to many people worldwide. Zephyr Technology’s BioHarness BT sensor technology is used by third-party manufacturers of wearable fitness gear to add biometric monitoring capabilities. An example of this technology is under Armour’s E39 electronic compression garment, which tracks data such as the wearer’s breathing and heart rate [18]. The data can be transmitted to a computer or mobile device. Other measures that the BioHarness BT can monitor are blood oxygen, ECG, and blood pressure. The device can also connect to a smartphone to transmit data to the Zephyr portal. From there, the data can be pushed to the user’s personal electronic health record or to dispatch and service center applications on the World Wide Web.

C. *Robotic Assistive Devices*

Many robotic devices have been used in many medical interventions. For instance, robotic interaction can transcribe and store crucial medical information minimizing the possibility of error as well as helping doctors and nurses to early diagnose patients and even assisting lower-skilled people to administer operation with less input from higher-skilled personnel.

More so, robotic technology interaction can help older adults and chronically ill patients to remain independent, reducing the need for carers and the demand for care homes. They may also serve as a companion to patients who have a few or no visitors by entertaining them.

Robots can efficiently address cognitive decline issue by reminding care-receiver when to eat, or drink or take medication, do exercise or attend an appointment. Such tasks can be performed by nursing-care robots with a high level of accuracy and constantly, even during holidays or Night working hours thanks to the fact they can work endlessly and do not suffer from fatigue or die of boredom [19].

Robots can be extremely helpful in continuous monitoring of patients and data collection for emergency cases like heart failure and diabetes and then relay such data to a human nurse or doctor for action to be taken [20]. Robots unlike human being are most reliable systems that can help define the earliest possible diagnosis of common ailments.

III. Some Common Medical Diagnostics

This study attempts to bring out the concept of cost-effective implementation of standalone Medical Robotic Assistive system at public conveniences for performing innovative telemedicine in South Africa for early diagnosis of common ailments. The studies show that South Africa has been ranked the unhealthiest country in the world by World Health Organization (WHO) statistics in 2019 [21]. The index created a series of rankings based on 10 key measures, which were healthy life expectancy, blood pressure, blood glucose (diabetes risk), obesity, depression, happiness, alcohol use, tobacco use, inactivity (too little exercise), and government spending on healthcare. The latest statistics from the World Health Organization (WHO) shows that South Africa have a 26% probability of dying from cardiovascular disease, cancer, diabetes, or chronic respiration disease between ages 30 and 70. The WHO also found that more than 28% of adults were obese – the highest obesity rate among sub-Saharan African countries [21]. Below is the discussion on some of common ailments diagnostics which are not only chronic but are also fatal, if remain undiagnosed or delayed.

A. *Temperature*

Body temperature is one of the critical measures of the health status of a patient. The Body temperature is typically, measured into three categories: hypothermia, which occurs when the body temperature is below 36.0 ◦C; normothermia, which is the adequate range of 37.5 ◦C to 36.5 ◦C for the human body; and hyperthermia, which occurs when the body temperature exceeds 37.5 ◦C. Hypothermia is regarded as a potentially fatal emergency condition, and it is possible that even coma could occur if it is not treated quickly. Hyperthermia is a raised body temperature due to failed thermoregulation, a situation that may cause organ damage or death [22].

B. *Heart Rate*

The heart rate (HR) is another measure of patient health. In fact, evidence of high HR variability can support diagnoses such as infection, high levels of triglycerides or cholesterol, and lethal arrhythmias [23]. Some researcher's shows that they are able to measure the patient's HR through a non-invasive photoplethysmographic [24]. The system detects the heart beats per minute (BPM) and normal-to-normal heartbeat intervals (N-N intervals) from a continuous ECG wave record. Conventionally, the time at which the photoplethysmographic pulse waveform reaches 50% of its maximum value is used to indicate the beginning of a pulse [25]. The N-N interval is the elapsed time between pulses.

C. *Diabetes*

Diabetes is a disease that results from abnormal levels of insulin in the body, due to either a malfunction of the pancreas not producing enough insulin or the cells in the body not using it adequately [26]. Insulin is a hormone that regulates the level of glucose by allowing cells to absorb it from the bloodstream to obtain energy or store it for future use. However, if the level of glucose in the blood remains very low or very high for long periods of time, it could cause hypoglycemia or hyperglycemia, respectively, leading to severe medical conditions, including tissue damage, stroke, kidney failure, blindness, amputation of legs and heart disease, among others, and finally, death if left untreated [27]. However, South Africa has the fastest-growing epidemics of Diabetic amputation. The studies show that managing diabetes is complicated when diagnosed late, and that is the main problem for most South African [28]. Furthermore, the South African government revealed that estimation of six amputations occur every single day in one province KZN alone. Moreover, once they have lost a limp their chances of getting a prosthetic one in the public sector is virtually impossible. In South Africa, 7% of adult's aged 21 to 79 – 3.85 million people – have diabetes. A large proportion of these remain undiagnosed [28].

IV. Infrastructure-Less Telemedical Technologies in South Africa

The limitation in South African Healthcare systems currently used in medical facilities are that they do not effectively manage the workflow healthcare system. In addition to diagnosing medical problems, it is useful to have a system for tracking the flow of people, patients in day to day. Present systems used in South Africa do not effectively integrate workflow tracking with medical diagnosis functions. Another limitation of existing Healthcare systems in South Africa is that the access barriers to the medical facilities which also include vast distances and high travel costs, especially in rural areas. This is a significant drawback in medical diagnosis because it does not provide the people or patient with information that will help them been diagnosed earlier and make educated decisions on treatment of it. Furthermore, in result of this present healthcare system in South Africa, the study shows that about 50 percent of diabetic patients in hospital have had some form of amputation. This shows that the present system does not effectively manage early diagnosis due to that South Africa could results in hospitals been a factories of chop off legs, leading to crises of mobility. The future interventions of new medical system have to be researched and implemented.

V. Discussion of Findings

Table I lists some of the works that have been performed on wireless patient monitoring systems to advance healthcare especially in South Africa. Each research project attempts to solve a specific problem and uses different technologies, such as different types of sensors, monitors, and wireless communication technology. Remote patient monitoring faces several obstacles, in developing countries such as South Africa. Many people might be unfamiliar with the technology, and people of all ages might still have to be persuaded to use it. Furthermore, the wearable medical device was designed to further improve healthcare system. However, the cost of smart devices is too expensive. Although, there are applications of wireless biomedical monitoring systems, the literature review exposes the gap in early diagnosis and some part of opportunity that have not been explored at all in South Africa and the world at large, such as Non-invasive Interactive Robotic Medical Assist System (NIRMAS) for early diagnostics to advance healthcare systems. The development of a simple user-friendly remote system, that could monitor people's health more regularly, is the future needed for early diagnostics. In summary, to operate such systems in Table I, requires a clear understanding about how the system works. However, the use of these systems for early diagnostics is scarce. Cost is also a major challenge that has hindered these kinds of interventions. These systems create a gap for early diagnosis, More-likely people who would remember to utilise such systems are patients. Furthermore, the major factor that could decrease early diagnosis is the complexity of the system. The more complex the system is, largely people will avoid using them. Although, most systems shown in table 1 are non-invasive but they still require people to wear or attached them for medical testing to take place. To attach such systems more knowledge and skill is needed, for remote monitoring in rural areas this could be more challenging and problematic way. Furthermore, some system performs eye screening for early diagnosis of common ailments as shown in Table I. The challenging part of this system is that people with poor eye vision might be undiagnosed or wrongfully diagnosed.

TABLE I. SUMMARY OF KEY APPROACHES AND CHALLENGES OF MONITORING SYSTEMS FOR EARLY DIAGNOSIS IN SOUTH AFRICA

Ref	Monitoring Techniques	Parameters Checked	Communication Techniques	Sensors	End-User devices	Key Benefits	Key Challenges for early diagnosis
[29]	Non-Invasive Cardiovascular Monitoring System	heart disease management, body temperature, heart rate	Wi-Fi module (ESP 8266 Internet of Things (IoT),	Temperature Sensor (LM35), Heart rate sensor (Max 30100), ECG Sensor	Mobile phone, Think Speak, and LCD	Open platform, low cost, open-source Internet of Things (IoT)	More complex, people in rural regions might be unfamiliar
[30]	Zephyr Technology's BioHarness	Cardiac activity, Body temperature, blood oxygen, ECG, and blood pressure	ZigBee, Bluetooth and mobile network communication	BioHarness BT sensor technology	Wearable device, Computer	Mobility and Management of multiple signals	Too expensive, majority of people in South Africa will not afford.
[31]	Cardiac condition monitoring system	Cardiac activity, pressure and volume	ZigBee	Conductance catheter	Computer	Management of multiple signals	More complex,
[32]	Parkinson's disease monitoring system	Gait, posture, leg and hand movement	ZigBee	Accelerometer, gyroscope, microphone	PDA, Computer	Focused on one disease	Minimising the personal freedom of human kind.
[33]	General patient monitoring system	Cardiac activity, respiration, muscle activity	ZigBee, Bluetooth, WiFi	EMG, EEG, EKG	PDA, Computer	Communication with medical server through Internet	More complex, people have to be pursued to use it.
[34]	General patient monitoring system	Cardiac activity, Body temperature	WiFi	ECG, Body temperature	Smartphone, Computer	Communication with nurse server and smartphones through Internet	More complex, people have to be pursued to use it.
[35]	Smartphone-Based Dilated Fundus Photography and Near Visual Acuity Testing	Diabetes	Bluetooth, Wifi and mobile network communication	near visual acuity, dilated posterior segment photographs placed on smartphone	smartphone	Inexpensive Screening Tools	Early diagnosis could be decreased by poor eye vision.

VI. CONCLUSION

This study exposes a gap in early diagnosis by using medical Robotic devices and hence, presents an opportunity that has not been explored, such as Non-invasive Interactive Robotic Medical assist system (NIRMAS) for early diagnostics to advance healthcare system. The development of user-friendly remote systems that could monitor people's health more regularly, could be the future needed for earliest possible diagnosis. The consequences of delayed or inaccessible healthcare diagnosis are lower likelihood of survival for some common ailments, greater morbidity of treatment and higher costs of care, resulting in avoidable deaths and disability. Early diagnosis improves disease outcomes by providing care at the earliest possible stage and is therefore an important public health strategy in all settings. In areas where the majority of patients are diagnosed at late stage, early diagnosis can have a great impact and build health system capacity. Hence this paper has discussed various technological ways to enhance the medical healthcare system, to promote early diagnosis of common ailments to minimize the consequences of delayed, leading to extremity of diseases. This discussion has been presented in the context of rural South African Communities where these services are nearly non-existent.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

OS conducted the research; ED and OS analyzed the data; OS wrote the paper; all authors had approved the final version.

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