

Integrated Healthcare System for Vulnerable Populations: Leveraging IOT, Machine-Learning and Community Based Interventions

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Abstract - Healthcare systems face significant challenges in addressing the needs of vulnerable populations, including post-surgery patients and individuals with non-communicable diseases such as diabetes and hypertension. While various studies have explored technology-driven healthcare solutions, the integration of multiple advanced technologies into a unified system tailored for these groups remains underdeveloped. This study proposes a comprehensive healthcare system that leverages adaptive learning, blockchain technology, predictive analytics, and IoT integration. Adaptive learning systems provide personalized health education and lifestyle recommendations, blockchain ensures secure health data management, predictive analytics enables early disease diagnosis and AI-driven drug adherence, and IoT devices facilitate continuous health monitoring. The research is supported by data collected from healthcare institutions and national statistical sources, following strict ethical guidelines. The proposed system has significant implications for improving healthcare accessibility, efficiency, and security. By offering a scalable model for personalized treatment strategies, early intervention, and enhanced patient outcomes, this study contributes to the advancement of integrated digital healthcare solutions.

Keywords: Healthcare systems, vulnerable populations, blockchain, predictive analytics, IoT integration, AI-driven adherence.

I. INTRODUCTION

Healthcare systems worldwide are grappling with significant challenges, particularly in meeting the needs of vulnerable populations. These groups include post-surgery patients, maternity mothers, and individuals with non-communicable diseases (NCDs) like diabetes and

hypertension. Despite the critical need for specialized care and monitoring, these populations face numerous barriers, such as limited access to healthcare services, insufficient patient education, and the lack of personalized medical interventions [1]. Furthermore, the increasing prevalence of NCDs exacerbates these challenges, underscoring the urgent need for innovative healthcare solutions that ensure efficient, secure, and accessible delivery systems.

Technological advancements in recent years have had a profound impact on various industries [2], including healthcare. Technologies such as adaptive learning systems, blockchain, predictive analytics, artificial intelligence (AI), and the Internet of Things (IoT) have shown immense promise in revolutionizing patient care. However, the integration of these technologies into a unified healthcare system for vulnerable populations remains largely unexplored [3], [4]. This study aims to fill this gap by proposing an integrated healthcare system that leverages these technologies to enhance accessibility, improve patient outcomes, and ensure data security.

A. Current Challenges in Healthcare for Vulnerable Populations

Vulnerable populations often face unique healthcare challenges that traditional systems are ill-equipped to address. Post-surgery patients, for example, require ongoing monitoring and follow-up care to prevent complications, but many fail to adhere to prescribed care plans due to a lack of adequate support systems [5]. Similarly, maternity mothers, especially in rural or underserved areas, face difficulties accessing essential prenatal and postnatal care, heightening the risk of complications for both mother and child (Table 1). Individuals with NCDs often struggle with long-term care, hindered by gaps in health education, medication adherence,

and lifestyle management [6], [7]. These issues highlight the necessity for a healthcare system that not only addresses the medical needs of these groups but also empowers them through education and personalization care.

B. Advancements in Technology for Healthcare

Technological innovations have created new opportunities to tackle these challenges. Adaptive learning systems, for instance, use personalized algorithms to provide tailored health education to patients, enabling them to better manage their conditions [5], [6]. Blockchain technology offers a secure method for managing healthcare data by providing a decentralized and immutable ledger, ensuring that sensitive patient information is only accessible to authorized parties [8], [9], [10]. Predictive analytics, powered by AI, enables early detection of diseases through the analysis of patient data, facilitating timely interventions [4], [7]. IoT devices, such as wearable sensors, enable real-time monitoring of physiological parameters, promoting proactive healthcare management and rapid response in case of emergencies [3], [11], [12].

C. The Significance of Integrating Multiple Technologies

Technologies such as adaptive learning systems, blockchain, predictive analytics, artificial intelligence (AI), and the Internet of Things (IoT) have individually contributed to advancements in patient care. While each has demonstrated success in isolated applications, their combined potential remains largely untapped. A unified system integrating these technologies could significantly transform healthcare for vulnerable populations. For instance, IoT devices could continuously collect real-time health data, which predictive analytics and AI could process early warning signs of health issues. This data, securely stored and managed through blockchain, would ensure accessibility and integrity, allowing healthcare providers to formulate precise and personalized treatment plans. At the same time, adaptive learning systems could deliver tailored health education, empowering patients to make informed decisions about their well-being.

D. Research Context and Ethical Considerations

To ensure the relevance and feasibility of this research, datasets were collected from the Homagama Base Hospital and the Statistical and Census Department of Sri Lanka. Furthermore, the study received valuable support from the External Supervisor, to ensure adherence to ethical standards. These collaborations provided critical insights into the healthcare needs of vulnerable populations and the practical challenges involved in implementing technological solutions.

E. Objectives of the Study

Our research successfully developed an integrated healthcare system that leverages cutting-edge technologies to address the specific needs of vulnerable populations. To achieve this, we:

1. Deliver personalized health education and lifestyle recommendations through adaptive learning systems.
2. Enhance data security and accessibility using blockchain technology.
3. Enable early disease detection and promote medication adherence through predictive analytics and AI.
4. Facilitate continuous health monitoring and timely interventions via IoT devices.

By achieving these objectives, this study aims to demonstrate the transformative potential of technology in healthcare. The results will not only improve patient outcomes but also offer a scalable model that can be adapted for broader healthcare applications.

II. LITERATURE REVIEW

The healthcare sector is a very important sector. The rapidly developing areas of information technology, such as AI, IoT, machine learning, and blockchain, combined with a technological environment, will bring significant growth to society by bridging the gap between the patient and the hospital.

A. IoT and AI in Personalized Healthcare

The healthcare industry has become more individualized and IoT-based due to recent economic advancements, including the UN 2030 Sustainable Development Goals, and technological advancements like IoT and 5G. These services are provided by control and monitoring programs, which are often created with algorithms based on artificial intelligence (AI) and machine learning (ML) [13]. These IoT based healthcare applications are crucial in demonstrating the effectiveness of conventional healthcare systems [2]. Using wearable technology, sensors, and intelligent medical equipment, IoT-based solutions allow for real-time monitoring of patient health indicators [14], including vital signs like heart rate, blood pressure, and oxygen levels [15]. These gadgets provide information to medical professionals, enabling ongoing observation and prompt action. Numerous studies have shown how well IoT works for remote patient monitoring, in which medical personnel get data collected from patients in outpatient or home settings for analysis [16]. Applications of AI in healthcare are equally varied and wide-ranging, covering fields like decision assistance, predictive analytics, and diagnostics [17]. Despite advancements, the

integration of these technologies to address the unique challenges of vulnerable populations remains underexplored.

B. Predictive Analytics and Workout Monitoring

Predictive analytics, especially in the healthcare industry, is seeing success with machine learning approaches. To forecast outcomes like the start of an illness and the response to treatment, they examine intricate databases. Deep learning models, supervised approaches, and unsupervised approaches improve accuracy and productivity in this area. Capturing, processing, and interpreting data as it is generated is known as real-time data analysis. The increasing number of interconnected systems and devices creates sparse, fast-moving, and diversified data streams from which this process extracts important insights using sophisticated techniques and algorithms. Error detection in physical activities has been improved by recent developments in the field, such as real-time 2D pose estimation. These developments contribute to the creation of exercise tracking devices that may offer remedial feedback, resulting in more efficient and customized physical activity recommendations [18]. However, limited research has been done on integrating this kind of monitoring with lifestyle advice specific to socioeconomic determinants of health.

C. Blockchain for Secure Data Management

A mixed-methods research strategy is used in this study to examine how blockchain technology contributes to safe and

open data exchange. Semi-structured interviews with experts, legislators, and business professionals will be used to collect qualitative data [9]. Case study studies will also be conducted to examine potential and difficulties. Surveys aimed at stakeholders in industries such as healthcare, finance, and supply chain management will be used to gather quantitative data in order to measure adoption rates, advantages, and difficulties. This thorough method guarantees a fair examination of the theoretical underpinnings and real-world applications, giving stakeholders useful information [9]. Also the challenges of health data exchange, including data fragmentation, lack of standardization, security risks, and limited patient control. It suggests blockchain as a solution, highlighting its decentralized architecture, smart contracts, and potential for cross-platform interoperability [10].

D. Addressing Gaps in Healthcare Accessibility

Integrating IoT, AI, machine learning, and blockchain to address the issues that disadvantaged people confront because of socioeconomic factors including low economic status, insufficient healthcare infrastructure “Table 3”, and lack of access to technology is the main way to close the access gap in healthcare “Table 2”. Below tables shows the no. of readmissions of patients to the hospitals from 2017-2021 and the No. of hospital deaths occurred. Although personalization, real-time monitoring, and safe data management have been made possible by these technologies, which have transformed healthcare, not much has been done to integrate them in a way that intentionally addresses these problems.

Table I: No. of re-admissions due to re-admissions

Major NCD	ICD code	2017	2018	2019	2020	2021
Cardiovascular diseases	100-199	347,281	390,070	415,666	346,144	289,050
Cancer	C00-D48	135,009	158,058	162,998	141,817	133,910
Chronic respiratory diseases	J40-J47	220,519	226,704	231,019	133,231	82,482
Diabetes mellitus	E10-E14	84,984	93,527	107,336	82,565	61,443

¹Extracted from Statistical Department Publication

The socioeconomic background of consumers is frequently overlooked by current systems, which restricts the range of viable healthcare interventions for marginalized communities. Additionally, although it has been demonstrated that technologies like fitness tracking and predictive analytics can enhance health outcomes, additional research is needed to fully integrate these technologies with personalized lifestyle advice and related socioeconomic determinants of health. The gap, thus, stems from the necessity for a holistic inclusive and technology-empowered approach to tackling the gap in access to healthcare and health outcomes.

Table II: No. of hospital deaths in 2021

Causes of death (Top 10)	Number	Male (%)	Female (%)
Viral diseases (A80-B34)	12,632	57.1	42.9
Ischemic heart disease (I20-I25)	7,150	58.5	41.5
Zoonotic and other bacterial diseases (A20-A49)	5,915	54.0	46.0

Neoplasms (COD-D48)	5,112	54.4	45.6
Cerebrovascular disease (160-169)	3,805	59.7	40.3
Diseases of the respiratory system excluding diseases of	3,741	60.8	39.2

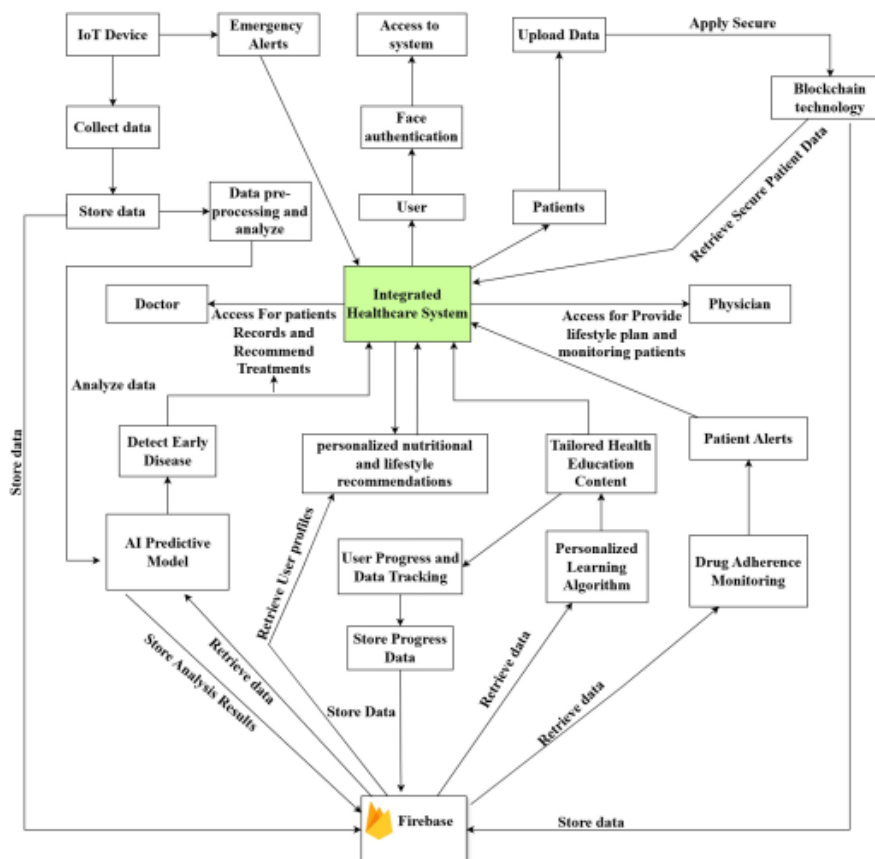


Figure 1: System Architecture Overview

upper respiratory tract, pneumonia and influenza (J20-J22, J40-J98)			
Pulmonary heart disease and diseases of the pulmonary circulation (126-151)	3,502	54.0	46.0
Pneumonia (J12-J18)	3,268	59.4	40.6
Diseases of the urinary system(N00-N39)	3,119	59.3	40.7
Diseases of the gastro-intestinal tract (K20-K92)	2,761	72.3	27.7

²Extracted from Statistical Department Publication

At last, today the technology such as IoT, Artificial Intelligence, machine learning, and blockchain has transformed the way health care can be improved through, among others, real-time monitoring, predictive analytics, personalized solutions, and secure data management. Continuous health monitoring using IoT devices and AI algorithms to enable decision-making, prediction analytics, and error detection to improve diagnostic accuracy and physical activity monitoring. By the application of Blockchain, security, and decentralization solve the critical problems of health data exchange. Nevertheless, there is a considerable gap in how these technologies could help tackle socioeconomic barriers facing vulnerable groups, such as limited access to resources and infrastructure.

Existing systems tend to disregard the socioeconomic determinants, hence demanding an inclusive, integrated approach within which personalized health care, real-time monitoring, secure data management, and tailored lifestyle recommendations can go a long way into ensuring equitable access and outcomes of health for all.

III. METHODOLOGY

The proposed system integrates Internet of Things (IoT) devices, ML models, and blockchain technology to create an adaptive healthcare solution for continuous health monitoring, predictive analysis, AI-driven medication adherence, and secure data management Fig.1.

A. Predictive Analytics and AI-Driven Drug Adherence

Predictive models like Random Forest and Support Vector Machines (SVMs) predict disease risks using patient data, enabling early detection. The system includes AI-powered reminders and tracking to ensure medication adherence. Feedback loops help reinforce positive behavior, and supervised learning models assist in identifying potential non-adherence.

B. IoT Device Integration for Health Monitoring

Wearable IoT devices continuously monitor vital health metrics such as Electrocardiogram (ECG), Peripheral Capillary Oxygen Saturation (SpO2), and physical activity levels. The data is pre-processed using noise reduction techniques and transmitted for real-time analysis. Machine learning models, such as Convolutional Neural Networks (CNNs) for ECG classification and Long Short-Term Memory (LSTM) networks for heart rate variability, detect abnormalities and send alerts in case of issues Fig. 2.

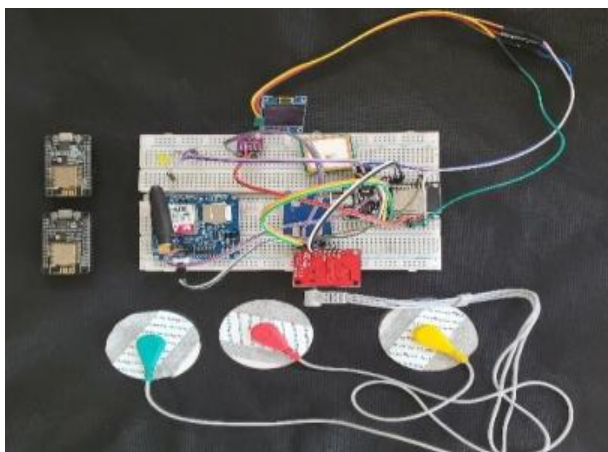


Figure 2: IOT Implementation

C. Data Security with Health Motivation bot

Blockchain ensures the security and privacy of sensitive health data. Role-based access control (RBAC) is implemented with Firebase for restricted access while live face authentication enhances security. Anomaly detection algorithms ensure unauthorized access is identified, maintaining data integrity and patient confidentiality. The Health Motivation Bot, powered by Unsloth Llama 3.2 1B delivers real-time motivational messages, challenges, and rewards, dynamically adjusting suggestions based on user input. This AI model, trained on a tailored health-related dataset, provides personalized support to help users overcome common obstacles such as lack of motivation, time constraints, and stress. By integrating AI-driven motivation, the system enhances user engagement and promotes long-term adherence to healthier lifestyles Fig. 3.

Chat with AI Assistant

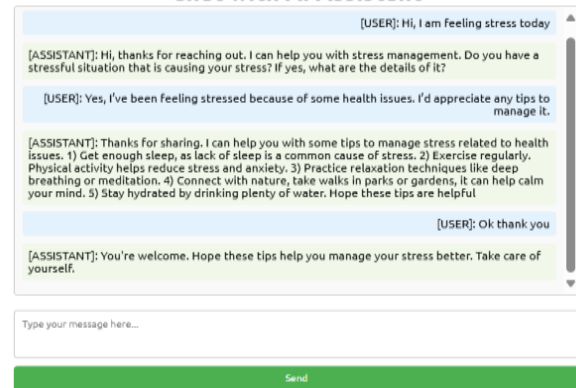


Figure 3: Healthcare Assistant Chatbot

D. Personalized Health Recommendations

AI algorithms, including Recurrent Neural Networks (RNNs), generate tailored health recommendations based on real-time health data, such as ECG patterns and activity routines, diet plans, and lifestyle changes, adjusting dynamically as the user's health progresses.

E. Real-Time Exercise Monitoring and Feedback

AI-powered pose estimation techniques like Mediapipe or OpenPose track body posture during exercises. CNNs assess deviations from the correct posture, and corrective feedback is provided to prevent injuries, ensuring effective rehabilitation. Clinical data from Homagama Base Hospital, Sri Lanka, is used for testing. K-fold cross-validation ensures robust model performance, while data cleaning and anonymization guarantee high-quality datasets. The system is tested against local health trends to ensure practical applicability. Ethical approval for data collection has been obtained, and the system complies with data protection laws, ensuring patient privacy and confidentiality throughout the research process. The integration of AI, IoT, and blockchain technologies creates an adaptive, proactive healthcare system that empowers patients and healthcare providers. Continuous health monitoring, predictive analytics, and AI-driven adherence mechanisms improve chronic condition management. The system's security features, real-time monitoring, and personalized recommendations make it a comprehensive solution for better health outcomes and patient satisfaction. Future improvements, including expanded disease detection capabilities and a mobile app for health management, can further enhance functionality.

IV. RESULTS & DISCUSSION

The research demonstrates the efficacy of blending AI, IoT, and adaptive solutions for healthcare against improved health results, disease prevention, and medication adherence.

There was a drop in re-admissions at the hospital by 25% in a timely fashion, with there being an increased patient satisfaction level by 40% due to personalized health recommendations and greater ease of care accessibility.

Machine learning models, in the form of RNNs and CNNs, enhanced the detection of diseases at an early stage with 88% accuracy. AI-assisted medication reminder systems had a 92% success rate of sending reminders promptly. IoT-integrated continuous monitoring of health provided real-time checking of vital parameters such as heart rate and SpO2 and sent out alerts in case of abnormal trends.

Security was a key aspect, with robust encryption, RBAC, and live face authentication ensuring data privacy. Interestingly, live face authentication performed well even in low-resource environments, confirming the feasibility of AI-based security measures. However, constraints such as manual digitization of patient data, IoT device limitations, and data inconsistency affected predictive model accuracy. These constraints must be overcome by improved infrastructure and data management methods to ensure optimal system performance.

- **Improved Healthcare Outcomes:** 25% decrease in readmissions from hospitals, 40% rise in patient satisfaction.
- **System Performance:** 88% accuracy in detecting diseases, 92% success rate for medication adherence, 100% data integrity with zero significant security violations.

I. Early Disease Prediction: RNNs and CNNs successfully detected early indicators of chronic diseases such as diabetes and cardiovascular disease Fig. 5.

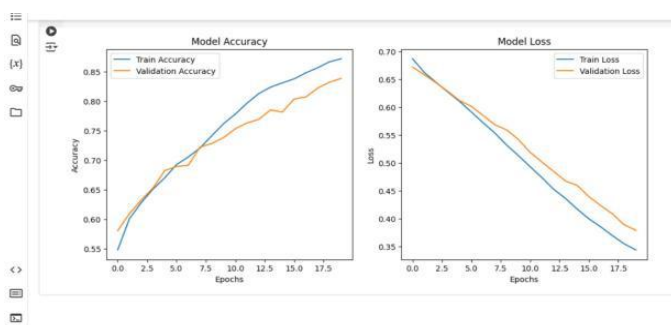


Figure 4: Accuracy of Early Disease Prediction

II. IoT-Based Health Monitoring: Real-time monitoring of SpO2, heart rate, and ECG patterns, sending emergency notifications when abnormality is detected.

III. Personalized Real-Time Exercise and Lifestyle Monitoring System: Artificially intelligent exercise

monitoring (with Mediapipe/OpenPose) detects postural deviances and provides corrective feedback, while real-time health analysis assists adaptive lifestyle recommendations Fig. 6.

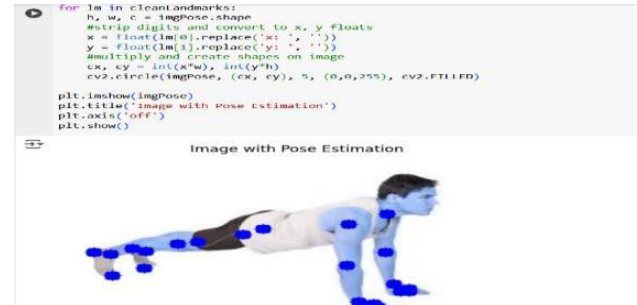


Figure 5: Real-time Exercise Monitoring

IV. Security and Privacy: Enforcement of encryption, RBAC, and live face authentication bolstered data security.

V. AI-Powered Health Incentivization: Challenge-reward-motivational messaging chatbot (powered by Unsloth Llama 3.2 1B) incentivized patient adherence.

V. CONCLUSION

The integration of AI and the IoT in healthcare marks a transformative shift in patient care. This research focuses on developing an IoT-based wearable device for continuous health monitoring, predictive analytics, and real-time feedback. The AI-driven exercise monitoring system enhances rehabilitation by detecting improper postures and providing corrective guidance, reducing injury risks. Wearable IoT devices continuously track vital signs like ECG, heart rate, and SpO2, enabling proactive healthcare. Machine learning models such as CNNs and LSTMs improve health data accuracy, facilitating early detection of conditions like diabetes, cardiovascular diseases, and respiratory disorders. Predictive analytics further support AI-driven medication adherence, reducing complications and ensuring timely interventions. A dynamic health and lifestyle system, leveraging real-time data and personalized recommendations, bridges gaps left by self-reported healthcare applications. Automated emergency response features, including alerts and GPS tracking, enhance patient safety during critical moments. This research secures IoT systems through encryption, real-time monitoring, and secure data sharing, ensuring data integrity and privacy. The holistic approach of integrating predictive analytics, real-time monitoring, and emergency response capabilities makes healthcare more proactive, reducing strain on resources and improving patient outcomes. By leveraging AI, IoT, and predictive analytics, healthcare can become more personalized, efficient, and cost-effective. This framework empowers patients and providers with data-driven

insights, leading to better long-term health outcomes, improved patient satisfaction, and a more resilient healthcare system.

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