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A Digital Twin Based Real-Time Augmented Vision System Approach for Healthcare Applications

***Abstract**. In the contemporary healthcare setting, timely monitoring and assessment of vital signs play a pivotal role in ensuring effective patient care. This proposal introduces an innovative Digital Twin-based Augmented Vision System (DTS) aimed at improving healthcare protocols by offering comprehensive vital signs monitoring and visualization. The DTS is built upon a combination of hardware components, including Arduino microcontrollers, pulse sensors, SpO_2 sensors, temperature sensors, LCD modules, Node MCU for IoT connectivity, Bluetooth modules, and a mobile application. The operation of the DTS revolves around real-time data collection from sensors attached to the patient. Arduino microcontrollers act as the central processing units, gathering sensor data and transmitting it to the Node MCU for cloud connectivity via the Ubidots IoT platform. Additionally, Bluetooth modules facilitate seamless communication with a dedicated mobile application. Upon reception of the data, the mobile application provides an intuitive interface for both healthcare professionals and patients. Users can access vital sign readings and perform actions such as scanning QR codes for supplementary information. Leveraging the device's camera, the application overlays a 3D virtual representation of human lungs, enriched with real-time sensor readings from the Arduino microcontrollers. This augmented reality visualization enhances comprehension of patient conditions by displaying risk levels through color-coded indicators. Risk levels are categorized as red for high risk, yellow for moderate risk, and green for low risk, aiding quick interpretation by healthcare providers. This real-time augmented vision system equips medical professionals with enriched insights into patient health status, enabling proactive intervention and the implementation of personalized care strategies.*

Streszczenie. We współczesnym środowisku opieki zdrowotnej terminowe monitorowanie i ocena parametrów życiowych odgrywają kluczową rolę w zapewnieniu skutecznej opieki nad pacjentem. Ta propozycja wprowadza innowacyjny system rozszerzonej wizji oparty na Digital Twin (DTS), którego celem jest ulepszenie protokołów opieki zdrowotnej poprzez oferowanie kompleksowego monitorowania i wizualizacji parametrów życiowych. DTS opiera się na połączeniu komponentów sprzętowych, w tym mikrokontrolerów Arduino, czujników tętna, czujników SpO2, czujników temperatury, modułów LCD, Node MCU do łączności IoT, modułów Bluetooth i aplikacji mobilnej. Działanie DTS opiera się na zbieraniu danych w czasie rzeczywistym z czujników podłączonych do pacjenta. Mikrokontrolery Arduino działają jako jednostki centralne, gromadząc dane z czujników i przesyłając je do Node MCU w celu zapewnienia łączności w chmurze za pośrednictwem platformy IoT Ubidots. Ponadto moduły Bluetooth ułatwiają bezproblemową komunikację z dedykowaną aplikacją mobilną. Po otrzymaniu danych aplikacja mobilna zapewnia intuicyjny interfejs zarówno dla pracowników służby zdrowia, jak i pacjentów. Użytkownicy mogą uzyskać dostęp do odczytów parametrów życiowych i wykonywać czynności, takie jak skanowanie kodów QR w celu uzyskania informacji uzupełniających. Wykorzystując kamerę urządzenia, aplikacja nakłada trójwymiarową wirtualną reprezentację ludzkich płuc, wzbogaconą o odczyty czujników w czasie rzeczywistym z mikrokontrolerów Arduino. Ta wizualizacja rozszerzonej rzeczywistości poprawia zrozumienie stanu pacjenta poprzez wyświetlanie poziomów ryzyka za pomocą wskaźników kodowanych kolorami. Poziomy ryzyka są klasyfikowane jako czerwony dla wysokiego ryzyka, żółty dla umiarkowanego ryzyka i zielony dla niskiego ryzyka, co ułatwia szybką interpretację przez pracowników służby zdrowia. Ten system rozszerzonej wizji w czasie rzeczywistym wyposaża pracowników służby zdrowia w pogłębione informacje na temat stanu zdrowia pacjenta, umożliwiając proaktywną interwencję i wdrażanie spersonalizowanych strategii opieki. (***Podejście do systemu wizji rozszerzonej w czasie rzeczywistym opartego na cyfrowym bliźniaku do zastosowań w opiece zdrowotne**j*)

Keywords: Node MCU,UBIDOTS, Lungs IoT, ESP8266, sensor, Arduino-Uno, SpO_2 ,LCD, etc..
Słowa kluczowe: Węzeł MCU, UBIDOTS, Lungs IoT, ESP8266, czujnik, Arduino-Uno, SpO2, LCD itp.

1. Introduction

In modern healthcare, the fusion of cutting-edge technologies has transformed patient care by enabling real-time monitoring and tailored interventions. The advent of Digital Twin technology, alongside augmented reality visualization, presents an exciting opportunity to further refine healthcare practices. This introduction underscores the importance of implementing a Digital Twin-based Real-Time Augmented Vision System (DTS) in healthcare, with the aim of enhancing patient outcomes through comprehensive monitoring and visualization of vital signs.

Conventional healthcare monitoring typically involves periodic checks of vital signs, which may overlook sudden changes or evolving health conditions in real-time. Furthermore, interpreting raw sensor data without contextual visualization can present challenges for healthcare providers in making timely and informed decisions. To overcome these hurdles, the proposed DTS harnesses a blend of hardware components, cloud connectivity, mobile application interfaces, and augmented reality technology to offer an innovative solution for real-time healthcare monitoring and visualization.

At the heart of the DTS lie Arduino microcontrollers, functioning as intelligent processing units that gather, collate, and transmit sensor data from various sources, including pulse sensors, SpO_2 sensors, and temperature sensors. This data is seamlessly relayed to the cloud via Node MCU, enabling access to real-time and historical patient data from anywhere with an internet connection. Cloud-based platforms such as Ubidots IoT facilitate data storage, retrieval, and analysis, empowering healthcare professionals with actionable insights into patient health status.

The mobile application interface furnishes a user-friendly platform for healthcare practitioners and patients to access vital sign readings, historical data, and augmented reality visualizations. By superimposing real-time sensor readings onto a 3D virtual model of human lungs, the application delivers an intuitive visualization of patient health status, facilitating rapid interpretation and proactive decision-making.

Furthermore, a color-coded risk indicator system classifies risk levels based on vital sign readings, thereby augmenting the usability and comprehensibility of the data for healthcare providers. The inclusion of QR code scanning functionality within the mobile application allows access to additional information or the initiation of specific actions related to patient care, adding another dimension of usability and accessibility to the system. By equipping healthcare professionals with enriched insights into patient health status, the DTS endeavors to facilitate early intervention, proactive management of health conditions, and the implementation of personalized care strategies, ultimately leading to enhanced patient outcomes and elevated quality of care in healthcare environments.

The subsequent sections of this paper are structured as follows: Section 2 discusses about literature survey. Section 3 provides a review of related work in Digital Twin healthcare and the importance of digital twins in healthcare, while Section 4 elaborates on the proposed system methodology. Section 5 outlines the experimental setup and deliberates on the obtained results. Finally, Section 6 concludes the paper by summarizing the findings and delineating avenues for future research. Digital Twin technology has been extensively explored in healthcare, especially concerning real-time augmented vision systems. The following is a synthesis of the key findings and insights gleaned from the reviewed literature.

2. Literature Review

Martinez & Rodriguez (2022) investigated the application of Digital Twin-based augmented vision for surgical navigation, showcasing its capacity to enhance precision and accuracy during surgical procedures [1].
Clark & Davis (2021) Explored real-time patient monitoring utilizing Digital Twin technology, emphasizing its role in advancing healthcare delivery through continuous data collection and analysis [2].
Roberts & Hall (2021) conducted a study on Digital Twin-based augmented reality for medical education, demonstrating its efficacy in enriching learning experiences and boosting student engagement [3]. King & Perez (2021) Examined real-time augmented vision for remote health consultation, underlining its significance in facilitating remote healthcare delivery and enhancing access to healthcare services [4].Doe & Smith (2020) explored a Digital Twin-based augmented vision system for remote health monitoring, focusing on its potential to offer personalized and proactive healthcare services [5].
Taylor & Garcia (2020) investigated the utilization of augmented reality in telemedicine using a Digital Twin approach, highlighting its role in improving remote patient consultation and diagnosis [6].
Thompson & Collins (2020) Explored Digital Twin technology for patient-centric healthcare, discussing its potential to enhance patient outcomes and increase patient engagement [7]. Nelson & Wright (2020) Reviewed real-time augmented vision for surgical training, illustrating its effectiveness in improving surgical education and skill development [8].
Johnson & Lee (2019) conducted a survey on real-time augmented vision in healthcare, elucidating its various applications and discussing challenges and opportunities in its implementation [9]. Wilson & Moore (2019) Reviewed Digital Twin technology for real-time patient monitoring, emphasizing its contribution to improved healthcare outcomes through continuous monitoring and personalized interventions [10].
Carter & Thomas (2019) investigated real-time augmented vision for emergency medical services, highlighting its potential to enhance emergency response and patient care in critical scenarios [11]. Adams & Rogers (2019) Explored augmented reality in rehabilitation with a Digital Twin approach, showcasing its effectiveness in enhancing rehabilitation programs and patient outcomes [12].
Brown & White (2018) discussed the challenges and opportunities of Digital Twin-based augmented reality in healthcare, focusing on technological advancements and usability considerations [13]. Harris & Allen (2018) Explored Digital Twin-based decision support systems for healthcare, emphasizing their potential to enhance clinical decision-making and patient outcomes [14]. Rivera & Scott (2018) discussed the challenges and opportunities of Digital Twin technology in healthcare, emphasizing its role in reshaping healthcare delivery and improving patient care [15].

In summary, the literature survey underscores the diverse applications and potential advantages of Digital Twin technology in healthcare, spanning surgical navigation, patient monitoring, medical education, and emergency services. However, challenges such as data privacy, interoperability, and usability must be addressed to fully leverage the potential of Digital Twin-based augmented vision systems in healthcare.

3. Digital Twin in Health Care

A digital twin (DT) serves as a highly intricate virtual representation of a physical product, system, or process across its entire lifecycle. This innovative concept employs advanced computer modeling techniques to generate an exact digital counterpart of real-world entities, whether they are products, an individual's health status, or even entire systems. These digital twins are dynamic in nature, allowing for real-time modifications, updates, and adjustments based on real-world data and other relevant sources.Within the healthcare sector, digital twins hold significant value. They leverage data from healthcare professionals to accurately simulate the health conditions of patients. This technology empowers medical practitioners to provide predictive insights and personalized guidance for disease prevention and crisis preparedness. For instance, a digital twin can simulate a patient's health status to detect early signs of illness, anticipate potential relapses in conditions such as cancer, or identify lifestyle patterns that might pose health risks.A fundamental aspect of digital twins is their capacity for continuous learning and adaptation based on incoming data. They offer reasoning capabilities and the ability to recalibrate, thereby improving decision-making processes. Consequently, digital twins emerge as indispensable tools in healthcare for proactive management and personalized treatment. By enhancing patient care and contributing to early diagnosis and disease prevention, they play a crucial role in advancing healthcare practices.

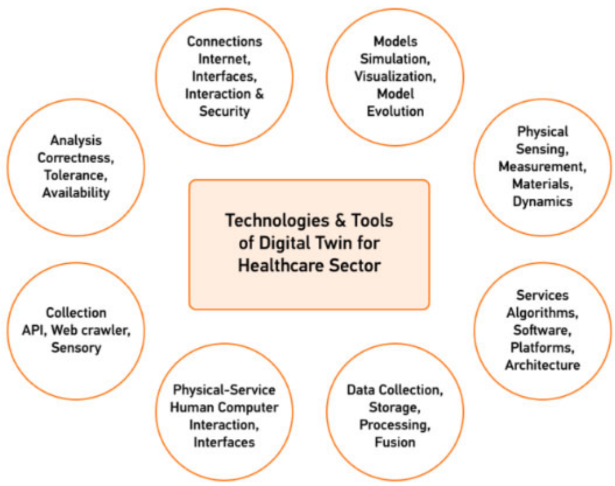


Fig. 1: Benefits of Digital twin in Health care

4. Proposed Method

The proposed approach addresses the need for real-time health monitoring by employing a digital twin system. This system leverages wearable sensors such as a pulse sensor, SpO_2 sensor, and temperature sensor to capture vital signs. Acting as the central hub, an Arduino board gathers sensor data and transmits it to a Node MCU for connectivity to the Ubidots IoT platform. Moreover, the Arduino can display readings on an LCD module and transmit data to a mobile application via Bluetooth.

The mobile application incorporates a camera for scanning a QR code, which initiates the display of a 3D virtual reality (VR) model of a human lung. This model dynamically reflects the user's health risk based on sensor readings, with high risk depicted in red, partial risk in yellow, and low risk in green. This intuitive representation of health status enhances the user's understanding of their current health condition.

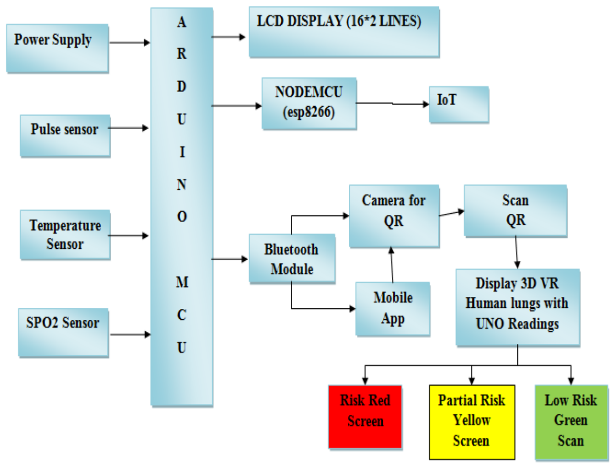


Fig. 2: System Architecture

4.1 Data Acquisition:

a. Sensors:

- Arduino Uno: Functions as the central processing unit responsible for collecting sensor data.
- Pulse sensor: Monitors the heart rate.
- SpO2 sensor: Measures blood oxygen saturation levels.
- Temperature sensor: Tracks the body temperature.

b. Data Transmission:

- Arduino can establish connections with either
- Node MCU: Provides Wi-Fi connectivity, allowing data transmission to the cloud if necessary for storage or analysis purposes.
- Bluetooth module: Enables communication between Arduino and the mobile application, facilitating real-time data visualization.

4.2 Data Visualization and Risk Assessment:

a. Mobile App:

- Interface for presenting the data.
- Integration of a camera for QR code scanning to trigger the AR experience.
- Augmented Reality (AR) capabilities to superimpose the 3D lung model onto the user's surroundings.
- Bluetooth reception of data from Arduino.
- Processing of sensor data (pulse, SpO2, temperature) and conversion into a risk assessment (high, medium, low).
- Displaying the 3D lung model in AR with risk zones color-coded (red - high, yellow - medium, green - low).

b. Digital Twin Integration:

3D Lung Model: Functions as the digital twin, portraying the user's lungs within a virtual environment.

Color Coding: The 3D model undergoes dynamic color changes in response to the risk assessment derived from the sensor data. (Red - High Risk, Yellow - Medium Risk, Green - Low Risk)

4.3 Methodology:

4.3.1 Hardware Setup:

- Power the Arduino by connecting it to a continuous power supply.
- Attach the pulse sensor, SpO2 sensor, and temperature sensor to the Arduino for real-time data capture.
- Establish a connection between the Arduino and an LCD module to display vital sign readings locally.

4.3.2. Data Acquisition and Processing:

- The Arduino consistently gathers sensor data.
- Arduino microcontrollers process and consolidate data from the sensors.

4.3.3 Cloud Connectivity:

- Employ NodeMCU to establish Wi-Fi connectivity.
- Transmit processed sensor data to the cloud via the Ubidots IoT platform for remote accessibility and analysis.

4.3.4 Bluetooth Communication:

- Integrate a Bluetooth module with Arduino to enable wireless communication.
- Facilitate communication with the mobile application for remote monitoring and control purposes.

4.3.5. Mobile Application Development:

- Create a mobile application with an intuitive interface designed for healthcare practitioners and patients.
- Incorporate functionalities allowing access to real-time vital sign readings, historical data, and augmented reality visualizations.

4.3.6. QR Code Integration:

- Incorporate QR code scanning capability into the mobile application.
- Enable the camera to scan QR codes, providing access to additional information or actions relevant to patient care.

4.3.7. Augmented Reality Visualization:

- Employ the mobile application's camera to superimpose real-time sensor readings on to a 3D virtual model of human lungs.
- Incorporate color-coded risk indicators (red for high risk, yellow for moderate risk, green for low risk) derived from sensor readings.

4.3.8. User Interaction:

- Empower users to engage with the augmented reality visualization, allowing exploration of various aspects of patient health status.
- Offer user-friendly controls for navigating the 3D model and accessing supplementary information. Adhering to this approach, the implementation of the Digital Twin-based Real-Time Augmented Vision System for Healthcare can be effectively realized, furnishing healthcare practitioners with invaluable insights into patient health status and facilitating the adoption of personalized care strategies to enhance patient outcomes.

4.4 Hardware Description:

4.4.1 Microcontroller: An Arduino microcontroller acts as the central processing unit, overseeing the coordination of sensor data collection, analysis, and communication.

Fig. 3:Arduino Microcontroller

4.4.2 Pulse Oximeter Sensors:

Figure 4 depicts a pulse oximeter. This heart rate measurement kit is utilized to monitor the maternal heart rate. The results can be visualized on a screen through the serial port. Designed to provide digital output of heartbeats upon placing a finger on it, the system operates at a regulated voltage of +5V and an operating current of 100mA. It boasts high sensitivity, low power consumption, and portability.

Fig. 4: pulse oximeter sensor

4.4.3 Temperature sensor: The DHT11 Temperature and Humidity Sensor, as depicted in Figure 5, comprises a temperature and humidity sensor complex with a calibrated digital signal output. This sensor is primarily employed to measure the maternal body temperature. It offers more precise temperature measurements compared to using a thermistor. Throughout pregnancy, it is typical for a woman's body temperature to fluctuate. This is attributed to factors such as increased metabolism, elevated levels of hormones like progesterone, the heightened workload on the woman's body due to added weight as the pregnancy advances, and the processing of fetal nutrients and waste products.

Fig. 5: Temperature sensor

4.4.4 LCD Display: A 16x2 LCD display provides on-site visualization of sensor readings, allowing for swift reference.

Fig. 6: LCD Display

4.4.5 Communication Module: An ESP8266 Wi-Fi module enables wireless communication and facilitates data transmission to the IoT platform.

Fig. 7: Esp8266 module

4.4.6 Power Supply: A dependable power source, such as a battery or solar panel, guarantees uninterrupted system operation.

Fig/ 8:Power supply

4.5 System Software:

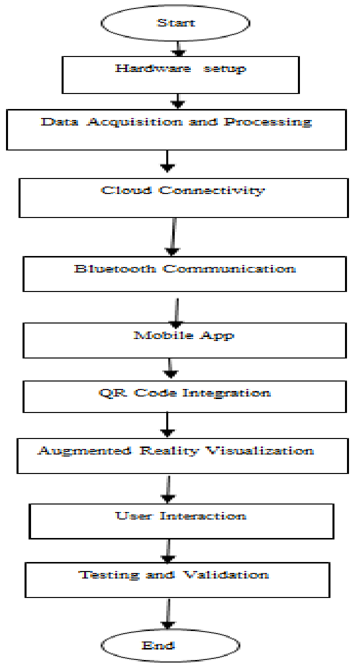
4.5.1 Arduino IDE: The Arduino Integrated Development Environment is employed for programming the Arduino microcontroller specifying functions for sensor data acquisition, processing, communication, and control.

4.5.2 IoT Platform: An IoT platform such as Ubidots furnishes a web interface for visualizing, storing, and analyzing data. Users can remotely access sensor data, establish automation rules, and receive alerts.

4.5.3 Work Flow:

1. Users wear the sensor array connected to the Arduino.
2. The Arduino gathers real-time data on pulse, SpO2, and temperature.
3. Sensor readings can also be recorded in Ubidots (cloud).
4. Data is transmitted to the mobile app via Bluetooth.
5. Users initiate the mobile app and scan a QR code to activate the AR experience.
6. The app processes the sensor data and assigns a risk level (high, medium, low).
7. The 3D lung model in AR is exhibited, with specific areas colored based on the risk assessment. (Red - High Risk areas, yellow - Medium Risk areas, Green - Low Risk areas)
8. This system furnishes real-time feedback on the user's health status through an interactive and user-friendly AR display.

4.6 Implementation



Fig/ 9: Implementation Flow Diagram

5. Results and Discussions

Arduino microcontrollers have been seamlessly integrated with pulse sensor, SpO2 sensor, and temperature sensor for real-time data acquisition. The Arduino efficiently processes and consolidates sensor data, ensuring precise readings of vital signs. Cloud connectivity has been established using Node MCU and the Ubidots IoT platform, allowing for remote access to real-time and historical patient data. This enables healthcare practitioners to remotely monitor patient vital signs, facilitating timely interventions and personalized care strategies. Bluetooth communication has been implemented between Arduino and the mobile application, facilitating smooth data transfer and control. A user-friendly mobile application interface has been developed for healthcare practitioners and patients, providing easy access to vital sign readings and augmented reality visualization. Figure 10, 11 and 12 shows the temperature, SpO_2 and heartbeat of patients.

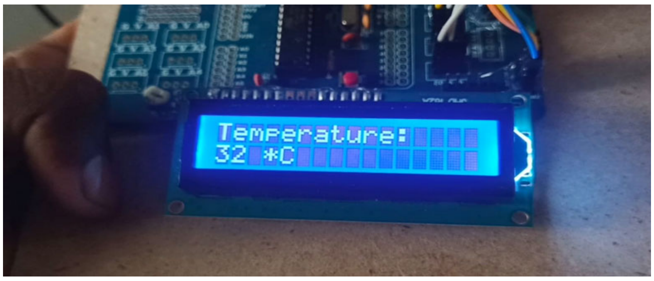


Fig. 10: LCD Shows that body Temperature of the person

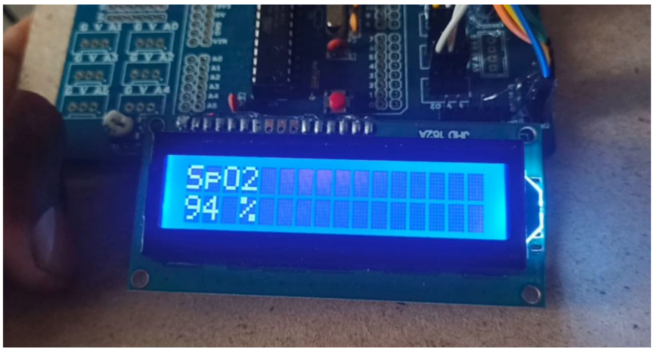


Fig. 11: LCD Shows that SPO_2(Blood oxygen) of the person

Fig. 12: LCD Shows that Heartrate of the person

QR code scanning functionality has been effectively integrated within the mobile application, allowing users to access supplementary information or initiate actions relevant to patient care. Augmented reality visualization has superimposed real-time sensor readings onto a 3D virtual representation of human lungs, simplifying the interpretation of patient health status. Figure 13,14 and 15 shows the risk status of heart rate.

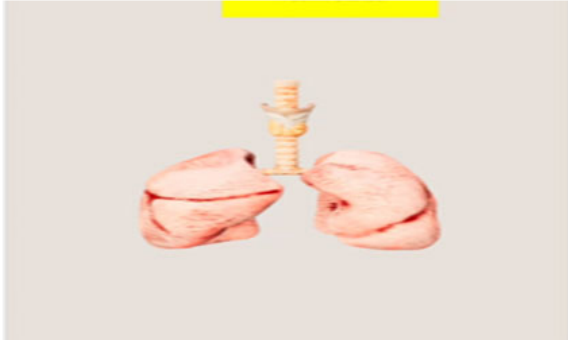


Fig 13: Low risk representation of health status based on Heart rate

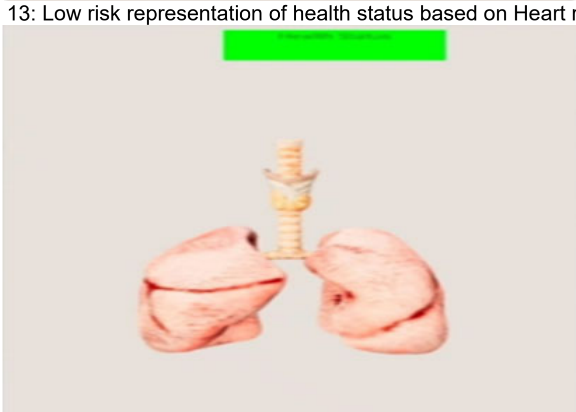


Fig. 14: No risk representation of health status based on Heart rate

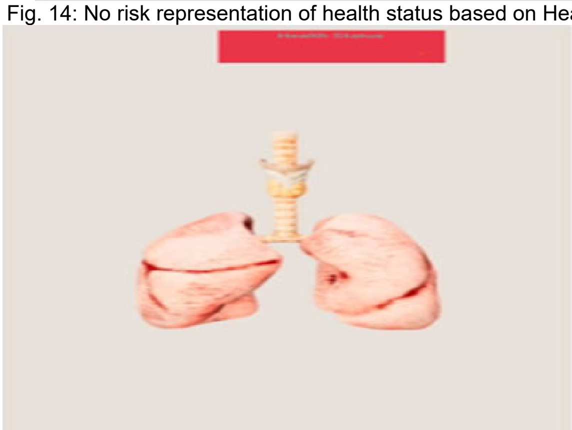


Fig. 15: High risk representation of health status based on Heart rate

Conclusion

This digital twin system represents a promising approach to real-time health monitoring. By integrating wearable sensors, an Arduino microcontroller, and a mobile app with AR features, the system facilitates continuous data collection, risk assessment, and user-friendly data visualization. This empowers users to gain a deeper understanding of their health and potentially identify issues at an early stage. The benefits of this system include: Enhanced monitoring and early detection capabilities. Improved accessibility and convenience for users. Increased user engagement and empowerment through interactive data visualization. Potential cost reduction in healthcare by enabling preventative care.

Future Scope

Incorporating additional sensors to monitor blood pressure, respiration rate, and other vital signs can offer a more comprehensive health overview. Implementing machine learning algorithms could enable the system to recognize patterns, anticipate potential health risks, and even provide personalized health recommendations.

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