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Research Article

Human-Centric IoT for Health Monitoring in the Healthcare 5.0 Framework Descriptive Analysis and Directions for Future Research

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ABSTRACT

This Study explores the evolving role of the Internet of Medical Things (IoMT) in healthcare, specifically within the context of healthcare 5.0. It provides a comprehensive review of existing IoT-based health monitoring systems, highlighting their technological advancements and identifying critical gaps in human-centered design. While much of the research has focused on the development of hardware, software, and data transmission technologies, insufficient attention has been given to tailoring these systems to meet individual patient needs and preferences. Furthermore, long-term health monitoring and personalized data analytics are often overlooked. The paper proposes future research directions to address these gaps, including the integration of human-centered design principles in IoMT devices, the development of personalized biometrics profiles, and the application of statistical process control methods for continuous health monitoring. Additionally, it suggests incorporating machine learning and deep learning techniques to enhance data analysis and support real-time interventions. By emphasizing multi-biometrics monitoring and real-time alarm systems, the paper aims to provide a roadmap for more personalized, effective, and sustainable healthcare solutions in the era of Healthcare 5.0.

1. INTRODUCTION

1.1 Overview of Healthcare 4.0 and Transition to Healthcare 5.0

Healthcare 4.0, inspired by Industry 4.0, has transformed medical practices through the integration of smart systems and connected devices [1]. Key technologies like the Internet of Things (IoT), artificial intelligence (AI), big data analytics, robotics, and cloud computing have driven significant innovations:

- Remote Patient Monitoring: Continuous tracking of health metrics like heart rate, blood pressure, and glucose levels, reducing hospital visits while enabling timely interventions.
- Surgical Robotics: Advanced robotic systems ensure precision in minimally invasive surgeries, leading to better outcomes and quicker recovery times.
- Data-Driven Decisions: AI and big data analyze clinical records and health trends to offer predictive insights and personalized treatment plans.

While Healthcare 4.0 emphasizes automation and digitalization, Healthcare 5.0 addresses its limitations by adopting a human-centered approach [2]. This evolution prioritizes patient needs, preferences, and emotional well-being alongside technological advancements. Key goals include:

- Personalized Care: Integrating health history, genetics, and lifestyle for tailored treatments.
- Emotional Well-Being: Focusing on psychological and emotional support to build trust and empathy in healthcare.
- Sustainability and Accessibility: Advocating for eco-friendly practices and equitable access to care worldwide.
- Collaborative Ecosystems: Encouraging partnerships between technologists, healthcare providers, and policymakers to create inclusive solutions.

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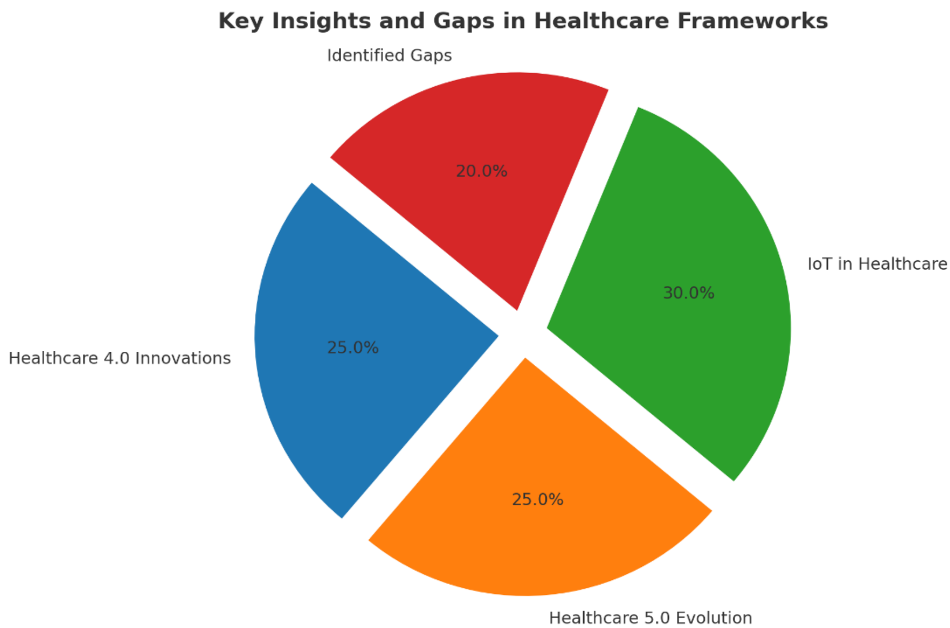

Fig 1.highlighting the key insights and gaps in the transition from Healthcare 4.0 to Healthcare 5.0

In Healthcare 5.0, IoT evolves into the Internet of Medical Things (IoMT), emphasizing human-focused outcomes. This shift represents a move from episodic care to adaptive, personalized healthcare, improving long-term quality of life[3].

1.2 Role of IoT in Modern Health Monitoring Systems

The Internet of Things (IoT) has transformed modern health monitoring by enabling continuous, real-time tracking of patient health. Using wearable sensors, data analytics, and communication networks, IoT creates seamless connections between patients, healthcare providers, and caregivers. By collecting and transmitting vital signs such as heart rate, blood pressure, and oxygen levels remotely, IoT extends health monitoring beyond traditional clinical settings [4].

A key advantage of IoT is its ability to reduce the need for frequent hospital visits. Patients can remain at home or carry on with daily activities while healthcare providers monitor their well-being remotely. Real-time data enables the early detection of irregularities, such as abnormal heart rhythms or high blood pressure, allowing for swift interventions to prevent emergencies [5].

IoT also supports personalized health management by analyzing individual health trends. Patients receive tailored insights and recommendations through apps or other user-friendly platforms. For those managing chronic conditions like diabetes or hypertension, IoT devices offer consistent monitoring, medication reminders, and actionable advice to minimize complications [6].

When combined with artificial intelligence, IoT elevates healthcare to a predictive level. Data analysis helps identify risks, empowering providers to implement preventive care. Secure cloud platforms facilitate safe data sharing among stakeholders, improving communication and coordination across healthcare systems [7].

Applications of IoT include wearable devices like fitness trackers and biosensors, which monitor vital signs and provide feedback on health. Remote patient monitoring systems enable quality care at home, particularly for elderly or immobile patients. In hospitals, IoT-powered systems automate tasks such as medication management and environmental controls, enhancing safety and comfort [8].

By enhancing accessibility, enabling quicker responses, and personalizing care, IoT has become a cornerstone of modern healthcare. These advancements improve patient outcomes while fostering a more efficient and sustainable healthcare ecosystem [9].

1.3 Identification of Gaps in Existing IoT-Based Health Monitoring Systems

Current IoT applications in healthcare primarily focus on developing hardware and software for efficient data collection and transmission. While these innovations have improved health monitoring systems, they often neglect critical human-centered aspects [10]. Many systems are not tailored to the unique needs, preferences, or limitations of users, including individuals with disabilities or specific health conditions.

Additionally, a significant gap exists in addressing long-term health data analysis, which is vital for detecting patterns, predicting health risks, and enabling informed decision-making. This shortfall underscores the need for IoT solutions that emphasize personalization and incorporate advanced analytics to deliver comprehensive, user-centered healthcare support [11].

1.4 Research Objectives and Key Questions

This study seeks to address the following:
1. The extent to which human-centered health monitoring has been explored.
2. Dominant trends in IoT health monitoring literature.
3. Analytical techniques needed for future human-centered IoT systems.

This section emphasizes the importance of transitioning to human-centered IoT-based health monitoring, highlighting the need for research on personalized and sustainable healthcare solutions tailored to the Healthcare 5.0 era

2. BACKGROUND

2.1 Remote Health Monitoring

Continuous, real-time health monitoring is crucial in modern healthcare, especially for managing chronic diseases, elderly care, and early detection of health issues[12]. Traditional hospital-based monitoring often provides only periodic assessments during scheduled visits, leaving gaps in care that can delay interventions and obscure long-term health trends. Technologies like IoT, cloud computing, and blockchain have revolutionized health monitoring by enabling continuous, remote care. IoT wearables and sensors collect real-time data on metrics like heart rate, blood pressure, and glucose levels. Cloud computing offers scalable platforms for data storage and analysis, while blockchain ensures secure, transparent data sharing between patients and providers[13].

This shift to home-based care represents a major advancement in healthcare delivery. IoT-driven remote monitoring empowers patients to manage their health at home while staying connected to healthcare professionals. This approach reduces strain on healthcare facilities, cuts costs, and enables timely, personalized care, creating a more patient-centered and efficient system[14].

2.2 Internet of Medical Things (IoMT)

The Internet of Medical Things (IoMT) is a network of connected devices and sensors that gather, transmit, and analyze health data to enhance patient care. These devices range from wearables like smartwatches and fitness trackers to specialized medical tools such as ECG monitors, glucose meters, and blood pressure cuffs[15].

Key components of IoMT systems include:
- Sensors: Collect biometric data like heart rate, temperature, blood pressure, and glucose levels, either embedded in medical devices or worn by patients for continuous health monitoring.
- Communication Modules: Transfer data from sensors to processing units using technologies such as Wi-Fi, Bluetooth, Zigbee, or cellular networks, ensuring reliable, real-time data flow.
- Processing Units: Analyze data from sensors, either within the device or on cloud-based platforms, preparing it for advanced use.
- Databases: Securely store health data, often using cloud computing for scalability and easy accessibility, enabling healthcare providers to review and utilize the information.

After data collection and storage, IoMT systems use AI, machine learning, and big data analytics to identify health trends, detect issues, and predict future risks. Insights are shared with doctors, caregivers, and patients, supporting remote monitoring, personalized care, and timely interventions. By integrating these components, IoMT facilitates continuous real-time health monitoring and enhances coordination and decision-making in healthcare[16].

2.3 Health Measures

Vital health metrics are key indicators of an individual's well-being, regularly monitored to evaluate their health status. These metrics include heart rate, blood pressure, glucose levels, body temperature, respiratory rate, and oxygen saturation (SpO2). They offer valuable insights into a person's physiological state and aid in detecting early signs of conditions such as cardiovascular diseases, diabetes, respiratory disorders, and other chronic illnesses[17].
- Heart Rate: Tracks beats per minute, providing crucial information about heart health.
- Blood Pressure: Measures the force of blood against artery walls, highlighting risks like hypertension, stroke, or heart disease.
- Glucose Levels: Essential for diabetes management by monitoring blood sugar levels.
- Body Temperature and Respiratory Rate: Detect fever, infections, and respiratory issues.

Accurate measurements are vital for effective care, requiring IoMT devices to capture precise data. Reliable data helps healthcare providers make informed decisions, while secure data collection ensures patient privacy and compliance with regulations like HIPAA[18]. IoMT systems employ encryption and secure communication protocols to protect patient information during transmission. Continuous monitoring enables real-time condition assessments, allowing professionals to detect abnormalities promptly and intervene when necessary. For chronic conditions, this approach supports long-term health management by creating a consistent record of health trends over time[19].

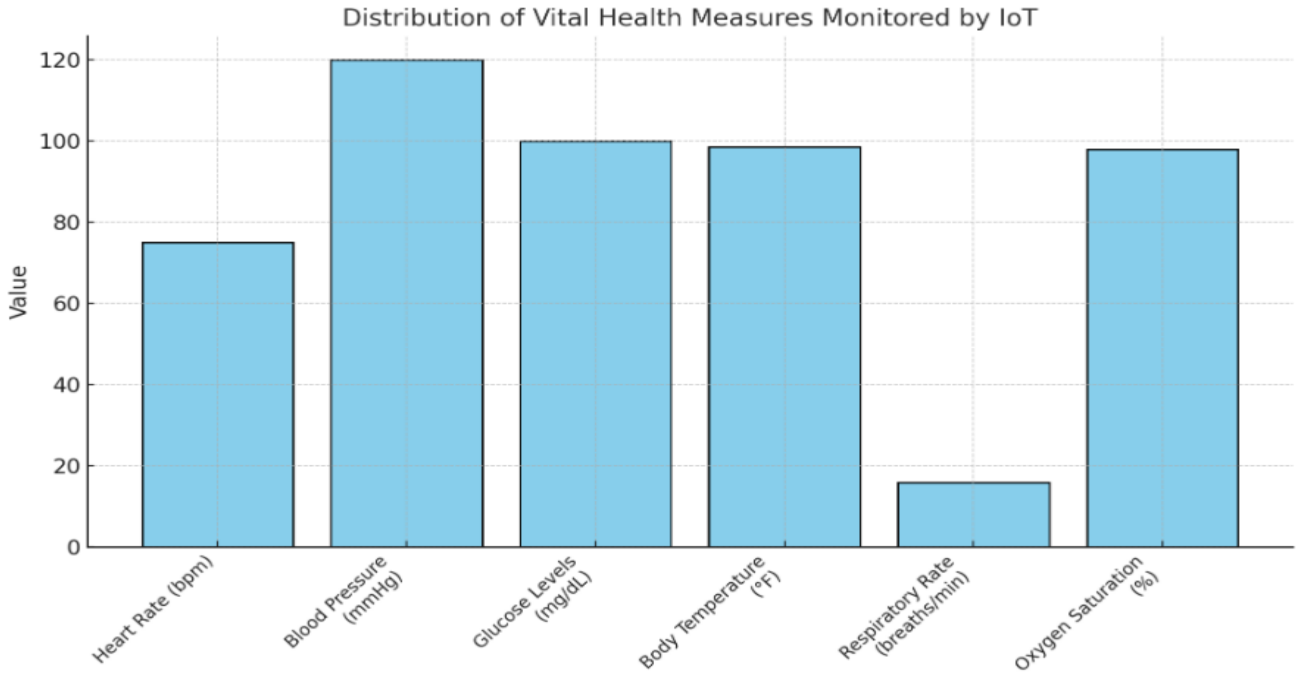

Fig. 2 Example Column Chart Representing Vital Health Measures Monitored by IoT Devices. Metrics include Heart Rate, Blood Pressure, Glucose Levels, Body Temperature, Respiratory Rate, and Oxygen Saturation (SpO2).

Health metrics form the foundation of IoMT systems, ensuring early detection, effective treatments, and better patient outcomes. Accurate, secure, and continuous tracking makes them indispensable in modern healthcare.

3. IOT-BASED HEALTH MONITORING LITERATURE DESCRIPTIVE ANALYSIS

Existing studies on IoT-based health monitoring have been largely focused on the technological components, such as the biometrics monitored, the communication modules used, the software and hardware platforms, and the sensors involved. In terms of biometrics, much of the research has concentrated on vital signs such as heart rate, blood oxygen levels (SpO2), blood pressure, and glucose levels, as these are the most commonly tracked health parameters. Studies have also explored a variety of sensors for monitoring these biometrics, including ECG sensors for heart activity, accelerometers for physical movement, and pulse oximeters for oxygen levels[20].

Regarding communication modules, technologies like Bluetooth, ZigBee, and Wi-Fi are widely used in IoT health systems to enable the transfer of data from wearable devices or medical sensors to centralized databases or healthcare providers. In parallel, software platforms such as Python and MATLAB are commonly used for processing and analyzing the data collected from these devices. For hardware, the Raspberry Pi and Arduino UNO are frequently chosen due to their versatility, affordability, and ease of integration with various sensors and communication technologies[21].

while the technological development of these components has received considerable attention, there is a notable lack of focus on human-centered design in many of the studies. Most research tends to prioritize the enhancement of the hardware and software systems themselves rather than considering how these systems can be personalized to meet the unique needs and preferences of individual patients. This oversight is particularly evident in the lack of long-term health monitoring strategies, which are crucial for chronic disease management and the ongoing care of elderly or vulnerable populations[22].

there is insufficient emphasis on human-centered data analytics. While data collection and transmission are well-developed, the analysis of that data often lacks personalization. Many systems do not tailor the insights to the specific health contexts or needs of individual patients. For instance, instead of offering recommendations or interventions based on a person's medical history, lifestyle, or emotional state, the focus remains primarily on the raw data itself[23].

Finally, existing research tends to favor the technological aspects of IoT health monitoring over more holistic, human-focused solutions. This reveals a significant gap in addressing long-term, personalized health monitoring and the integration of human-centered data analytics. Future studies should focus more on designing systems that consider the patient's specific needs, preferences, and emotional well-being, while also developing analytics that can offer personalized, actionable insights for better health management[24].

4. FUTURE RESEARCH GUIDELINES

To address the existing gaps in current IoT-based health monitoring systems, future research should focus on several key areas that enhance personalization, long-term monitoring, and data analytics.

First and foremost, there is a need for human-centered design in the development of IoMT hardware and software. This means creating devices and platforms that are not only technologically efficient but also tailored to the specific needs, preferences, and capabilities of individual users. For example, wearable devices and sensors should be designed with user comfort, accessibility, and ease of use in mind, especially for patients with chronic conditions or disabilities. Additionally, software platforms should offer customizable features that allow for more individualized health tracking and decision-making, ensuring that the system adapts to the user's unique health profile.

Another important area for research is the development of personalized biometrics profiles. This involves creating systems that can track and analyze an individual's specific health metrics over time, taking into account factors such as age, gender, medical history, and lifestyle. By establishing personalized health profiles, IoMT systems could provide more accurate predictions and recommendations, improving the overall effectiveness of remote monitoring. Furthermore, systems should incorporate personalized tolerances for biometrics, which would allow for more flexible and accurate health assessments based on each person's unique baseline.

Long-term monitoring is another critical component that requires attention. Researchers should explore the use of statistical process control methods, such as control charts, to manage health data over extended periods. These tools could help detect subtle changes in a patient's health, providing early warning signs for potential issues before they become serious. Long-term monitoring is particularly important for managing chronic diseases, where daily or weekly fluctuations may indicate the need for intervention.

Incorporating machine learning and deep learning techniques will also play a pivotal role in improving the analytical capabilities of IoMT systems. These technologies can be used to process and analyze large volumes of health data, identifying patterns, trends, and anomalies that would be difficult for human analysts to detect. Machine learning models could be trained to offer more accurate, real-time predictions and tailored recommendations, based on an individual's specific health conditions and needs.

Finally, multi-biometrics monitoring should be a priority in future research. Most current systems focus on tracking a single health metric at a time, such as heart rate or blood pressure. However, a comprehensive approach that monitors multiple biomarkers simultaneously could provide a more complete picture of a person's overall health. Real-time alarm systems should also be integrated to alert both patients and healthcare providers when any of the monitored metrics fall outside of normal ranges, enabling quick interventions when necessary.

By focusing on these areas, future research can enhance the capabilities of IoMT systems, making them more personalized, effective, and responsive to the needs of individual patients.

5. CONCLUSION AND RECOMMENDATIONS

This study highlights the current focus on technology-driven advancements in IoT-based health monitoring, such as hardware and software development, but identifies significant gaps in human-centered approaches. While these systems have improved efficiency, they often overlook the personalization of care and long-term health monitoring, especially for patients with chronic conditions.

To address these gaps, future research should prioritize developing IoMT systems tailored to individual needs, disabilities, and emotional factors. A stronger focus on personalized, long-term monitoring and decision-making frameworks is essential. By integrating human-centered design and advanced analytics, IoMT systems can offer more effective, patient-centric solutions that improve overall healthcare outcomes.

In conclusion, it is crucial for future work to bridge the gap between technology and human-centered care, ensuring IoT health systems serve both the technical and emotional needs of patients.

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Conflicts of Interest:

The authors declare that there are no conflicts of interest to report.

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