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Research on the Application and Development Trends of Embedded Systems in Smart Healthcare Internet of Things

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Abstract. With the global population aging and the increasing demand for health, fueled by the development and application of the Internet of Things, smart healthcare has become a trend in the medical industry, further promoting medical intelligence and data integration. This paper focuses on the application of embedded systems in the smart healthcare Internet of Things (IoT), exploring the current state, key technologies, challenges, and development directions through literature review and case analysis. Research has demonstrated that embedded systems significantly enhance healthcare efficiency and quality, optimise resource allocation, and foster healthcare innovation. Additionally, this paper suggests that in the future of smart healthcare, there is a need to strengthen technology research and development and explore new application models to accelerate smart healthcare growth. It also advocates promoting the unification of standards in the medical system nationwide. Furthermore, the paper emphasizes deepening the integration of AI with medical systems to enhance the security of patient medical data.

Keywords: Embedded Systems, Smart Healthcare, Internet of Things, Telemedicine, Data Security

1. Introduction

The intensifying aging global population and the ever-increasing health demands have made smart healthcare an inevitable trend in the development of the healthcare industry [1]. Through the integration of advanced information technology, medical equipment, and resources, smart healthcare aims to enhance the efficiency, quality, and accessibility of medical services, thereby providing personalised and precise medical services [2]. In this development process, Internet of Things technology plays a crucial role, enabling the interconnectivity of medical devices, breaking down the information silos of the traditional healthcare system, and facilitating the sharing and circulation of medical data.

As the core component of smart medical IoT, embedded systems can efficiently perform key tasks such as the collection, processing, and transmission of medical data due to their specificity, real-time capabilities, and reliability [3]. From intelligent medical imaging systems and medical endoscopy systems to remote medical monitoring systems, the application of embedded systems spans multiple areas of smart healthcare, providing robust technical support for advancements in medical technology. In-depth research into the application of embedded systems within the smart

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medical IoT not only promotes the development of smart healthcare technologies, improves the quality and efficiency of medical services, but also optimises the allocation of medical resources, delivering a more convenient and efficient healthcare experience for patients, which holds significant theoretical and practical implications.

This paper provides an in-depth discussion of the current application status, key challenges, and future development directions of embedded systems in the smart medical IoT based on a comprehensive literature review. By summarization and analysis of the specific applications of embedded systems in this field, this study provides valuable insights and guidance for the further advancement of smart healthcare.

2. Drawbacks of the current healthcare system

2.1. Severe phenomenon of information silos

Due to the lack of an effective interconnection mechanism between information systems in different medical institutions, medical data is often dispersed across the independent systems of various healthcare providers, making effective integration and sharing impossible. This phenomenon of information silos not only results in the repeated collection and storage of medical data, increasing healthcare costs, but also prevents doctors from obtaining patients' medical records and test reports from other institutions in a timely manner during diagnosis, which in turn incresase the risk of misdiagnosis and missed diagnosis. Moreover, information silos hinder the optimal allocation and collaborative utilisation of medical resources, impacting the overall efficiency of healthcare services.

2.2. Low level of equipment intelligence

Traditional medical equipment cannot meet the demands of modern healthcare for real-time monitoring and remote diagnosis. Traditional medical devices necessitate that patients visit hospitals for examinations and diagnoses, which is extremely inconvenient for patients, especially those in remote areas.. Moreover, the low intelligence level of such devices leads to inefficient medical data utilisation, thus failing to provide timely and accurate data support for medical decision-making. This restricts doctors from monitoring patients' conditions in real-time and conduct remote diagnoses, ultimately affecting both the healthcare experience and treatment outcomes. Additionally, the accuracy of current telemedicine instruments requires improvement. On one hand, device limitations such as low measurement accuracy and suboptimal image processing lead to significant diagnostic errors. On the other hand, treatment devices cannot process vast amounts of information simultaneously, jeopardising the consistency and accuracy of clinical diagnostics. Furthermore, configuration and intelligence level disparities of telemedicine equipment across healthcare institutions exist, influencing the complexity of achieving a unified telemedicine system. In this context, the telemedicine networks in tertiary and secondary hospitals primarily utilise dedicated networks. Tertiary hospitals exhibit the highest rate (54.6%) for remote education recording and broadcasting, accounting, while secondary hospitals feature remote ECG collection terminals, accounting for 46.4% [4].

2.3. Insufficient data security and privacy protection

Due to the lack of effective data encryption, authentication and access control mechanisms in the traditional medical system, medical data is vulnerable to compromise and tampering during

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transmission and storage. In addition, data management in thse systems often relies on manual operations and lacks automated backup and recovery mechanisms. Once data loss or corruption occurs, it can inflict serious losses on patients and medical institutions. As a result, traditional healthcare systems experience is a high incidence of data breaches, most of which are attributed to insufficient data security and privacy measures [5].

2.4. Unequal distribution of medical resources

The allocation of medical resources is often influenced by geographical, economic, and policy factors. High-quality medical resources tend to concentrate in large cities and developed regions, whereas remote and rural areas possess relatively scarce medical resources. The uneven distribution of medical resources has led to an extreme shortage in remote areas, compromising the medical experience and treatment outcomes for patients in these regions and exacerbating the healthcare disparity between urban and rural areas.

3. Advantages of IoT technology in intelligent healthcare

3.1. Interoperability of healthcare data

The IoTs technology facilitates real-time data collection and analysis by connecting various medical devices and systems, thereby addressing the phenomenon of information islands prevalent in traditional medical systems. For instance, monitors, X-ray machines, CT scanners, and other devices in hospitals can be interconnected through IoT technology, which automatically transmits detected patient physiological parameters and medical image data to the medical information system for information exchange [1]. This interconnection not only enhances the efficiency of data collection but also establishes a foundation for the unified management and analysis of medical data. Moreover, IoTs technology supports the standardised collection, storage, exchange, and sharing of medical data, enabling cross-institutional and cross-regional data interconnection.

3.2. The improvement of the intelligence level of medical equipment

The IoTs technology has significantly enhanced the intelligence level of medical devices, enabling real-time monitoring and remote diagnostic capabilities [6]. For instance, remote electrocardiogram (ECG) monitoring devices can collect patients' ECG data in real-time and transmit it to a medical centre via a wireless network, allowing doctors to conduct diagnoses and interventions anytime and anywhere. This intelligent medical equipment not only improves the accuracy and timeliness of diagnoses but also enhances the patient experience, particularly for those in remote areas who can access expert medical services without lengthy travel.

3.3. Enhancement of data security and privacy protection

IoT technology offers distinct advantages in data security and privacy protection. By adopting advanced encryption technologies, identity authentication, and access control mechanisms, IoT systems can effectively prevent the leakage and tampering of patient medical data during transmission and storage. For instance, healthcare institutions can leverage IoT technology to build secure transmission channels for patient medical data, ensuring the confidentiality and integrity of such information. Moreover, IoT technology also supports granular data governance, achieving hierarchical and category-based access control to further enhance data security [7].

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3.4. Optimisation of healthcare resource distribution

Through the application of telemedicine and smart medical devices, IoTs technology has effectively optimised the distribution of medical resources and improved healthcare conditions in remote areas. For example, the remote consultation system allows patients in remote areas to access medical advice from specialists in major cities, reducing the imbalance in medical resources caused by geographical barriers. Regional imaging system facilitates cross-institutional medical collaboration by establishing patient-specific electronic imaging records, which provide comprehensive diagnostic reports and associated imaging data. Meanwhile, IoT technology can monitor the usage of medical equipment in real-time, enhancing the utilisation and maintenance effectiveness of such equipment, thereby alleviating the strain on medical resources to a certain extent [8].

4. Embedded systems and smart healthcare IoTs

4.1. Critical technologies

4.1.1. Sensor technology

Sensor technology, as the foundation of embedded systems in the smart medical IoTs, is primarily responsible for collecting various physiological parameters and environmental data. In medical IoTs, sensor network technology plays a vital role in advancing smart healthcare and telemedicine. Numerous sensor nodes deployed in the monitoring area can detect and gather relevant information about perceived objects in real time. This enables real-time monitoring of the entire medical process and effectively enhances the quality of healthcare services. Additionally, the integration of technologies enables real-time localisation and tracking of medical supplies, ensuring the timely transfer and sharing of medical information, thereby providing solid technical support for the advancement of telemedicine [9].

4.1.2. Radio Frequency Identification (RFID) technology

Radio Frequency Identification (RFID) technology is one of the core technologies in embedded systems. The chip containing product information is embedded in the medical supplies. When combined with computers and identification systems, RFID technology enables tracking management and automatic identification of these supplies. The whole process require no manual intervention, enhancing control over medical supplies even in various harsh environments. In medical IoTs, RFID technology is mainly used in the visual management of medical materials, such as medical device management, disinfection package management, medical waste disposal, drug anti-counterfeiting, drug status monitoring, biologics management, and drug supply chain management. As a result, real-time monitoring and tracking of medical supplies can be realised, effectively avoiding public medical safety issues [9].

4.1.3. Intelligent embedding technology

Intelligent embedding technology endow objects with a level of intelligence by embedding intelligent systems. allowing them to interact with users actively or passively. In medical IoTs, this technology enables medical devices intelligent, facilitating efficient interaction between the devices and users, and enhancing usability and user experience. For example, it equips medical devices with

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automatic fault diagnosis and alert functions, promptly notifying maintenance personnel for repairs, thereby reducing downtime and improving both the availability and reliability of devices [9].

4.1.4. Cloud computing technology

The application of cloud computing technology in the medical IoT is referred to as "health cloud", which dynamically provide services in accordance with the pre-agreed service level agreement between provider and user, with characteristics including service resource management, scalability, measurability, and reliability. With cloud computing, dynamic management of medical system can be achieved, optimising the allocation and utilisation efficiency of medical resources. The robust data storage and computing capabilities of cloud platform support centralised storage, management, and analysis of medical data, providing substantial data support for medical decision-making [9].

4.1.5. Network transmission technology

Embedded systems must possess efficient data transmission capabilities to ensure medical data can be transmitted to medical information systems or cloud platforms timely and accurately. Network transmission technology encompasses two modes: wired transmission and wireless transmission. Wireless transmission is widely used in medical IoTs due to its flexibility and convenient deployment, with common technologies including Wi-Fi, Bluetooth, ZigBee, and so on. Additionally, low-power wide-area network (LPWAN) technologies (such as NB-IoT, eMTC, and LoRa) are suitable for low-power, long-distance data transmission scenarios, better meeting connectivity needs of numerous devices within the medical IoTs [10].

4.2. Application

4.2.1. Intelligent medical imaging system

The Neusoft Smart Medical Imaging Data Platform (N-VNA) employs an embedded system based on ARM architecture, characterised by low power consumption and high efficiency. The flexibility and scalability of the ARM architecture enable N-VNA to seamlessly interface with various business systems. Through embedded system optimisation, N-VNA facilitates rapid data transmission and storage, supporting remote diagnosis and data sharing. Additionally, N-VNA integrates data from multiple imaging modalities (such as CT, MRI, X-ray, etc.), providing comprehensive, multi-phase, and multi-modal image data comparison and review to assist physicians in precise diagnoses. In response to address uneven medical resources, N-VNA offer comprehensive regional medical imaging solutions for healthcare institutions at all levels, leveraging Internet technology conjunction with clinical medical imaging to facilitate data sharing and collaborative diagnosis.

In addition, based on the comprehensive multi-modal data, N-VNA integrates diagnostic and treatment process data, follow-up data, and scientific research data to form a high-quality structured standardised data set, thereby achieving the orderly and efficient integration of diagnostic and treatment information throughout the hospital. Among these, medical imaging research services also support the scientific research application of data.

4.2.2. Medical endoscopic systems

Based on the NXP i.MX8M Plus processor, Qiyang Solution launched the IAC-IMX8MP-CM core board, suitable for medical endoscopes and other equipment. The processorfeatures low power

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consumption, high performance, high stability, and rich functional interfaces, which can meet the high requirements of medical endoscopes for image processing. Based on the high-performance ARM architecture, the embedded system can ensure the clarity, colour reproduction and stability of the image, and provide reliable visual information for doctors. Among them, the Rockchip RK3399 platform, as one of the commonly used embedded system solutions, supports Android and Linux systems, and has a wealth of function expansion interfaces, which is convenient for customers to adjust product definitions, hardware configurations, software functions and user interfaces according to their needs. The RK3399-based medical endoscope solution enable real-time image acquisition, processing and display, with high-definition images through the HDMI. The system also supports the secure transmission and sharing of data to meet the needs of remote diagnosis.

4.2.3. Remote medical monitoring system

The STM32-based intelligent medical monitoring system employs the STM32F103C8T6 microcontroller as its core processor. Based on the ARM Cortex-M3 core, the microcontroller features low power consumption and high efficiency, thus meeting requirements for medical data processing and real-time control. Embedded systems efficiently process and transmit large volumes of medical data, ensuring real-time and accurate information. The system uploads the collected physiological data including ECG, blood oxygen levels, and body temperature, to the APP debugger for remote monitoring via the WiFi module. Medical staff can remotely monitor patients' health status anytime and anywhere using mobile apps or computers. When abnormal data is detected, the system automatically trigger an alarm to notify medical staff to respond promptly. Additionally, the system's flexibility and scalability enable it to seamlessly connect with various sensors and communication modules, supporting multi-parameter monitoring and data transmission. In terms of data security and privacy protection, the system employs AES-128 encryption technology to ensure the security of medical data during transmission and storage. Furthermore, the system supports hierarchical and classified access control of data, allowing only authorised medical staff to access patients' sensitive information.

4.3. Related issues and recommendations

4.3.1. Data security and privacy protection

In the smart medical IoTs, data security and privacy protection face severe challenges. With the widespread adoption of medical IoT devices, vast amounts of sensitive patient data are at risk of cyberattacks and unauthorised access during collection, transmission, and storage. For instance, remote operation and maintenance services provided by IoMT equipment vendors may introduce vulnerabilities that could lead to data breaches and security intrusions. Moreover, medical IoT devices often lack adequate security measures, making them susceptible to counterfeit access, which further escalates the risk of data leakage.

To address these challenges, embedded systems need to implement a range of security measures. Using advanced encryption technologies (such as AES-128) can effectively ensure security data during transmission and storage. Implementing strict access control mechanisms, coupled with authentication and privilege management, can restrict access to sensitive data. Healthcare institutions should also conduct regular security audits and vulnerability scans to identify and rectify potential security issues timely.

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4.3.2. System integration and compatibility

The integration and compatibility of embedded systems across different medical institutions and devices are among the significant challenges in smart healthcare IoTs. Due to the absence of unified standards and regulations, seamless integration and data interoperability across devices and systems from various manufacturers remain challenging to achieve. For instance, the IoT application system in a smart hospital tends to have limited functionality and low maturity, failing to meet the unified standards of the healthcare industry, which increases the complexity of data fusion.

To tackle this issue, it is essential to reinforce the formulation and promotion of technical standards and norms. Healthcare organisations should implement standardised interfaces and protocols to ensure seamless integration and data sharing across various systems. Furthermore, through open APIs and modular design, the scalability and compatibility of the system can be enhanced, thus reducing the cost and complexity of future upgrades.

4.3.3. Diagnostic accuracy and reliability

AI algorithms and sensor accuracy in embedded systems significantly impact diagnostic accuracy. Although AI technology has played an important role in medical diagnosis, the interpretability and reliability of AI algorithms remain urgent challenges. Moreover, the precision and stability of sensors can affect data quality, consequently impacting diagnoses accuracy.

In order to improve diagnostics reliability, embedded systems need to employ high-precision sensors and advanced AI algorithms. At the same time, healthcare facilities should regularly maintain and calibrate the equipment to ensure its proper functioning and provide data accuratcy In addition, through big data analysis and machine learning technology, AI algorithms can be continuously optimised to improve the accuracy and interpretability of their diagnosis.

4.3.4. Energy consumption and endurance

Embedded medical devices face challenges related to energy consumption and battery life during prolonged continuous operation. As medical devices often need to operate for extended periods without interruption, low-power design and effective energy management are particularly crucial. However, achieving low-power design and energy management is not a straightforward task and requires a comprehensive approacb to hardware selection, software optimisation, and power management.

To tackle the challenges of energy consumption and battery life, embedded systems can employ low-power processors and sensors, such as those based on the ARM architecture, which are ideal due to their low power consumption and high efficiency. Furthermore, through dynamic power management and optimisation algorithms, the power consumption of device can be effectively reduced, thereby extending its battery life. Simultaneously, implementation efficient energy management strategies, such as intelligent sleep and wake-up mechanisms, can further enhance the energy efficiency of devices.

4.4. Future direction

Embedded systems can integrate heterogeneous medical data from multiple sources (e.g., images, physiological signals) to provide comprehensive and accurate patient information and improve diagnosis and treatment outcomes [11]. The combination of AI and machine learning technologies enhances its ability to analyse complex data in real time, automatically identify disease patterns, and

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assist doctors in diagnosis and treatment decisions, thereby improving equipment automation and intelligence, and enhancing medical efficiency. For example, deep learning algorithm models can establish a clinical decision-making intelligence system based on emergency database, enabling intelligent pre-examination and disease assessment of patients to address current situation in emergency department services [12].

In terms of miniaturisation and wearability, with advancements in technology, embedded medical devices will become increasingly miniaturised and wearable, allowing patients to wear them for extened periods and achieving continuous health monitoring. This will be particularly beneficial for the health management among chronic disease patients and the elderly. For instance, an NB-IoT-based embedded solution enables the collection and reporting of basic vital signs data, and reminders for bedridden patients regarding their intravenous infusion status [13]. Additionally, embedded systems combining edge computing and cloud computing can reduce data transmission latency, improving real-time performance and responsiveness. Efficient data storage and processing also enhance support for complex medical applications. For example, edge computing processes data locally, reducing transmission delays and enhancing real-time responsiveness [13]. Furthermore, due to the focus on data security and privacy protection, embedded systems will adopt advanced encryption, access control, and data anonymisation technologies to ensure the patient data security and privacy while complying with regulatory standards [11]. In the context of the medical IoTs, the 'dual authorisation' mechanism of patient informed consent authorisation and hospital data use authorisation, in conjunction with multi-party secure computing (MPC) and encryption technology, can effectively safeguard privacy security [14].

5. Conclusion

This paper comprehensively analyzes the application status, key technologies, challenges, and future development directions of embedded systems in the smart medical IoTs. It examines the drawbacks of traditional medical systems, explores the advantages of IoT technology in smart healthcare, and elaborates on the key technologies of embedded systems, including sensor technology, radio frequency identification (RFID) technology, intelligent embedding technology, cloud computing technology, and network transmission technology. Through application cases such as intelligent medical imaging systems, medical endoscope systems, and remote medical monitoring systems, it demonstrates the practical applications and technological characteristics of embedded systems. The study concludes that embedded systems hold a significant position in smart healthcare, capable of considerably enhancing medical efficiency and quality, optimising resource allocation, and driving medical innovation.

However, this article has some shortcomings. First, the scope of references is relatively narrow, mainly concentrated in a few areas, and there is a lack of broader relevant research support. Secondly, the number of case studies is limited, and only three typical application cases are selected, which cannot cover all the application scenarios of embedded systems in the smart medical IoTs. In addition, no empirical research has been conducted in this paper, and the conclusions are mainly based on theoretical analysis and existing literature reviews, which are not supported by actual data.

To optimise and enhance this research, future efforts should expand the scope of references, increase analyses of practical application cases, conduct empirical research, and further exploration of the integration of embedded systems with emerging technologies (such as blockchain, 5G communication, etc.), to expand the breadth and depth of their application in the smart healthcare field .

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