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PICU ward construction based on 5G unified cloud-edge collaborative AI smart healthcare

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ABSTRACT

The traditional ward management model fails to meet the growing medical needs, necessitating the integration of various technological means to enhance medical quality and service levels. Currently, smart healthcare remains in an exploratory phase both domestically and internationally. The Pediatric Intensive Care Unit (PICU) at the Third Affiliated Hospital of Sun Yat-sen University has utilized a 5G medical private network that integrated healthcare monitoring, treatment, and assisted intelligent medical terminals into one to establish an integrated platform for PICU based on a cloud-edge collaborative architecture. It facilitats a seismic shift from traditional towards smart healthcare, promots information symmetry among healthcare providers, improves work efficiency, and tailors the requirements of patients as well as the needs of their families. This platform serves as an inspiration for the intelligent construction of PICU.

Key words: 5G technology, smart ward, smart healthcare, pediatric intensive care units

INTRODUCTION

With the deepening developments in smart healthcare and continuous advancements in medical technologies, patients' needs and expectations in healthcare are increasingly growing. The concept of smart healthcare originated from the "Smarter Planet" strategy proposed by IBM in 2008.[1] Although China's exploration of smart healthcare can be traced back to the information system construction in the 1990s, including Hospital Information Systems (HIS), Picture Archiving and Communication Systems (PACS), and Laboratory Information Systems (LIS), the basic framework and standards for smart healthcare in China were not clearly defined until 2019 in the "Hospital Smart Service Grading Evaluation Standard System" issued by the National Health Commission.[2] In recent years, cloud computing, artificial intelligence and other technologies have been widely applied in smart healthcare construction. The announcement of the first batch of "Smart Hospital" pilot units (12 in total) marked the rapid rollout of smart healthcare initiatives in the country.[3] At the beginning of 2020, with the rise of 5G technology, the field of smart healthcare underwent profound changes. The deep integration of smart healthcare and 5G technology accelerated the processes of digitalization, networking, and intellectualization.[4] Subsequently, the "Three-Year Action Plan for New Infrastructure Construction of the Internet of Things (2021–2023)" issued in 2021 clarified one of its four key development tasks: encouraging the use of the "5G + IoT" model to promote the integrated upgrading of traditional infrastructure such as health services, and committing to transforming and innovating application scenarios in the field of public health,[5] which charted a new direction for the field of smart healthcare.

The design of smart wards is still in the exploratory stage. Under the traditional ward management model, information asymmetry among physicians, nurses, and

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patients often leads to wasted human resources and low work efficiency, which is not conducive to the centralized management of medical staff and equipment, and fails to meet the clinical treatment needs of patients and the psychological and emotional needs of their families.[6] Therefore, based on a 5G medical private network integrating monitoring, treatment, and auxiliary intelligent medical terminals, we explored the establishment of an integrated platform for the Pediatric Intensive Care Unit (PICU) based on a cloud-edge collaborative architecture to create an integrated application system tailored for pediatric intensive care.

APPLICATION-ORIENTED DESIGN OF THE OVERALL ARCHITECTURE FOR THE 5G SMART PICU INTEGRATED PLATFORM

Considering the ward construction environment and clinical service requirements, a 5G smart PICU integrated platform was designed using a cloud-edge collaborative distributed computing architecture, and the logical architecture of it is illustrated in Figure 1. Various terminal devices within the hospital collect user data and transmit it to the edge cloud *via* the 5G private network. The central cloud side interfaces with core hospital service data and performs complex computations on large-scale datasets, subsequently deploying data and models to the edge cloud. For scenarios requiring real-time responsiveness, the edge cloud directly performs computational processing and transmits instructions and results back to the terminal devices for user viewing or interaction. For data analysis, decision-making, and cross-regional collaboration scenarios, data is aggregated and summarized at the edge before being uploaded to the central cloud for further analysis and storage. Ultimately, six application modules are formed: the Mobile Nursing System, Ward Interactive Large Screen System, Bedside Care System, Remote Visitation System, Real-time Monitoring System for Critically Ill Patients, and Consumables Management System.

Mobile nursing system

This system uses the 5G network as its data exchange carrier, 5G medical Personal Digital Assistants (PDAs) as the terminal carrier, and cloud nursing software as the service platform. It extends the integration of nursing services—such as medical order execution verification, patient information query, and vital sign recording—to the mobile terminal. It fully leverages Artificial Intelligence (AI) image recognition technology for pressure ulcer risk assessment. By performing instance segmentation on images of potential pressure ulcer location, it rapidly evaluates the risk level, provides a description of the condition, and suggests appropriate nursing interventions to clinical nurses. In cases of severe pressure ulcers, the system can directly alert clinicians. Also, it capitalizes on natural language processing (NLP) for AI-based natural language input. The system converts voice samples from nurses into text *via* speech recognition, then subjects the transcribed natural language to lexical and semantic analysis, which efficiently transforms clinical dictated notes into standardized medical data, stored in the patient's temperature chart, nursing records, *etc.*

Ward interactive large screen system

The ward interactive large screen system integrates and intelligently handles nursing processes and information *via* a touch-enabled large screen. Utilizing 5G medical network slicing technology, it enables the efficient, real-time transmission of massive patient medical record data and nursing data between the system, edge cloud, and hospital data center. Different medical network slices ensure logical isolation and secure transmission between data streams. The system interfaces with the HIS, automatically classifies various nursing information, provides risk warnings and active reminders, performs structured handover extraction, optimizes the traditional methods of manual whiteboard recording and checking, aids rapid information retrieval, and enhances nursing quality and efficiency across all links, achieving interoperability of data among physicians, nurses, and patients.

Bedside care system

The bedside care system features display, communication, interaction, and alarm functions. Leveraging information technology, IoT platforms, and hardware terminals, it automatically updates and displays patient information, nursing labels, dietary status, high-risk monitoring warnings, *etc.*, improving the accuracy and accessibility of patient identity and key clinical information, assisting in the implementation of verification systems, and ensuring nursing safety. Based on AI technologies like speech recognition and natural language processing, it performs speech recognition, speech-to-text conversion, and semantic analysis on queries and consultation questions voiced by medical staff or patients, then matches search results within an established professional knowledge base, trains models using machine learning and deep learning techniques, and finally generates effective answers, facilitating quick queries by medical staff and patients, and allowing timely access to information including lab and examination reports, cost details, and health education.

Remote visitation system

The ICU remote visitation system fully utilizes audio and video transmission technology, using patient bedside interactive tablets and the hospital's inpatient service WeChat official account as a platform to enable remote video communication between ICU patients and their

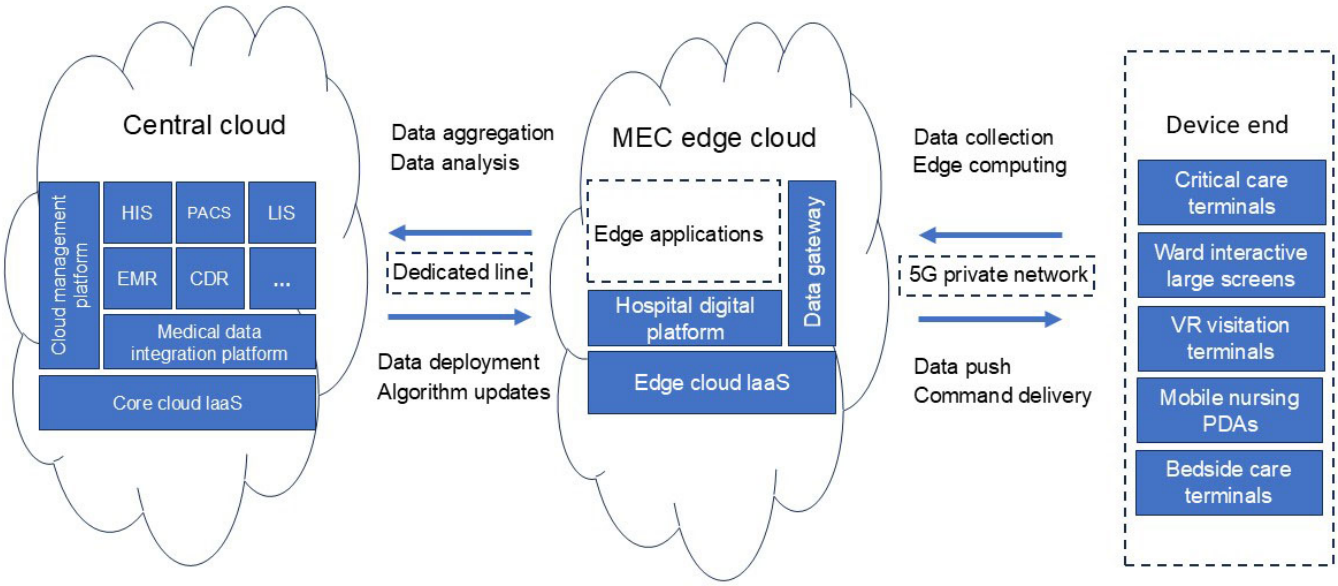

Figure 1. Logical architecture of 5G smart PICU integrated platform system. MEC: multi-access edge computing; PICU: pediatric intensive care unit; HIS: hospital information systems; LIS: laboratory information systems; PACS: picture archiving and communication systems; EMRs: electronic medical records; CDR: clinical data repository; PDA: personal digital assistants.

families. Considering the need for child companionship, the system incorporates Virtual Reality (VR) and 360-degree panoramic video technology, enabling bidirectional VR visits between parents and children, with 720-degree high-definition real-scene overlay. Leveraging the advantages of the 5G network, high-definition video data streams are pushed in real time from panoramic cameras in the ward to family members' mobile phones, tablets, or VR all-in-one machines, enabling remote, real-time, high-speed transmission of HD video images, avoiding blurry pictures or lag. This effectively enhances the practicality and realism of remote video visits, effectively comforting patients emotionally and reducing family members' psychological stress. Medical staff can also use this system to observe the patient's condition at any time, allowing for necessary emergency measures to be taken to ensure patient safety.

Real-time monitoring system for critically ill patients

The new-generation real-time monitoring system for critically ill patients supports stable connection of various vital sign devices within the same network. Utilizing the high-speed, low-latency network, it uniformly collects and processes in real time the vital sign data from various models of medical equipment connected to patients in the department, and uploads the collected data stably and rapidly to various service systems *via* the 5G network, continuously providing medical staff with real-time patient vital sign monitoring data, and breaking down the data barriers inherent in traditional hospital central monitoring systems limited by medical device brands and models. Furthermore, this system supports personalized configuration of vital sign collection items and critical value thresholds, enabling second-level alarms when patient vital signs exceed critical values. It also supports multi-screen display of hospital-wide nursing data, greatly improving nurses' work efficiency.

Consumables management system

The consumables management system uses Ultra-High Frequency Radio Frequency Identification (UHF RFID) technology tags to create a unique identity ID for each consumable item, establishing an IoT-based smart management model of "one object, one code." The smart consumables management cabinets help manage consumables inventory and usage efficiently, including automatic sensing and recording of inbound and outbound consumables. The system also automatically performs regular inventory checks of cabinets and generates reports. Intelligent alarms are issued for low stock or nearing expiration dates, ensuring safe inventory and usage. This system encompasses the management of all consumables (especially high-value consumables), making it particularly advantageous for PICUs, which typically have large quantities and wide varieties of consumables, and high manual verification and management costs.

After multiple rounds of platform debugging and optimization, this system has been put into clinical practice in the Children's ICU of the Third Affiliated Hospital of Sun Yat-sen University and has achieved

construction goals in five "dimensions".

CLINICAL APPLICATION EFFECTS OF 5G CLOUD-EDGE COLLABORATION COMBINED WITH AI SMART HEALTHCARE

Temperature—high-definition visitation system

Owing to the high bandwidth and low latency of the 5G network, the remote visitation system based on 5G + VR technology achieves real-time transmission of 4K video and audio. Simultaneously, combined with VR devices, the system adopts a 5G cloud-edge collaboration mode. By deploying the visitation service application on the edge cloud, it enables proximity computing and synthesis of multiple video streams. The innovative technology can reduce the delay of VR devices during visits to just 1 millisecond, which effectively solves the problems of poor VR device performance and slow processing speed, representing a new type of humanized medical service, enabling remote visitation without direct contact while ensuring infection prevention and control.

Width—device data collection

The real-time critical care monitoring system based on IoT technology uses RFID sensors to connect various terminal devices (such as ECG monitors, ventilators, EEG monitoring systems, continuous hemofiltration devices, bedside color ultrasound machines, *etc.*) to the internet according to predetermined protocols, achieving integrated collection and comprehensive management of multi-source heterogeneous data. Meanwhile, relying on the excellent communication, bandwidth capabilities, and precise positioning of the 5G network, it ensures the high-speed, stable transmission and immediate reporting of monitoring data. The system also features automatic abnormal data alert functions, effectively solving the problem of delayed synchronization of monitoring data caused by lack of coordination between devices in the past. This critical care monitoring system integrating 5G network and IoT technology provides an innovative monitoring solution for the medical field and promotes the development of the medical Internet of Things.

Speed—integrated processing of medical orders, nursing instructions, and patient services

The PICU ward utilizes 5G + bedside interactive tablets as terminal carriers, fully leveraging 5G accompanying private network to achieve an upgrade from mobile nursing to bedside nursing, enabling nurses to use interactive tablets at the bedside for key operations such as recording medical order execution and entering vital signs. The data can be instantly synchronized to various display terminals within the ward, significantly improving the efficiency of data entry and synchronization. Furthermore, the platform introduces AI risk warning functions, capable of providing alerts such as Modified Early Warning Score (MEWS) and Pediatric Early Warning Score (PEWS) alerts, risk assessment warnings, and high-risk medication (Level 3) warnings based on patient vital signs and treatment status. Simultaneously, due to the seamless switching between internal and external networks of the 5G accompanying private network, nurses can provide video-based education at the bedside interactive tablet, and patients can enjoy convenient internet-based hospitalization services such as smart ordering, IPTV, and online consultations provided on the bedside tablet. This comprehensive system greatly enhances the nursing quality in the PICU ward and the patient's medical experience.

Accuracy—whole-process consumables management

The consumables management system establishes a large-scale model for consumables data analysis in the central cloud, which is trained by deep learning techniques on data generated by the consumables management system, such as daily usage volume. The system generates consumables replenishment reminders and configuration suggestions based on clinical daily needs, thereby optimizing the hospital's consumables inventory and usage management model. Simultaneously, the system employs finger vein recognition modules to replace traditional fingerprint recognition modes, enhancing the security of consumables management. Based on vascular network patterns, finger vein recognition technology is more accurate and more difficult to forge, and exhibits stronger anti-interference capabilities.[7] For the management of psychoactive and narcotic drugs, the system uses finger vein recognition technology to ensure that only authorized medical professionals can dispense narcotic drugs, further enhancing the safety of the medication process. This innovative technology helps achieve full-process traceability for medium and high-value consumables while also reducing the hospital's comprehensive expenditure on consumables.

Precision—intelligent interactive auxiliary diagnosis management

The bedside round assistant, *via* the Uplink Classifier User Plane Function (ULCL UPF) gateway deployed in the hospital's server room through the 5G accompanying private network, enables real-time access to internal network service flows such as patient diagnosis, treatment, and monitoring data. Simultaneously, by connecting the ULCL UPF gateway to the public network service flow *via* the 5G accompanying

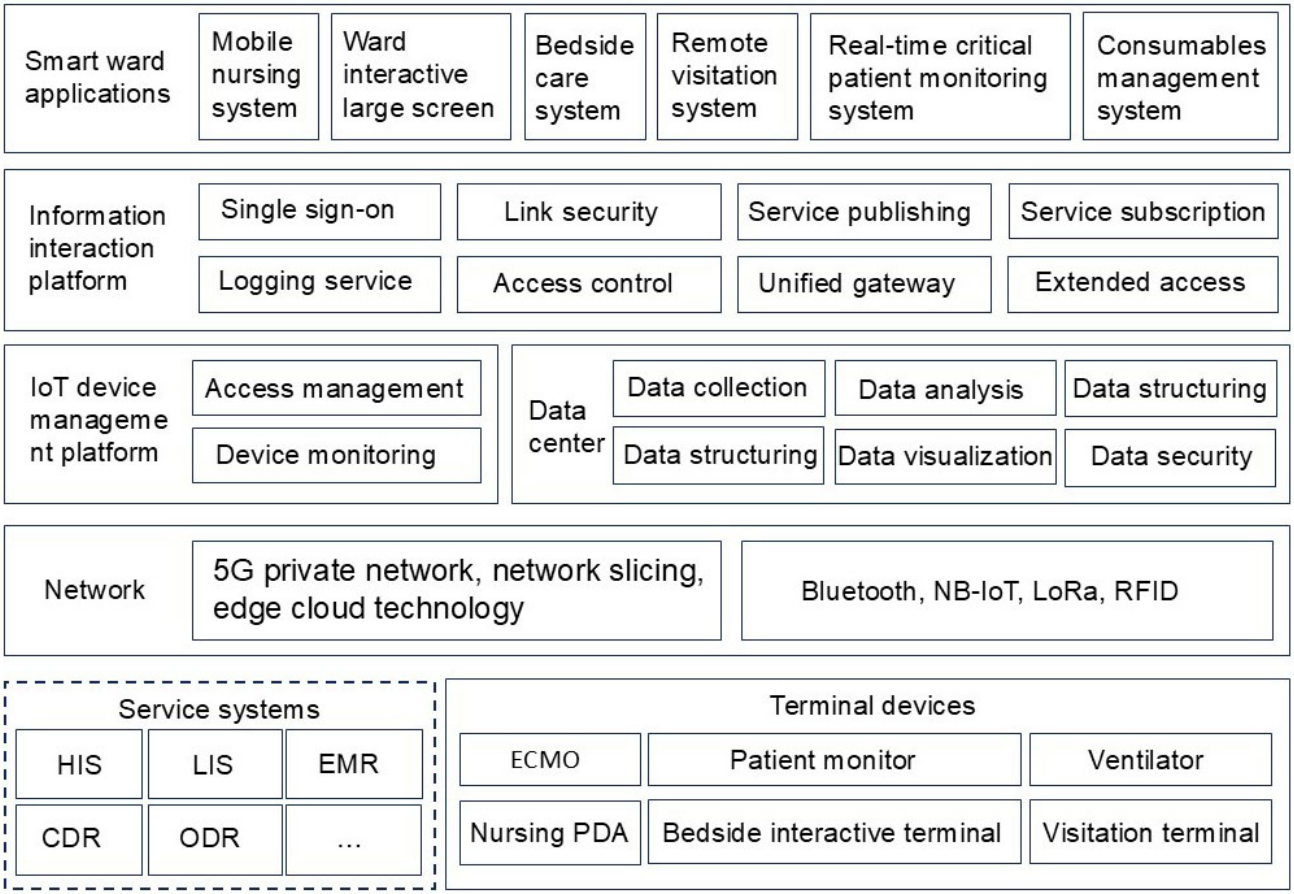

Figure 2. Schematic diagram of the overall architecture of the 5G smart PICU integrated platform. PICU: pediatric intensive care unit; HIS: hospital information systems; LIS: laboratory information systems; EMRs: electronic medical records; CDR: clinical data repository; ODR: operational data repository; ECMO: extracorporeal membrane oxygenation; PDA: personal digital assistants.

private network, it enables public-network video rounds among physicians, nurses and patients, addressing data security concerns on both internal and external networks. The AI Nurse builds a structured critical illness warning data model to intelligently extract data, including nursing documents and patient vital signs, from mobile nursing and patient critical care monitoring. The data, combined with matched search results from the hospital's nursing terminology knowledge base on the central cloud, can quickly generate risk warning prompts and diagnosis/treatment decision suggestions according to the disease stage, enhancing the precision of risk warnings and reducing the occurrence of adverse events.

DISCUSSION

The integrated platform, based on 5G cloud-edge collaboration and AI smart healthcare, adopts a loosely coupled, highly scalable, layered technical architecture, building a personalized smart service system tailored to the specific needs of the PICU ward, as shown in Figure 2. This system, centrally managed through the 5G private network gateway and combined with diverse IoT communication technologies such as Bluetooth, LoRa, and NB-IoT, effectively and securely completes the multi-modal data collection from various mainstream service systems and terminal devices within the hospital. Data is cleansed, integrated, mined and analyzed by the IoT management platform and data center, and then distributed to wards *via* an information interaction platform for clinical utilization and visual display, demonstrating great potential in optimizing healthcare workflows and enhancing the patient hospitalization experience.

In 2020, as part of our hospital's overall smart hospital construction, the Pediatric Intensive Care Unit, a key pilot department, conducted preliminary exploration into transforming the traditional PICU into a smart ward. Since 2022, it has been clinically implemented. The results of such a transformation can be summarized in three aspects. First, the department successfully achieved intelligent integrated management of multi-source heterogeneous data, structured extraction of medical record content, and introduced the "bedside round

assistant," allowing medical staff to review integrated data in real time, easily manage medical orders and nursing instructions, thereby reducing the burden on healthcare providers and improving the efficiency of clinical data analysis. Second, given that the department treats young but critically ill patients, a humanized VR remote visitation service was implemented. Surveys have shown that the incidence of Post-Traumatic Stress Disorder (PTSD) in children after PICU admission is approximately 5% to 28%, while the incidence of PTSD in parents after their child's PICU admission is about 10.5% to 21.0%.[8,9] Owing to the high bandwidth and low latency of 5G technology, VR technology integrating 4K panoramic video capture input, real-time network image transmission, and high-speed image stitching makes remote visitation possible.[10] Family members and children can have virtual face-to-face communication through VR technology, which not only avoids the risk of cross-infection but also provides emotional support, potentially reducing the chance of ICU-related syndromes (like PICS-Ped/f-PICS) in both families and children to some extent.[11] Furthermore, during the transition period when a critically ill child is about to be transferred from the PICU to the general ward, medical staff can use the VR remote visitation system to educate parents on the maintenance of specific tubes (such as tracheostomy tubes, central venous lines, urinary catheters, nasogastric tubes, *etc.*), which helps reduce the incidence of catheter-related infections and the risk of accidental catheter dislodgement. Third, in terms of department management, UHF RFID technology was applied to establish an intelligent consumables management system of "one object, one code" and "one object, one chip", which helps understand the department's consumables usage and needs clearly, formulate more accurate requisition plans, and avoid cases of insufficient or expired consumables, exerting a profound significance for standardizing the department's consumables management process and promoting the normalization of consumables management.

Currently, smart healthcare construction has become an important way to enhance hospital competitiveness and innovation, representing a new starting point for the hospital information revolution. As an emerging foundational technology, 5G not only supports the construction of existing hospital base networks and collaborative networks, but more importantly, opens up more application prospects for realizing patient-centered, smart healthcare throughout the entire health process. The department's children's intensive care unit successfully transformed into a 5G smart ward, achieving the transition from a traditional medical model to a smart healthcare model, which signifies a new step in exploring smart healthcare under the background of the new era of "Comprehensive National Health", and holds referential significance for the intelligent construction of other pediatric intensive care units.

DECLARATIONS

Author contributions

All authors conceived the idea and contributed to the final manuscript.

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Use of large language models, AI and machine learning tools

None declared.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interest

There is no conflict of interest among the authors.

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No additional data is available.

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