Application of Digital Circuits in Artificial Intelligence Medical Devices

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Abstract. In today's medical field, artificial intelligence medical devices have developed rapidly and have become an important part of the modern medical system. Digital circuit technology, as the cornerstone of modern electronic systems, is crucial in advancing artificial intelligence of medical devices. This paper first introduces the background of the research topic, emphasizing the importance of digital circuits in artificial intelligence medical devices. Then, the sub-topics of the paper are briefly introduced, including the application of digital circuits in signal processing, power consumption optimization and other applications in wearable medical devices, the role of improving the accuracy and efficiency of image analysis in medical image processing, and the application of improving device performance and medical service quality in medical device automation control. The research in this paper is of great value to promote the further development of artificial intelligence medical equipment and promote the intelligence and efficiency of the medical industry.

Keywords: Digital Circuits, Artificial Intelligence, Medical Devices.

1 Introduction

In the present-day medical landscape, artificial intelligence medical devices have witnessed remarkable growth and have emerged as an integral component of the modern medical system. Ranging from the early detection of diseases, formulating personalized treatment strategies, to the real time tracking of patients' health status, these devices have transformed the medical field with their high efficiency, precision, and intelligence. They've notably enhanced the quality and efficiency of medical services by rapidly processing and analyzing large volumes of complex medical data.

Being the cornerstone of modern electronic technology, digital circuit technology plays a pivotal role in the development of artificial intelligence medical devices. Following Moore's Law, digital circuits have advanced from basic logic gates to highly integrated systems. Meanwhile, operational speed has substantially increased, power consumption has decreased, and integration levels have significantly improved. These advancements have enabled the miniaturization, intelligence, and high-performance capabilities of artificial intelligence medical devices.

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Specific to different application scenarios, in terms of wearable medical devices, various sensors fabricated on flexible substrates through printing technology can monitor a variety of physiological indicators of the human body in real time, such as blood sugar, heart rate, and respiration [1]. These sensors work in conjunction with digital circuits to enable fast data processing and wireless transmission, providing a convenient way for health management. In the field of medical image processing, CPU, GPU, FPGA and other digital circuit hardware architectures play a key role in the real-time processing of medical images [2]. Different architectures show unique advantages in tasks such as image reconstruction, segmentation and analysis based on their specific strengths. In the field of automated medical equipment control, digital circuit technology is indispensable. For instance, ARM and FPGA-based electronic balance systems significantly enhance measurement accuracy and operational efficiency [3].

In summary, this paper explores the application of digital circuits in artificial intelligence medical devices. First, analyze the application of digital circuits in wearable medical devices in detail, covering signal processing, power consumption optimization, etc.; Secondly, study its role in medical image processing, such as improving the accuracy and efficiency of image analysis; Finally, analyze the application of digital circuits in medical device automation control, and its impact on improving device performance and medical service quality. These studies aim to provide valuable insights for advancing artificial intelligence medical devices and fostering a smarter, more efficient medical industry.

2 Digital Circuits in Artificial Intelligence Medical Devices

2.1 Application of Digital Circuits in Wearable Medical Devices

Wearable medical devices are becoming increasingly important in modern healthcare. They enable real-time and continuous monitoring of human physiological parameters, providing key data support for disease prevention and health management. With its unique advantages, digital circuit technology has become the core force driving the development of wearable medical devices, playing an indispensable role in signal processing, power consumption optimization and overall performance improvement of devices.

In terms of biological signal processing and power consumption optimization, Janwadkar et al. proposes an innovative ASIC design idea [4]. The design uses the 64-order digital low-pass FIR filter of the hybrid Vedic-Wallace tree multiplier, which is specially used for denoising the electrocardiogram (ECG) signal in cardiovascular health monitoring. Given the strict requirements of portable devices on power consumption and chip area, the researchers performed targeted optimization of the filter. Implementation on the Artix-7 FPGA demonstrated that the hybrid multiplier significantly reduces area and power consumption compared to traditional multipliers. In the subsequent ASIC implementation process, the SCL 180 nm technology was used to reduce the filter architecture by 16.38% and the power consumption by 79.58% compared with contemporary designs. This achievement makes the design very suitable for wearable cardiovascular health monitoring devices, providing a strong guarantee for accurate acquisition and analysis of ECG signals, and effectively improving the performance of wearable medical devices in biological signal processing.

From the typical wearable medical device processing flow shown in Figure 1, it can be seen that data collection, processing and transmission all consume a lot of energy [5]. Khan et al. focuses on how to use FPGA technology to improve the energy efficiency of wearable medical devices [5]. The article studies the low-power FPGA families produced by different manufacturers in detail and analyzes their potential advantages in wearable device applications. At the same time, it comprehensively summarizes the power optimization strategies at multiple levels, from algorithm design to data transmission to task scheduling. In algorithm design, arithmetic operations and parameter quantization are simplified to ensure accuracy while reducing power consumption. For example, replacing complex multiplication operations with simple shift and addition operations, such as replacing multiplication MAC with SAC operations mentioned in the literature, effectively reduces hardware complexity and power consumption [5]. In data transmission, technologies such as data compression, compressed sensing, and compressed learning are employed. These methods aim to reduce data transmission volume and energy consumption. In terms of task scheduling, strategies such as event-driven, duty cycle optimization and time-division multiplexing of hardware components are used to reduce unnecessary component activation time and further reduce overall power consumption.

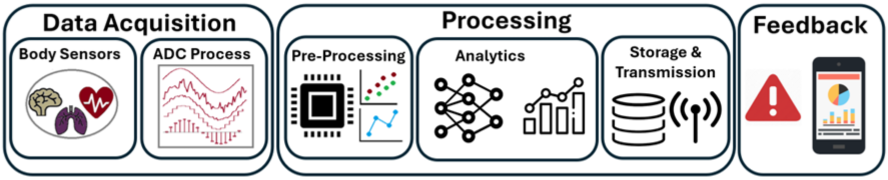

Fig. 1. Typical processes in wearable medical devices [5].

Ma et al. provides an in-depth review of the application of printed electronics technology in wearable health monitoring devices from the perspective of sensor and circuit design [6]. In the field of temperature sensors, a variety of materials are widely used in the fabrication of printed temperature sensors, among which PEDOT: PSS/CNTs composites show good performance. By optimizing the material composition and sensor structure, the performance of the sensor can be effectively improved. For example, in one study, the sensitivity of the prepared sensor was as high as 0.89%/° C after fine adjustment of the ratio of PEDOT: PSS and CNTs. Pressure sensors show varying characteristics based on their sensing principles. Capacitive pressure sensors often use the MIM structure, which is popular because of its simple structure and high sensitivity. Such sensors have been prepared in research to detect pressure up to 900 kPa, with a sensitivity of 0.34%/kPa. Piezoelectric pressure sensors can detect tiny dynamic pressures with the help of the piezoelectric properties of materials such as PVDF, such as the PVDF-based pressure sensor array in one study, which can generate a peak voltage output of 10-V. Strain sensors play a key role in monitoring human movement. Printed strain sensors are mostly based on the principle of resistance change and have characteristics of flexibility and stretchability. For example, a strain sensor based on a carbon nanotube/PDMS composite has a strain resolution of 0.038%, enabling precise monitoring of muscle movement and joint flexion. Biopotential electrodes are used to detect electrical signals from the human body, such as ECG signals. Compared with traditional wet Ag/AgCl electrodes, printed dry electrodes have many advantages. Dry electrodes based on MWCNT/PDMS composites do not require wet gels and have better fit and longer service life.

In addition, printed interface circuits are explored in this document. Printed interconnects and electrodes typically use Ag-based inks to reduce resistance, and their stretchability and reliability can be improved through specific design methods, such as the use of zigzag shapes. Printed thin film transistors (TFTs), although larger in channel length than commercial products, show potential for flexible circuit development. Printed antennas offer the possibility for wearable devices to achieve wireless communication, enabling devices to more conveniently interact with external devices for data.

From the typical TFT structures shown in Figure 2 (including "top-gate top-contact (TGTC), top-gate bottom-contact (TGBC), bottom-gate top-contact (BGTC), and bottom-gate bottom-contact (BGBC) "), it can be seen that different structures are suitable for different application scenarios, providing a variety of options to meet the diverse needs of wearable devices. For example, in some wearable devices with high requirements for signal transmission speed and stability, a specific TFT structure can better play its performance advantages. In practical applications, CNT-based TFTs prepared by Lee et al. on ITO-coated PET films in 2012 exhibit excellent effective mobility (43cm2/(Vs)) and a high current on/off ratio (≥ 104) [6].

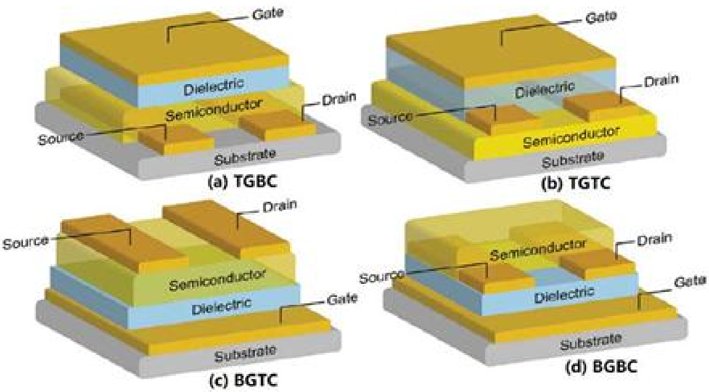

Fig. 2. Typical structures of TFT [6].

Printed TFT can also be used to build various related circuits, such as digital logic gates, analog amplifiers, and TFT arrays, etc., which greatly expands the functionality of wearable devices. Taking printed TFT-based digital circuits as an example, various logic functions, such as inverters, NAND gates, and NOR gates, can be realized through different circuit designs. These digital circuits play an important role in signal processing and control of wearable devices, enabling fast processing and analysis of sensor data. In terms of analog circuits, printed TFT-based amplification circuits can significantly improve the sensitivity of sensors and enhance the wearable device's ability to detect weak physiological signals.

In summary, digital circuit technology plays a vital role in wearable medical devices. It spans key aspects such as sensor signal processing, power consumption optimization, wireless communication, and multi-function integration. of the device. From their respective research perspectives, different literatures have provided rich technical solutions and theoretical support for the development of wearable medical devices, driving the continuous development of this field to meet the growing medical and health needs. In the future, with the continuous advancement of technology, digital circuit technology is expected to achieve more efficient and intelligent applications in wearable medical devices, bringing more convenience and protection to people's health management.

2.2 Application of Digital Circuits in Medical Image Processing

In the medical field, medical imaging plays a crucial role in the diagnosis and treatment of diseases. The development of digital circuit technology has brought new breakthroughs in medical image processing, significantly improving the accuracy and efficiency of image analysis.

In terms of breast cancer diagnosis, Panda et al. proposes a lightweight Deep Convolutional Neural Network (LWDCNN) based on Field Programmable Gate Array (FPGA) and Android devices [7]. Traditional ultrasound image-based automatic breast cancer diagnosis systems rely on cloud processing, which has problems such as high latency, continuous networking, and patient ultrasound image data privacy. The LWDCNN model designed in this study has only 1837 parameters. After training on Google Cloud CPU, it is deployed to FPGA and Android devices for inference. Experimental results on different databases show that its average accuracy in detecting malignant tumors on FPGA-based edge devices can reach 93.16%, and the accuracy on Android devices (INT8 quantization) is 93.76%. The inference time is only 6.44 seconds. Compared with other transfer learning techniques, it has higher accuracy and lower inference time and can realize real-time detection of breast cancer based on ultrasound images [7].

For the diagnosis of brain tumors, Gtifa et al. improved the accuracy of 3D MRI brain tumor segmentation by combining Particle Swarm Optimization (PSO) and Darwin Particle Swarm Optimization (DPSO) algorithms using Xilinx Virtex6 FPGA [8]. The study used Xilinx system generator to simplify FPGA hardware design, represent 3D images as matrices to reduce storage requirements, and adopt a parallel processing architecture to improve processing efficiency. Experiments on the BRATS 2021 and BRATS 2013 datasets show that the model can achieve a maximum accuracy of 99.9% under the DPSO algorithm, providing strong support for clinicians to diagnose brain tumors [8].

Another paper on brain tumor segmentation, “MRI – based brain tumor segmentation using FPGA – accelerated neural network”, propose a design of an FPGA-based brain tumor segmentation inference accelerator [9]. By quantizing and retraining neural networks, parameter size and computational complexity are reduced, and a pulsating array architecture is used to improve the processing speed of FPGAs. Test results on BraTS19 and BraTS20 datasets show that the accelerator is 5.21 times faster than the TITAN V GPU and 44.47 times faster than the Xeon CPU, respectively, while improving energy efficiency, providing an efficient solution for automatic segmentation and remote diagnosis of brain tumors [9].

These research results show that digital circuits have significant advantages in medical imaging processing, enabling more accurate and rapid disease diagnosis, providing important technical support for the development of the medical field. This is particularly evident in practical clinical applications, where fast and accurate diagnosis of breast cancer and brain tumors can help doctors formulate treatment plans in a timely manner, improving the cure rate and survival rate of patients.

2.3 Application of digital circuit in automated control of medical devices

In the field of medical equipment, the realization of automated control is of great significance for improving equipment performance and improving the quality of medical services. Digital circuit technology provides core support for the automated control of medical equipment, enabling medical equipment to operate more accurately and efficiently.

Wang et al. proposes a high-precision automatic acquisition and processing system for electronic balances based on ARM and FPGA, which aims to solve the problems of inaccurate measurement and low work efficiency in traditional flow testing [10]. In this system, the ARM processor is responsible for collecting the weight data of the electronic balance and managing the embedded system, and the FPGA generates high-precision time data through the internal Phase-Locked Loop (PLL). The clock pulse is phase shifted by PLL, and the time error is reduced to 1/N times of the original, which significantly improves the accuracy of Ultra-High Performance Liquid Chromatography (UHPLC) pump flow measurement. In terms of system connection, the CAN bus is used to realize the communication between the upper computer, the lower computer and the electronic balance, and the data transmission between the ARM and the FPGA is carried out through the parallel communication bus, which ensures the efficiency and reliability of data transmission [10].

Experimental verification shows that the system exhibits high precision and accuracy when testing the flow rate of UHPLC pumps. For example, in the test of flow rate of 0.4mL/min, the flow accuracy of the system reaches a high level, which has obvious advantages compared with traditional test methods and standard flow meters [10]. This system not only improves the core performance indicators of medical equipment (such as equipment involved in flow testing), but also reduces the labor intensity of testers, simplifies the test process, and improves work efficiency.

Digital circuits have enhanced the automation control of medical equipment, enabling more precise parameter control and data processing. This advancement ensures efficient and reliable medical operations. It has broad application prospects and important practical value in the medical field and helps to promote the development of the medical industry towards intelligence and automation.

3 Conclusion

This paper explores in depth the multi-faceted applications of digital circuits in artificial intelligence medical devices. In the field of wearable medical devices, digital circuit technology plays a key role ranging from biological signal processing and power consumption optimization to sensor and circuit design, improving the performance of the device and providing strong support for health management. In the field of medical image processing, related technologies realized by digital circuits, such as deep learning models based on FPGA, have substantially enhanced the accuracy and efficiency of disease diagnosis, providing critical support for clinical decision-making. In the automation control of medical devices, the system constructed based on digital circuit technology effectively improves the measurement accuracy and work efficiency of the device, and reduces the labor cost.

Looking to the future, with the continuous advancement of technology, the application of digital circuits in artificial intelligence medical devices will be more in-depth and extensive. On the one hand, wearable medical devices are anticipated to achieve more efficient data processing and analysis, along with enhanced multi-physiological parameter fusion monitoring capabilities, to provide more accurate and comprehensive services for personal health management. On the other hand, in the field of medical image processing and medical device automation control, digital circuit technology will be deeply integrated with emerging technologies such as the advancements in artificial intelligence algorithms and the application of new materials to further enhance the intelligence level of medical devices, help the medical industry to develop in a more efficient and intelligent direction, and make greater contributions to human health.

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