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Design and Implementation of Wireless Fetus Monitoring System Based on Non-standard Communication Protocol

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Abstract

The existing fetus monitoring system severely limits the space and time of maternal activities, which is not conducive to real-time network monitoring. In response to this shortcoming, this paper designs and implements a wireless fetus monitoring system based on a non-standard communication protocol. The system is designed based on the radio frequency chip CC1101 and non-standard communication protocol. Moreover, it uses dynamic channel selection and dynamic channel switching mechanisms, which can achieve an indoor single-hop coverage radius of 30 meters and network coverage from tens of meters to hundreds of meters. The results show that the wireless fetus monitoring system based on non-standard communication protocol meets the deployment requirements of the hospital's wireless fetus monitoring network, and has the advantages of strong anti-interference ability, large network capacity, high transmission rate, and good expansion performance.

Keywords

Fetus monitoring system, Monitoring network, Non-standard communication protocol.

1. Introduction

Reducing maternal mortality has long been the focus of global health and wellness, and is also one of the important goals of the UN Millennium Development Goals (MDG) [1, 2]. In 2017, approximately 295,000 women died during pregnancy and childbirth, and the vast majority of maternal deaths were avoidable [3]. Proper delivery monitoring through a fetus monitor can effectively prevent many pregnancy-related complications and is an important measure to reduce maternal mortality [4]. The fetus monitor is mainly used to monitor the fetus of the perinatal women in order to detect the intrauterine hypoxia and distress symptoms in time. Because traditional fetus monitors use a wired monitoring network to transmit data, it is easy for pregnant women to get out of monitoring when changing beds. For critical pregnant women, it is very likely that important monitoring information will be missed, which will indirectly lead to the death of the fetus and pregnant women.

In recent years, with the vigorous development of the Internet of Things (IoT), short-range wireless communication technologies based on standard protocols have been widely used in the field of mobile medical and healthcare, especially in personal health monitoring and chronic disease management [5]. However, in contrast, the technology has relatively few applications in the field of fetus monitoring. The wireless fetus monitor based on Bluetooth proposed by Bhong et al. [6] and the wireless fetus monitor based on ZigBee proposed by Goutam et al. [7] only solve the wireless of a single device and fail to realize the transmission of multi-device data. Roham et al. [8] proposed a fetus wireless monitoring system based on the combination of Bluetooth and wifi. Although it

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successfully achieved the remote transmission of Doppler data from the local to the cloud, the clinical performance of this system is not yet clear. It is limited by the special environment, of which the channel attenuation is so great that it leads to uncertain data transmission delay [9]. Zhang [10] et al. proposed a remote fetus monitoring system based on virtual instruments, which sent the collected fetus heart signals to PC devices and connected to the hospital service center through the gateway. This method greatly reduces the development cost of medical devices, but fetus monitoring performance and the range of maternal activities are limited by computer equipment. In general, the current main research focuses on the wireless design of a single fetus monitoring device based on the short-distance communication technology with standard protocols. It fails to fully meet the access requirements of a complex hospital environment with multiple device access, and fails to provide a complete wireless fetus monitoring system design.

In order to solve the shortcomings of the appealed wire and wireless fetus monitoring system, based on the existing short-range wireless communication technology, this study designed and implemented a wireless fetus monitoring system. Unlike the traditional single-channel communication mechanisms, the system uses dynamic channel selection and dynamic channel switching mechanisms, with higher network bandwidth and greater network capacity. The results show that the system can effectively solve the shortcomings of wire and wireless fetus monitoring systems in multi-device access, greatly improving the real-time fetus monitoring.

2. System Architecture

2.1 System Overview

This research designs a wireless fetus monitoring system based on non-standard communication protocol, which is composed of end device, router and coordinator. The end device is usually embedded in the fetus monitor as a wireless networking module, which is used to upload real-time data of the fetus monitor to the central monitoring station. The router is usually placed in the hospital corridor as a data forwarding module, which is responsible for forwarding the real-time data of the fetus monitor to the central monitoring station. As the initiator of the entire network, the coordinator is usually built into the central monitoring station and receives real-time data uploaded by the fetus monitor. Also, the system takes into account both wired and wireless connection methods. The overall structure of the system is shown in Figure 1.

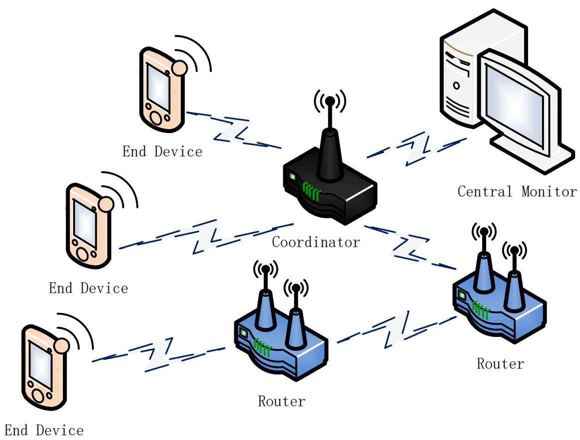

Figure 1. The overall structure of the system

2.2 Non-standard Communication Protocol

In this system, the end device, router and coordinator all work on a non-standard communication protocol. This section specifically defines the main content of the protocol's network structure and network topology.

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2.2.1 Network Structure

According to the OSI model, the wireless monitoring network is divided into 4 layers, including the Physical Layer (PHL), Media Access Control Layer (MAC), Network Layer (NWK) and Application Layer (APL), see Figure 2. PHL is composed of half-duplex wireless transceiver and its interface, which directly transmit data via wireless channel. The operating frequency of PHL is 407-425 MHz. The MAC provides a reliable data transmission link between the node itself and its neighbors. Its main task is to share transmission media and improve the effectiveness of communication. In order to implement and maintain star and tree networks, NWK utilizes reliable data communication at the MAC layer to provide routing and multi-hop forwarding capabilities. The task of APS is to forward network information to different applications running on the nodes.

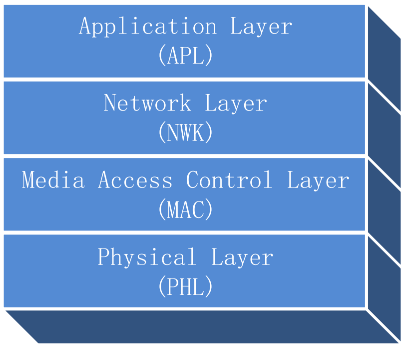

Figure 2. The structure of the network

2.2.2 Network Topology

The wireless monitoring network supports a star topology and a tree topology. The devices involved include end devices, routers, and coordinators. The router has two wireless transceivers, which can serve as both parent and child nodes; it has the following functions: data storage and forwarding, route discovery, connection and disconnection of child devices, maintenance of routing tables, etc. The coordinator has only one wireless transceiver, which can only serve as the parent node at the top layer of the network; in addition to completing some functions of the router, it is also responsible for formulating network rules, channel allocation, network startup, etc. The end device also has only one wireless transceiver, which can only be used as a child node to access the parent node, and only needs to be responsible for data reception and transmission.

2.3 End Device

Because the end device requires less peripheral resources, the main control MCU selects TI's ARM Cortex-M3 series LM3S610. On the one hand, the MCU communicates with the fetus monitor through the serial port; on the other hand, it expands the wireless transceiver CC1101 through the SSI port for wireless networking. In addition, an interactive interface for operating buttons and status displays is provided, see Figure 3.

Figure 3. The structure of end device

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2.4 Router

The router requires more peripheral resources, so the main control MCU chooses the LM3S6950 of TI's ARM Cortex-M3 series. The router includes two wireless transceivers CC1101. The first transceiver is extended as a parent node through the SSI0 port, allowing end devices or routers to access the wireless network; the other transceiver is extended as a child node through the SSI1 port, allowing access to the wireless network through a router or coordinator. And, the router supports RS485 communication and Ethernet communication. Similarly, an interactive interface for operating keys and status displays is also provided, see Figure 4.

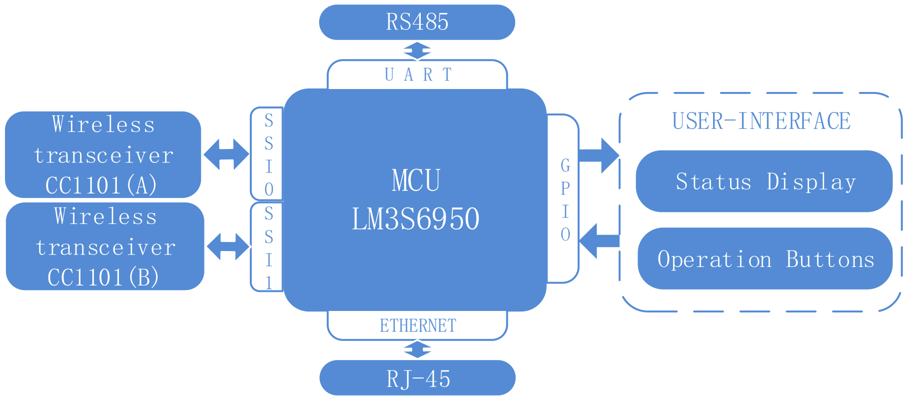

Figure 4. The structure of router

2.5 Coordinator

The main control MCU of the coordinator selects TI's LM3S6950 of ARM Cortex-M3 series. In the design of the coordinator, a compatible design with the hardware of the router is adopted, and only one wireless transceiver CC1101 is expanded than the router, see Figure 5.

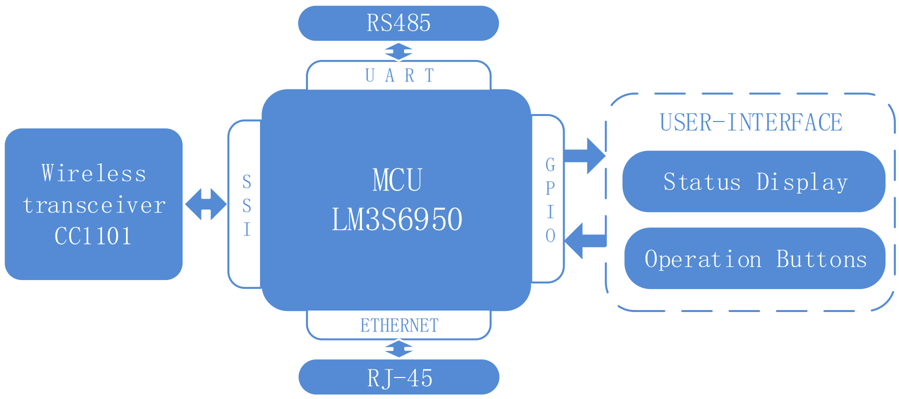

Figure 5. The structure of coordinator

2.6 Multi-channel Network

Considering the anti-interference ability and environmental adaptability of the system, this system adopts dynamic channel selection and switching mechanism. After the power-on initialization of the network device is completed, a channel scan is performed to detect the availability of all working channels. Next, when registering to access the network, the list of available channels is submitted to the parent node, which arbitrates and selects a suitable channel. Due to the dynamic channel selection mechanism, multiple sets of multi-channel wireless monitoring networks are independent of each other and do not interfere with each other. When the wireless monitoring network is interfered on the working channel, the interfered network device re-scans the channel, and submits the scan result to the parent node. According to the scan result, the parent node reselects the new working channel. Due to the use of a dynamic channel switching mechanism, the wireless network has a strong anti-interference ability.

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3. System Peformance

3.1 Communication Distance

Achieving point-to-point communication between the coordinator and end device to test the communication distance. The basic transmit power is set to 10 dBm. The barrier condition is set to wall barrier or door barrier with pedestrian interference. By adjusting the distance between the coordinator and the end device, test the loss rate of the test data packet under the conditions of line-of-sight and obstruction. After repeated tests, under line-of-sight conditions and without packet loss, the reliable communication distance is about 80 meters; under obstructed conditions, the reliable communication distance is about 30 meters.

3.2 Network Coverage

Network coverage performance includes star network and tree network. The coverage of the star network is tested by using a coordinator and multiple end devices. Under the condition of transmitting power of 10 dBm, the coordinator can cover end devices within a radius of 35 meters. The test of the tree network is divided into two parts. The first part consists of 1 coordinator, 1 router and multiple end devices. Under the condition of transmitting power of 10 dBm, the entire network coverage can reach 50 meters without the effect of network expansion. The second part consists of 1 coordinator, 4 routers and multiple end devices. Under the condition of 10 dBm transmission power, the entire network coverage can reach 100 meters without the effect of network expansion.

3.3 Network Rate

Use the coordinator and end device to achieve point-to-point communication to test the network rate of the system. The basic test conditions are set as follows: the distance between the coordinator and the end device is 15 meters, the transmission power is 10 dBm, and the data packet length is 100 B. After repeated tests, the effective data transmission rate of the network is about 75 kbps, which reaches 75% of the data transmission rate of the wireless network physical layer 100 kbps.

3.4 Adjacent Channel Interference

Achieving point-to-point communication between the coordinator and end device to test the degree of impact on adjacent channel interference. In the test, another end device, of which transmission power is 10 dBm, is used as the interference source by continuously transmitting data on the adjacent channel. After repeated tests, when the interference source is within 10 cm of the coordinator and end device, the coordinator and end device cannot communicate normally. However, when the distance is extended to 20 cm, the interference source has no effect on the normal communication between the coordinator and end device.

3.5 Channel Selection and Switching

In order to test channel selection and switching performance, a star network composed of a coordinator and multiple end devices is set within a range of 10 meters. In the test, the end device that continuously sends data is used as the source of interference. After repeated testing, the coordinator can detect the interference source channel and achieve channel selection during channel scanning; and after a period of normal operation, when another interference source is added within 10 meters, the network can automatically detect channel interference and complete the channel switching.

4. Conclusion

The current fetus monitoring system has several issues. On the one hand, due to the constraints of wired fetus monitoring cables, maternal activity space and time are severely disturbed. On the other hand, the wireless fetus monitoring system proposed by a large number of researchers fails to meet the deployment requirements of complex hospital environments with multiple device access. The proposed wireless fetus system based on non-standard communication protocol takes into account the needs of wireless fetus monitoring and stable access to multiple devices. The system adopts multi-

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channel working mode. While the network coverage is expanded, it can maintain high network performance and can support hundreds of monitors online at the same time, which effectively solves many issues faced by single-channel wireless networks. In general, the proposed system has the characteristics of strong anti-interference ability, large network capacity, high transmission rate, and good expansion performance.

Acknowledgments

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