Architecture of embedded intelligent video analysis system for forest fire prevention

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Abstract. Forest fire has always been an important hidden danger in forestry management. It is necessary to monitor and manage forest fire through video monitoring system. However, due to the lack of real-time performance of traditional video monitoring system and the difficulty in data processing, an embedded intelligent video analysis system is designed. The system uses a software and hardware design method based on Zynq SoC, first, each functional module of the hardware architecture is divided, then the system software is designed, and finally the system is evaluated as a whole. Based on the application requirements of forest fire prevention, this paper focuses on the detailed description of the underlying hardware architecture and operating system software design, and provides some value and reference for the application scenarios of forest fire prevention.

1. Introduction

Today, forest fires have become increasingly serious, in the face of complex forest environment, the occurrence of forest fires is uncertain and random. Once an unpredictable fire occurs, the consequences will be disastrous. Forest fires will not only cause huge damage to forest trees, but also have a bad impact on the living environment of animals, and even cause a huge impact on human society[1]. However, traditional monitoring systems can only monitor and cannot provide early warning. When a forest fire occurs, monitoring video data can be retrieved for analysis, but this has caused a huge disaster and cannot prevent the fire from the source. In addition, the amount of video data generated by video monitoring equipment is huge, so it is not easy to analyze the video data, which wastes a lot of time and financial resources, and the cause of fire cannot be concluded in real time. For the above problems, real-time monitoring and early warning of forest fires are particularly important[2]. Aiming at the problems of poor real-time performance and complex data processing in traditional monitoring systems, an embedded intelligent video analysis system based on forest fire prevention is designed. The system uses the Zynq SoC based on ARM + FPGA architecture as the core of the hardware processor, which can greatly enhance the system's processing and analysis capabilities, integrate more functional expansion interfaces, and meet the needs of different functions[3]. The artificial intelligence analysis module integrated in the system can monitor the recognition of the fire situation in real time[4], including smoke recognition, flame recognition, face detection and recognition, etc. According to different recognition results, the embedded intelligent video analysis system can carry out different voice broadcasts and alarms for dangerous situations,
which solves the problem that general voice alarm or voice broadcast can only send a monotonous or single voice function. Next the system uploads the danger signal data and the characteristic information data of the arsonist to the cloud analysis platform through the wireless network. After the platform receives the information, the staff will locate the location of the forest fire, deal with the dangerous situation, and criticize the suspected arsonists, and even arrest them, so as to prevent the occurrence of the fire. In addition, multiple fire monitoring points are arranged throughout the forest, so that once a fire breaks out, the scope of the fire can be predicted in real time, and the movement trajectory of arsonists can be tracked in real time. If necessary, the arsonists can be arrested, so as to predict the occurrence of forest fires. This system can not only solve the problem of non-intelligent video surveillance system, but also prevent the occurrence of forest fires from the source, and send out early warning information in the fastest way to help firefighters deal with the fire crisis.

2. System requirements analysis
The embedded intelligent video analysis system is mainly used in the application scenarios of forest fire prevention. Multiple embedded intelligent video analysis systems are built in the forest environment to achieve the prevention and early warning function of forest fires. The artificial intelligence analysis module integrated in the system has the functions of face detection and recognition, people counting and pedestrian trajectory, and also has intelligent analysis functions of fire situations such as flame recognition and smoke recognition. Considering the poor signal of 4G wireless network in the forest environment, the intelligent monitoring information is uploaded to the cloud server platform in the form of LoRa wireless network transmission. The structural diagram of the whole Internet of things system for forest fire prevention is shown in Figure 1. It can be seen that the embedded intelligent video analysis system plays an important role, mainly responsible for collecting camera video data, intelligently analyzing the video data, and transmitting the analysis results to the LoRa gateway transmission system. Once the system analyzes and recognizes the fire and smoke, it will immediately alert the fire danger through voice broadcast, and send out a timely fire extinguishing or evacuation signal to nearby people, which not only eliminates the fire risk from the source, but also timely extinguishes the forest area that has already occurred the fire risk to reduce the loss.

3. Hardware architecture and design
The hardware architecture of embedded intelligent video analysis system consists of three parts: core board, mother board and artificial intelligence analysis module. In addition, the system also provides a large number of peripheral interfaces to meet the needs of the system. Among them, the core board is based on Xilinx Zynq-7000 All Programmable SoC (AP SoC) as the main control chip, and Zynq SoC adopts the architecture of ARM + FPGA, and internally combines arm dual core A9 processing system.
(PS) and programmable logic (PL)[5]. The core board expands the storage unit to ensure the normal operation of the system and the need for system file access. In addition, the core board also expands some functional interfaces. The mother board has expanded some functional modules and interfaces of the system, such as Ethernet switch controller module, audio module and interface, BT.1120 interface for video stream data and UART interface, RS232 interface for information transmission, and status indication and sensor interfaces. The artificial intelligence analysis module integrates some deep learning algorithms to complete the intelligent analysis of video stream data. The data need to be input through the BT.1120 interface on the mother board. The hardware architecture block diagram is shown in Figure 2.

![Figure 2. Hardware system architecture](image)

3.1. Design development environment
The Xilinx Vivado design suite provides users with a large number of IP cores[6], and users can easily design hardware engineering with more powerful and convenient operation. The Xilinx Vivado High-Level Synthesis (HLS) is a high-level synthesis tool that directly introduces C, C++, and System C specifications into Xilinx programmable devices, enabling system and design architects to create IP more quickly[7]. In this chapter, we will use these two design tools to create hardware environment and design IP cores.

3.2. Ethernet switch controller module
The Ethernet switch controller module supports a 5-port 10/100M adaptive ethernet interface. According to the application requirements of the system for forest fire prevention, the module expands three external RJ45 Ethernet interfaces, two of which are used to access the video data of the IP cameras, and the other is connected to the Gigabit Ethernet interface of the core board, so that the core board processor can process the video stream data in real time. The module needs an external passive crystal oscillator to provide external clock for the switch controller chip to ensure the normal operation of the module.

3.3. USB hub module
The USB hub module provides a maximum of 4 USB interfaces. The module is connected to the core board's USB OTG controller chip and two external USB ports are expanded and the SD card reader chip is provided for connection. The SD card reader chip supports USB 2.0 high-speed transmission, which can be used for SD card interface. The SD card is used for the following purposes: first, the
amount of data stored is not large, and the SD card mainly stores a small part of video stream data, intelligent analysis data, as well as the log records and sensor data of the working state of the system, etc.; Second, the SD card occupies less space and is more convenient for plugging and unplugging. In addition, the extended two USB ports are reserved for use, and external devices such as hard disks, WiFi modules with USB interfaces can be connected to meet more functional requirements.

3.4. Audio module

3.4.1. Function description. Voice broadcast plays an important role in forest fire prevention. General voice alarms or voice broadcasts can only emit monotonic or single voice functions. The audio module of the system can broadcast different voice according to the results of some intelligent analysis or sensor data, and realize various functions. It implements different voice broadcast functions and realizes various functions. It implements different voice broadcast functions, realizing various functions.

The audio module has two functional requirements in forest fire prevention. The first is that when the system intelligently detects forest fire danger, it can send out alarm voice messages as soon as possible to remind field personnel to find dangerous situations and deal with them in time to achieve the root cause. Second, when the fire danger situation has occurred, the wide range of audio sound and clear sound quality can be used to remind people at the scene and nearby to stay away from the danger zone of fire, to avoid personal injury and property loss. Combined with the temperature sensor and infrared sensor, more functions of voice broadcast can be realized.

3.4.2. Audio module design. The audio module chip adopts the ADAU1761 stereo audio codec chip provided by Analog Devices Inc. The chip supports stereo 48 kHz recording and playback with low power consumption. The ADAU1761 chip has two control ports and supports the I2S data transmission format. The chip acts as a slave device on the I2C bus, transmitting information between the I2C master controller and the ADAU1761 chip. Each slave device on the I2C bus has a unique address[8]. The address of the ADAU1761 on the I2C bus and the I2C read-write bit format are shown in table 1.

| Bit 0 | Bit 1 | Bit 2 | Bit 3 | Bit 4 | Bit 5 | Bit 6 | Bit 7 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0     | 1     | 1     | 1     | 0     | ADDR1 | ADDR0 | R/W   |

the address of the ADAU1761 slave device depends on the pin settings of ADDR1 and ADDR0. and the comparison of ADDR1 and ADDR0 logical values is shown in table 2. In this hardware design, we set ADDR1 to 1 and ADDR0 to 1, that is, ADAU1761 device is mounted on I2C bus with address 0x3b.

| ADDR1 | ADDR0 | I2C Device ID |
|-------|-------|---------------|
| 0     | 0     | 0x38          |
| 0     | 1     | 0x39          |
| 1     | 0     | 0x3a          |
| 1     | 1     | 0x3b          |
In audio hardware design, I2S data format is used for input and output processing of audio stream data. I2S IP core implements the audio data storage function and provides different types of clock signals for the ADAU1761, which are connected to the corresponding clock pins of the ADAU1761 through constraint configuration. The user-defined I2S data IP core is shown in figure 3. The hardware design of audio module is the basis of voice broadcast and the audio module is an important functional requirement in the application of forest fire prevention.

3.5. Framebuffer video streaming design

The system obtains 1920x1080 25fps frame rate video stream data from the IP cameras, decodes and transcodes the video data in the memory DDR, and then reads the processed video stream data through the VDMA IP core[9], and finally output the processed video data through the BT.1120 interface. The artificial intelligence analysis module will receive the data and performs intelligent analysis. The process of video data processing and packaging is shown in figure 4.

Video Framebuffer design uses the VDMA IP core provided by Vivado tool. The VDMA IP core provides high-level storage access for video streaming data, which can efficiently implement data access. For this system, a large amount of video streaming data of the cameras needs to be processed, and the data needs to be decoded and transcoded. Three AXI VDMA IP cores are configured through the Xilinx Vivado tool for video streaming data acquisition and accelerate decoding processing, and then the video data needs to be transcoded through the YUV IP core of the custom design.

The hardware interface of the BT.1120 protocol is a 16-bit data pins and a 1-bit clock pin. In terms of hardware design, the user needs to design the IP core of BT.1120 protocol and the IP core of BT.1120 output interface. The BT.1120 protocol IP core is designed and implemented using the Vivado High-Level Synthesis tool provided by Xilinx Inc. It is designed using the C language and finally packaged into an IP core engineering file. The BT.1120 interface IP core is directly packaged and generated using Vivado tools and designed using Verilog HDL language. The interface IP core mainly outputs the data processed by the BT.1120 protocol IP core. It is connected to the artificial intelligence analysis module. The intelligent analysis module needs to provide an external clock. Therefore, the interface IP core also provides a standard external clock to meet the normal data analysis function of the intelligent analysis module.

3.6. Artificial intelligence analysis module

The artificial intelligence analysis module is a deep learning acceleration module for processed video data analysis. The relevant interfaces provided by this module are BT.1120 interface, which is mainly used to receive video stream data, UART interface, which is mainly used for data transmission, and SPI interface, which is mainly used to receive module software upgrade files, as well as other power supply interfaces, reset pin and GPIO interfaces. The system uses the artificial intelligence analysis
module as the main video intelligent processing module. In the application of forest fire prevention, it can intelligently analyze the fire situation and detect the characteristic information of arsonists.

4. System software design

The software design of the embedded intelligent video analysis system mainly uses the Petalinux tool provided by Xilinx as the system software development tool. Petalinux tool mainly provides everything needed to customize, build and deploy embedded Linux solutions on Xilinx processing systems. Using the development tool provides convenience for porting embedded operating systems. In addition, development designers can customize boot load programs, Linux kernels, or Linux applications, and new kernels, device drivers, applications, and libraries can be added to the physical hardware over the network or JTAG[10]. The system is designed according to different functional modules to meet the application requirements of the system.

4.1. Generate a hardware description file

Before using Petalinux tools to create a project, a system hardware description file is required. A hardware platform can be created through Vivado tools. The hardware platform mainly contains the hardware IP core and constraint files, and how to configure the hardware system [10]. Finally, The hardware platform generate bitstream data and import the required hardware description file (.hdf file).

4.2. Create Petalinux project

Based on the hardware description file generated in the previous section, Petalinux tool can be used to create a Petalinux project. Petalinux tool integrates a large number of components, including Xilinx embedded processing IP core, kernel and boot loader configuration, file system, libraries and system parameters, etc. In addition, users can customize design drivers, applications, and optional libraries. In the system Petalinux development process, we need to configure U-boot, Linux kernel configuration, device tree configuration, custom libraries and applications, file system configuration, etc. These configuration operations can be performed through the graphical interface and command line. It greatly reduces the development tasks and speeds up the development of system software.

4.3. Generate system files

The final system files of BOOT.bin and image.ub can be obtained by building system image and generating the boot image command through the petalinux project. The BOOT.bin file is the system boot image file. The boot image file usually contains the first stage bootloader image, the FPGA bitstream, and the u-boot file. The BOOT.bin file of this system is put into Quad SPIFlash, or it can be put into SD card or other storage media. After the system is powered on, the image file is automatically loaded. The image.ub file contains the Linux kernel, file system and device tree. Because the image.ub file is large, the system will put the file into the SD card mass storage media, and set to load the image file from the SD card boot. After the system starts, the script in the file system will be loaded to initialize the application configuration file or to run the application file automatically.

5. System evaluation and application

After the embedded intelligent video analysis system is powered on, the processor will automatically read the BOOT.bin file stored in the Quad SPIFlash, load the image.ub file stored in the e.MMC directory into the memory, and then start the script file in the file system. The script file performs the system initialization configuration and important system applications that need to be started.

The embedded intelligent video analysis system is mainly applied in the aspect of forest fire prevention. Facing the complex environmental factors of forest, this system can basically realize the demand of forest fire prevention. Monitoring points are arranged at important intersections of forest environment, which can obtain environmental data in real time, analyze the facial and physical characteristics of people in the environment, monitor the dangerous situations of smoke and fireworks
in the forest. The system integrates the function of voice broadcast. It can not only send out the alarm sound of warning in dangerous situation, but also broadcast the specific situation information of the scene through voice, which can remind the field personnel to deal with it in time, so as to prevent the occurrence of dangerous situation from the root cause. In addition, for the situation of fire, the system will upload the abnormal situation of the scene in time, so as to mobilize the staff to take emergency measures.

6. Conclusion
The embedded intelligent video analysis system plays a key role in the whole fire protection Internet of things. In view of the shortage of real-time and data processing in traditional monitoring system, which requires a large amount of manpower, this system can realize intelligent prevention of forest fire and intelligent scheduling and processing after a fire. The paper introduces the hardware architecture and operating system software of the embedded intelligent video analysis system for forest fire prevention in detail. This system chooses Xilinx’s Zynq-7000 FPGA main control chip, which can meet the above requirements. Based on the existing hardware resources, the development of the application program can meet the application requirements more richly. In short, the embedded intelligent video analysis system has a wider application value, which provides an important reference value for the realization of intelligent video monitoring of forest fire prevention. The system may also have data transmission security problems, which need further research and experiments.

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