A Novel IoT Access Architecture for Vehicle Monitoring System

Shulong Wang[1, 2], Yibin Hou[*1, 2], Fang Gao[1, 2] and Xinrong Ji[1, 2]
[1]Beijing Advanced Innovation Center for Future Internet Technology
[2]Beijing Engineering Research Center for IoT Software and Systems
Beijing University of Technology
Beijing, China
wangshulong@emails.bjut.edu.cn, ybhou@bjut.edu.cn,
{gaofang, jixinrong}@emails.bjut.edu.cn

***Abstract*—The Internet of Things (IoT) is becoming increasingly important for traffic monitoring, medical treatment and other industrial applications. With the continuous development of the IoT, more and more "things" will be able to access to the IoT. Considering a large number of heterogeneous "things", how to provide a unified access mechanism to the IoT is a fundamental and key issue. In this paper, we propose a novel IoT access architecture based on field programmable gate array (FPGA) and system on chip (SoC), which can provide a unified access to the IoT for a wide variety of low-speed and high-speed devices with associated extendibility and configurability. We have adopted IEEE1451.2 standard for this design and applied the proposed design to vehicle monitoring system. The results indicate that the system can provide good performance in practical application.**

***Index Terms*—FPGA, IoT, SoC, Vehicle Monitoring.**

I. Introduction

The Internet of Things (IoT) is an emerging technology which was first proposed to study RFID by Ashton, Professor of the MIT Auto-ID Center in 1999. IoT is a major drive to support service composition with various applications. It enables objects surrounding us with the ability to communicate each other through the Internet. The popular architecture of IoT is illustrated in Fig. 1. It consists of three layers: perception layer, network layer and application layer. Sensors, Actuators, RFID tags and other smart terminals are connected to the IoT from the perception layer. Network layer is responsible for the communication between "things" and human beings. Abundant applications are provided by the application layer [1] [2].

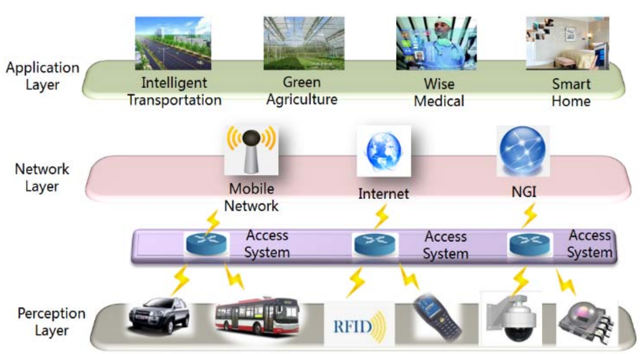

Fig. 1. Three-layer architecture of IoT.

Compared to traditional Internet, IoT mainly enables "things" to communicate with each other. Since the number of "things" is large and heterogeneous in nature, how to provide unified access to the IoT for various "things" is the fundamental and key issue for IoT applications [3].

At present, there are a lot of systems and interface equipment on the market. However, most of them work in specialized environment and could only access a very limited number of devices with specialized interfaces. To address this problem, we design and implement a novel IoT access architecture for various IoT devices. On one side, IEEE 1451.2 is adopted to support various sensors, actuators and transducers for data acquisition [4]. On the other side, we implement this design with FPGA and SoC technologies, which can make the entire system easily reconfigurable while consuming low power.

The rest of this paper is organized as follow. The proposed architecture is presented in Section II and the application in vehicle monitoring is described in details in Section III. Performance evaluation is discussed in Section IV. Finally, we conclude our work in Section V.

II. Proposed architecture

We propose a novel architecture for "things" to access the IoT. The architecture supports data acquisition, processing, storage and transmission functions for all kinds of devices and equipment under the IoT environment. This design can be widely used in different areas in the IoT environment for real-time monitoring, environmental data acquisition and equipment control.

In this design, we have adopted IEEE1451.2 standard as the reference to access multiple sensors, actuators and transducers. The standard stipulates a series of specifications from sensor interface definition to the data acquisition [5] [6]. In order to reduce the consumption of system hardware resources, we have adopted FPGA to implement the whole system. A variety of specific IP cores are designed and incorporated in this design. Meanwhile, under the coordination of SoC technology, the main module of the system is implemented on a single FPGA chip.

978-1-5090-4130-5/16/$31.00 ©2016 IEEE

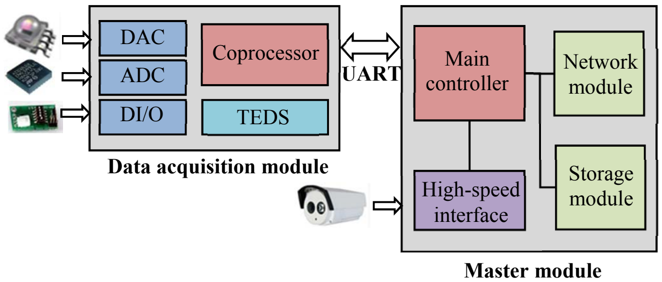

Fig. 2. Architecture overview.

As shown in Fig. 2, the system is mainly divided into two main parts: master module and data acquisition module, and the two modules communicate through the universal asynchronous receiver/transmitter (UART) interface. The data acquisition module is responsible for accessing multiple sensors and collecting environmental information. It can support both analog and digital signal inputs through analog-to-digital converter (ADC) and digital-to-analog converter (DAC). A coprocessor is implemented with IP core conducts control and signal disposal of the whole module. According to IEEE1451.2 standard, transducer electronic data sheet (TEDS) is used to describe the type, operation and attributes of sensors, actuators and transducers, which is implemented and stored in block RAM (BRAM) in this design [7]. As the major unit of the whole system, the master module provides other core functions: network communication, local storage, etc. Besides, the master module provides interfaces to access those high-speed devices such as digital camera. An ARM Cortex processor is adopted as the main controller with high performance, reliability and stability.

With this design, the system can access various kinds of sensors, actuators and other high-speed devices in IoT environment. The specifically designed data acquisition module undertakes data acquisition tasks, which enables the master module focus on the complex tasks such as network communication and local storage.

III. Application in Vehicle Monitoring

With the technology development, “intelligent traffic” has become an indispensable part of people’s lives. Although there are various similar products on the market, they generally lack generalization, expandability and reusability [9] [10]. In this paper, we design and implement a novel and intelligent vehicle monitoring system based on the proposed architecture. The typical application scenario is shown in Fig. 3. As the core unit of the whole system, the vehicle monitoring terminal collects a variety of environmental information such as video information, environment information and position information in real time, and further transmits the processed-data to the server through 4G. Users could easily access the multiple information via the client system.

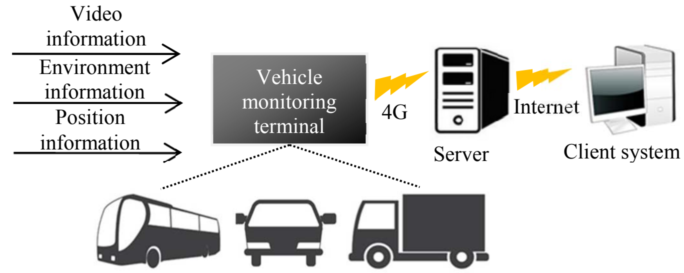

Fig. 3. Application scenario for vehicle monitoring.

A. The Introduction of the Hardware Architecture

The overall structure of hardware system is based on the Xilinx zynq-7000 SoC chip which integrates a feature-rich dual-core ARM Cortex-A9 MPCore based processing system (PS) and Xilinx programmable logic (PL). Beside the ARM processor, PS also contains on-chip memory, external memory interfaces, and a rich set of I/O peripherals. The PL consists of abundant FPGA logic resources which could be configured to different kinds of devices and interfaces [8]. In this application, we adopt MicroBlaze IP core as the coprocessor which is completely generated by FPGA resources with low-power and high performance. A UART interface is implemented for communication between ARM processor and coprocessor. Besides, the power supply and DDR are also supported on the board. Fig. 4 shows the hardware block diagram.

We use on board 12-bit ADC to support up to 17 external analog input channels. Sensors with analog signal output can access the system with the ADC. For those digital sensors, we adopt customized FPGA IP cores to implement different types of digital signal interfaces, such as UART, GPIO, IIC, etc. In this application, we designed and implemented two GPIO interfaces for temperature and humidity sensors as well as a UART interface for GPS module. In addition, a 64KB BRAM is implemented by FPGA resources for TEDS storage.

Taking full use of ARM rich I/O peripherals, we directly take the USB and Ethernet as a set of high-speed interfaces. In this application, digital cameras are connected to the board via Ethernet interface. Similarly, with connection to 4G module or Wi-Fi module through USB interface, the system could access the network over the air.

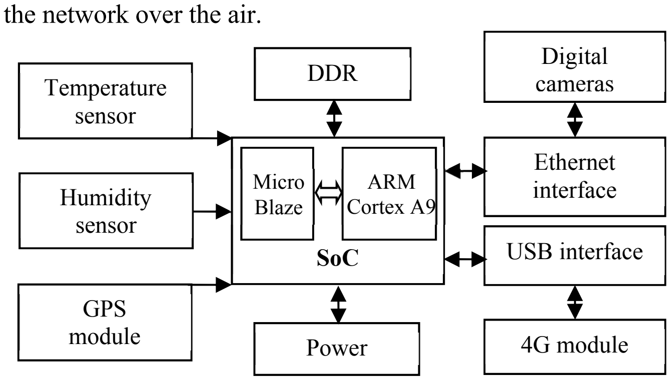

Fig. 4. Hardware design of the vehicle monitoring system.

B. Software design

In this application, the vehicle monitoring terminal mainly realizes environmental information acquisition, processing and transmission. Considering that the system consists of two parts: data acquisition module and master module, we take lightweight Standalone for data acquisition module as well as the high-performance Linux kernel for master module. With this design, the whole system can work with high performance and low power consumption.

For data acquisition module, we designed an independent software system for sensor data acquisition, processing and transmission according to IEEE1451.2 standard. As shown in Fig. 5, after powered on, the system completes initialization and then enters the waiting stage for request from the master module. When detecting the request signal, the module determines the request signal type and takes appropriate actions. For sensor data request, the module addresses it to the specific sensor, executes data read operation and transmits the results to master module. For TEDS data request, the module addresses it to the specific TEDS and transmits the table to the master module. Furthermore, we implement the self-test function to check the status of the entire module.

For the master module, it mainly performs system management, multiple data processing and transmission. In order to implement the above functions, we compile and transplant the peta-Linux operating system which can provide various device drivers and libraries for application development. We designed and developed data acquisition agent for retrieving sensor data from data acquisition module and video capture agent for retrieving video data from digital cameras. Furthermore, a transmission and management unit is developed for wireless network establishment, network maintenance and data communication. The software architecture of this module is shown in Fig. 6.

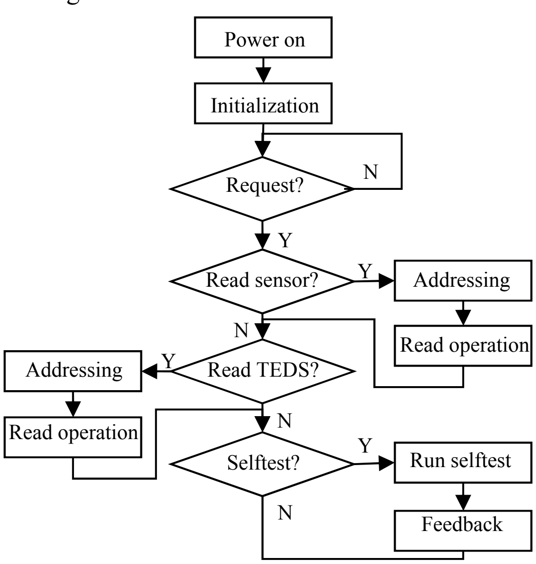

Fig. 5. Software workflow of the data acquisition module.

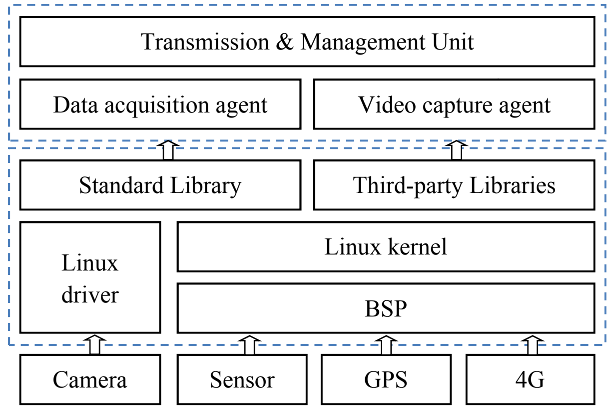

Fig. 6. Software architecture of the master module.

IV. PERFORMANCE EVALUATION

In the practical application, we have completed the development and production of the vehicle monitoring terminals, and deployed them on about one hundred buses in operation. According to different types of vehicles, we deployed 5 or 6 digital cameras in the bus which are connected to the vehicle monitoring terminal. The antennas of GPS and 4G were also equipped outside the vehicles. The product's appearance of the vehicle monitoring terminal is shown in Fig. 7.

In order to implement the full functions of the whole system, we also develop the server system and multi-client programs. The server system is responsible for transferring all the data and information from terminals to user client. the TCP/IP was adopted to transmit the sensor data and the RTSP was adopted to transmit the video data. The server has the public IP address to support the access of various terminals, and configured with high delivery bandwidth and strong real-time property to support multi-users access. On the client side, a real-time video monitoring program and a sensor data display program were developed respectively with C# language. Combined with matrix screen, a comprehensive monitoring and manager platform was built for user and traffic controller (Fig. 8).

Fig. 7. Vehicle monitoring terminal.

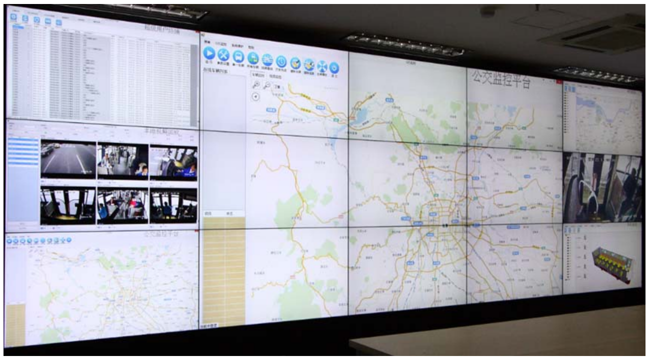

Fig. 8. Monitoring and management platform.

As a practical application, the vehicle monitoring system performs real-time and comprehensive monitoring for numerous buses, including temperature, humidity, real-time position and video information. All the information is displayed with visualization interface, which could be used for security monitoring and traffic dispatching. At the same time, all the collected data are stored in the server database which could be access in the future. After running for a long period, it is observed that the system runs in a stable state and obtains the desired effect.

Taking all advantage of the proposed smart interface architecture, the system has good compatibility and expansibility for different types of sensors, actuators and other devices in IoT. For specific user requirements, the system could be reconfigured and reused for other application environment.

V. Conclusion

Taking IEEE1451.2 standard for multiple devices in IoT environment, this paper describes a novel IoT access architecture. The proposed architecture could provide unified access to various sensors and actuators as well as high-speed devices, which meets real-time application requirements in IoT fields. Making full use of FPGA and SoC technologies, the system provides powerful processing capability, excellent compatibility and expansibility while requiring less hardware resources and reduced power consumption. By taking vehicle monitoring system as a typical example, we verified that the system achieved good performance in a practical application scenario.

Note that, many interesting directions are still remaining for further research. For example, considering that the system only realizes wired connection for a part of IoT devices, how to achieve wireless access for other devices is an important issue. Our future work will focus on this aspect.

Acknowledgment

This research was supported by the National Natural Science Foundation of China (No.61502018 2016.1-2018.12) and Beijing Innovation Platform of Science and Technology.

References

[1] A. Whitmore, A. Agarwal, and L. Da Xu, "The Internet of Things—A survey of topics and trends," Information Systems Frontiers, vol. 17, pp. 261-274, 2015.

[2] S. Li, L. D. Xu, and S. Zhao, "The internet of things: a survey," Information Systems Frontiers, vol. 17, pp. 243-259, 2015.

[3] Q. Sun, J. Liu, S. Li, C. Fan, and J. Sun, "Internet of Things: Summarize on Concepts, Architecture and Key Technology Problem," Journal of Beijing University of Posts Telecommunications, vol. 33, pp. 1-9, 2010

[4] IEEE 1451 Smart Transducer Interface Standards: www.nist.gov/el/isd/ieee/IEEE 1451.cfm.

[5] Q. Chi, H. Yan, C. Zhang, Z. Pang, and L. D. Xu, "A Reconfigurable Smart Sensor Interface for Industrial WSN in IoT Environment," IEEE Transactions on Industrial Informatics, vol. 10, pp. 1417-1425, 2014.

[6] A. Kumar, I. P. Singh and S. K. Sud, "Energy Efficient and Low-Cost Indoor Environment Monitoring System Based on the IEEE 1451 Standard," IEEE Sensors Journal, vol. 11, pp. 2598-2610, 2011.

[7] A. Kumar, V. Srivastava, M. K. Singh, and G. P. Hancke, "Current Status of the IEEE 1451 Standard-Based Sensor Applications," IEEE Sensors Journal, vol. 15, pp. 2505-2513, 2015.

[8] ug585-Zynq-7000-TRM: http://china.xilinx.com/support/documentation/user_guides/ug585-Zynq-7000-TRM.pdf.

[9] L. Hu, H. Li, X. Xu, and J. Li, "An Intelligent Vehicle Monitoring System based on Internet of Things," 7th International Conference on Computational Intelligence and Security, CIS 2011, pp. 231-233, 2011.

[10] P. Pyykonen, J. Laitinen, J. Viitanen, P. Eloranta, and T. Korhonen, "IoT for intelligent traffic system," IEEE 9th International Conference on Intelligent Computer Communication and Processing, ICCP 2013, pp. 175-179, 2013.