IoT-Architecture-Based All-in-One Monitoring System Design and Implementation for Data Center

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Abstract. Modularization and integration are becoming the mainstream trend in the development of data center. However, the integrated monitoring of power and environment has been a challenge in data centers. An All-in-One monitoring system design and implementation has been developed based on Internet of Things (IoT) architecture in this paper. The hardware is composed of two levels: one integrated monitoring gateway and several monitoring modules through the CAN-BUS network. The two-level structure design enables us to achieve module splicing and flexible deployment easily as well as rapid troubleshooting. A series of software applications are developed to establish the sensor network and collect sensor data. In addition, a web interface is provided for users to master the state of data center conveniently. Laboratory tests verify that the proposed system is able to offer automatic and intelligent support for data center management, thus significantly reducing the cost of labor and operation.

Keywords: All-in-One monitoring system · Data center · CAN-BUS · IoT · Integrated management

1 Introduction

Recently, Internet of Things (IoT) has become a future trend of technology in changing humans' life. IoT extends the concept of Internet from the network of computers to the network of all things [1]. In order to meet the needs of users, a new wave of smart IoT services has been set off by massive sensing analysis techniques to integrate more advanced and intelligent applications [2].

With the rapid development of information construction, more and more data centers are widely used around the world. Given the ever increasing role that data center plays in society, business, and science, it is obvious that the construction

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cost and operation management of data center have become a major concern. Managers of data center have been looking for methods to reduce expenses while still ensuring efficient and stable services. All-in-One data center integrates all systems in a standard container, including power supply and distribution, cooling, IT cabinets, cabling, fire extinguishing, surge protection, and monitoring. It has been the mainstream trend nowadays because of its rapid deployment, easy expansion, low operational costs and low energy consumption. Generally speaking, data centers are arranged with complex and expensive equipment which is sensitive to the external environment. Meanwhile, due to the particularity of data center, it does not have the capability to achieve real-time scene monitoring by managers. Therefore, it is difficult to make a timely response under the circumstance of an unexpected danger, resulting in abnormal and inefficient services, or even damaging the expensive server equipment which will lead to serious effects. According to the statistics, companies around the world spend a huge amount of human resources and financial resources to manage servers, but at these high costs, even companies with 99.9% normal time lose hundreds of thousands of dollars every year in unplanned fault time [3]. Nevertheless, power and environment monitoring system provides a possible solution to deal with the aforementioned problems in data centers.

The research in [4] includes monitoring system with the surveillance mainframe and several sensors based on Client/Server (C/S) architecture through the RS-485 network. Studies have been made in fuzzy control theory to reduce the energy consumption and ensure the real-time monitoring of data center using microcontroller in [5]. However, few works are involved in the power and environment monitoring system for All-in-One data center. Current power and environment monitoring systems on the market mostly adopt integrated solution, which combines the management module and the sensor collection module into a block of hardware [6]. Any broken part will lead to the replacement of the entire hardware. Moreover, due to the fixed number of hardware interfaces, the amount and location of mount nodes are subject to certain restrictions.

The architecture and key technologies of IoT offer a new way of rethinking monitoring system for data center [7,8]. Based on IoT architecture, this paper proposes a new All-in-One monitoring system for next generation data center. A two-level structure of one integrated gateway and several sensor monitoring modules through the CAN-BUS network is introduced in the All-in-One monitoring system. Different module splicing schemes support different combinations of monitoring parameters by using various sensors. Thus, the proposed system can achieve rapid and flexible deployment easily within existing Information Technology (IT) infrastructures while bringing a significant reduction in the cost of building a data center. Besides, the distributed structure design makes it convenient for troubleshooting and positioning. Therefore, managers only need to replace the broken parts instead of the whole hardware and the maintenance cost is also reduced.

The rest of this paper is organized as follows. Section 2 introduces the architecture of the All-in-One monitoring system. Section 3 elaborates on the design of hardware boards and their detailed usages. Section 4 describes the software products and applications developed to monitor the data center. Then, the implementation snapshots of the system are shown in Sect. 5. Section 6 provides some results and discussions. The conclusion and future work are given in Sect. 7.

2 All-in-One Monitoring System

The All-in-One monitoring system is deployed in key positions of the All-in-One data center container as depicted in Fig. 1. It consists of five monitoring subsystems and one integrated monitoring gateway. These monitoring subsystems, including IT monitoring system, network monitoring system, precision air-conditioning monitoring system, Uninterruptible Power Supply (UPS) monitoring system and environment monitoring system, almost cover all of the data center's monitoring parameters. Sensor data from different monitoring subsystems is gathered by the gateway in a unified way. The integrated monitoring gateway also offers a dedicated user-friendly web interface to diaplay the device information, the connection status and the sensor values of different sensor nodes.

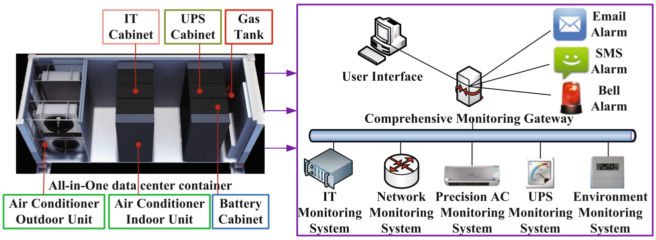

Fig. 1. System architecture of the All-in-One monitoring system

IT equipment can be monitored by IT monitoring system for parameters like Central Processing Unit (CPU) utilization, memory size and process state. Network monitoring system is able to obtain the current network status of data center. Precision air-conditioning monitoring system is mainly responsible for management of the cooling system in data center. UPS parameters such as input and output voltage and current, battery capacity and various powers are monitored by UPS monitoring system. Environment monitoring system provides temperature and humidity monitoring, smoke monitoring, water leakage monitoring, etc.

At present, most monitoring systems in data center are deployed by an integrated block of hardware. This solution actually reduces the flexibility of implementation and management. The architecture of IoT brings us a new idea for monitoring system. Generally, the structure of IoT is divided into five layers, which are the business layer, the application layer, the processing layer, the transport layer and the perception layer [9,10]. The perception layer deals with the identification and collection of sensor information. The transport layer transfers the data from sensors to the data processing system. The processing layer is responsible for storing and processing the information received from the transport layer. The application layer provides global management of diverse applications based on the information processed in the transport layer. The business layer manages the overall IoT system and helps make future decisions and business strategies through some data analysis.

CAN-BUS is becoming a standard bus protocol for embedded industry control network of area because of its good performance and high reliability. CAN-BUS communication can support up to 1 Mbps and upload emergency message in interrupt mode so that data transmission will be very quick. In addition, the number of mount nodes on CAN-BUS is significantly increased compared with the traditional way. This allows users to make the most suitable choice for different scale of data centers.

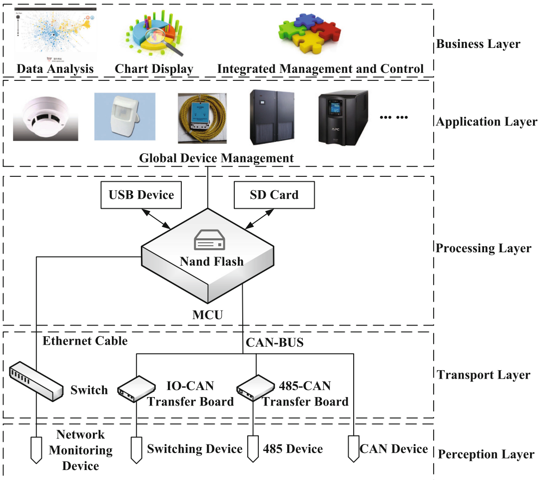

Fig. 2. Hardware collection structure of the All-in-One monitoring system

Based on IoT architecture, the two-level structure design of Micro Control Unit (MCU) and interface converter through CAN-BUS is shown in Fig. 2. It enables us to achieve module splicing and flexible deployment easily, as well as to facilitate the support of a variety of manufacturers, different interface devices and monitoring sensors, etc. The MCU is responsible for the collection and display of data from the CAN-BUS and acts as a gateway for external access, while the two types of interface converter, 485-CAN transfer board and IO-CAN transfer board, collect the data of third-party devices and send to the CAN-BUS. Of course, any CAN device is able to access our bus network directly just following the protocol and any network monitoring device could be reached by means of a switch connected to MCU. Device management and application development in the upper layer are mainly concentrated in the web interface.

3 All-in-One Monitoring System Hardware Design

The All-in-One monitoring system deployment in this work consists of four kinds of hardware which are described in following subsections, respectively. The MCU needs a powerful microprocessor to run an Operating System (OS) and process the data so AT91SAM9X25 is a good choice. As for three interface converters, the cost-effective stm32 singlechip can meet the demand and the hardware overhead can be reduced.

3.1 MCU Board

The MCU board plays the leading role in our All-in-One monitoring system, which just takes on the integrated monitoring gateway in Fig. 1. A series of add-ons modules are developed based on AT91SAM9X25 as shown in Fig. 3 to make the system more user-friendly. The 128 MB Double Data Rate 2 (DDR2) Random Access Memory (RAM) and 256 MB Nand flash enable us to run an embedded linux OS on the board. Two 10/100 M adaptive Ethernet chips are used for network communications to show the web interface and monitor network devices. Usually, the MCU board gets the sensor data through the CAN-BUS and these data can be stored in onboard flash or other external storage devices if needed, such as Universal Serial Bus (USB) and Secure Digital (SD) card. The program can read the different Dual Inline-pin Package (DIP) configurations to set different IP address for identifying each MCU board.

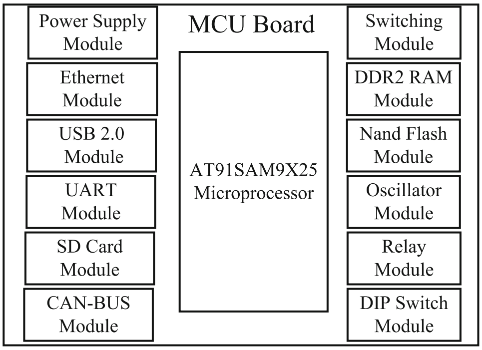

Fig. 3. Hardware components of the MCU Board

3.2 Temperature and Humidity Sensor Board

The temperature and humidity sensor board is applied to monitor environmental data relevant to the cooling processes at a data center. For this purpose, the Sensirion SHT11 temperature and humidity sensor is selected. The principle of this sensor is that the forward voltage of a silicon diode is temperature dependent. The sensor has inbuilt configurable 8/12 bit up to 12/14 bit Analog to

Digital Convertor (ADC) for relative humidity and temperature measurements, offering typical accuracy tolerance of $\pm 3.0\%$ for relative humidity and ± 0.4 ℃ for temperature. In the stm32 singlechip, the sensor data is obtained by means of Inter-Integrated Circuit (I2C) communication and sent to the CAN-BUS.

3.3 485-CAN Transfer Board

Based on the stm32 singlechip, the 485-CAN transfer board is composed of a series of main elements: one CAN interface, four RS485 ports and one 8-bit DIP switch. The board is used to collect 485 device data and transform them to CAN data. Since a lot of sensors only have 485 interface, our system can be compatible with those third-party 485 devices by this way. By taking full advantage of the stm32 singlechip's CAN and Universal Synchronous/Asynchronous Receiver/Transmitter (USART) Application Programming Interface (API), our transform program becomes easier. Noted that one MCU board can bear at most $2^8 - 1 = 255$ 485-CAN transfer boards by adjusting the 8-bit DIP switch.

3.4 IO-CAN Transfer Board

Similar to the 485-CAN transfer board, the IO-CAN transfer board is composed of such main elements: one CAN interface, eight switching signal ports, four relay output interfaces and one 8-bit DIP switch. The board is used to collect switching signal data and transform them to CAN data. By this way, those switching signal devices, such as smoke sensor and water leakage sensor, also have access to our system. Furthermore, users are able to send command to control a relay switch through the CAN-BUS. Similarly, noted that one MCU board can bear at most $2^8 - 1 = 255$ IO-CAN transfer boards by adjusting the 8-bit DIP switch.

4 All-in-One Monitoring System Software Design

Five software applications have been developed for our All-in-One monitoring system in order to communicate with sensors, establish the sensor network, and manage the sensor data such as collecting, storing and displaying.

4.1 Embedded Linux OS

With the growth of Internet, linux becomes the most popular free operating system because of its powerful kernel and hardware support. Our embedded software is just based on linux 2.6.39 kernel and some modifications are made on the drivers and pins for our specific hardware.

4.2 Embedded Web Server

For the purpose of providing users with a universal interface, transplanting an embedded web server is needed. As a lightweight opensource server, lighttpd has the characteristics of very low memory overhead, low CPU occupancy rate but good performance.

4.3 Singlechip Application

Three different applications have been developed in three different singlechip boards as mentioned in Sect. 3. The Keil integrated development tools and C programming language are adopted. In the 485-CAN transfer board, 485 devices communicate with the controller via Modbus protocol in which the controller acts as a master and the sensor acts as a slave. The sensor data will be read and filled in a generated CAN frame and then sent to the MCU board. Similar to the 485-CAN transfer board, the temperature and humidity sensor board's application and the IO-CAN transfer board's application adopt the similar schema. The only difference is that one reads the data from a temperature and humidity chip, while the other one reads the switch signal data.

4.4 Gateway Application

The gateway connects the CAN-BUS sensor network and the web interface for the bidirectional data movement shown in Fig. 4. Applications in the gateway collect data reported by sensors in order to update the status of real-time monitoring in the web interface. The gathered data will be converted into JavaScript Object Notation (JSON) format and sent to the web interface as a HyperText Transfer Protocol (HTTP) payload. At the same time, applications receive user commands and convert them into CAN command frames and then forward to the desired end board. There are four processes running in the background, dealing with device updating, device lost, data over threshold and commands delivering respectively. For the convenience of users, functions like changing the MCU board's IP, setting the date and time, and recording the system log are also fulfilled. A remote upgrade interface is provided in the web page for users to upgrade their software systems fast and easily.

One month's data is recorded on the gateway for further processing and analysis. Furthermore, four threshold values namely "low warning threshold", "low alarm threshold", "high warning threshold" and "high alarm threshold" can be preset for individual sensor nodes. Once the performance indicators for data center exceed the preset threshold or other abnormal situations appear, alarm information will be sent to the administrators immediately via bell, email or Short Message Service (SMS) and recorded to the system log at the same time.

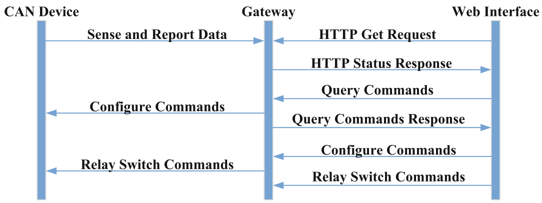

Fig. 4. Data flow of the gateway application

4.5 CAN Communication Protocol

The CAN communication protocol is customized in Table 1 by using the 32 bit ID of CAN extended frames. In the All-in-One monitoring system, each board, device and data has its own unique CAN ID. The MCU board identification depends on the DIP switch state, so does the board number identification. As for the board type identification, we set 0x01 standing for temperature and humidity sensor board, 0x02 standing for 485-CAN transfer board and 0x03 standing for IO-CAN transfer board. At last, the device identification relies on the hardware position of device and the data identification is on the basis of the user's configuration sequence.

Table 1. CAN communication protocol

ID bits (high→low)	Instructions
1 bit	Reserved
8 bit	MCU board identification
3 bit	Board type identification
8 bit	Board number identification
4 bit	Device identification
5 bit	Data identification

5 Implementation Snapshots

The proposed system will be deployed at banks and Internet companies to provide their data centers with a cost-effective and intelligent monitoring system. Compared to the integrated solution in [6], our two-level structure reduces the replacement probability of MCU and the maintenance cost of monitoring system. Besides, the CAN-BUS solution increases the number of mount nodes and reduces the purchase cost of MCU. Figures 5 and 6 show the physical hardware connection diagram and the web interface of the implementation respectively.

The All-in-One monitoring system supports various interface devices which are hot swap and offers dynamic device management. The web interface helps the operation and maintenance personnel master the state of data center whenever and wherever possible. The data collected from sensors distributed in every corner, such as temperature and humidity, could reflect how environmental parameters affect the conditions of data center. And they can be used to design dynamic control systems that would adjust the cooling resources or others according to the circumstance, for the target of maintaining the data center's normal running.

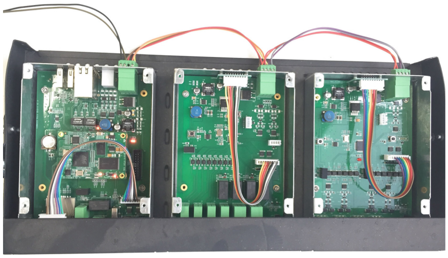

Fig. 5. Physical hardware connection diagram

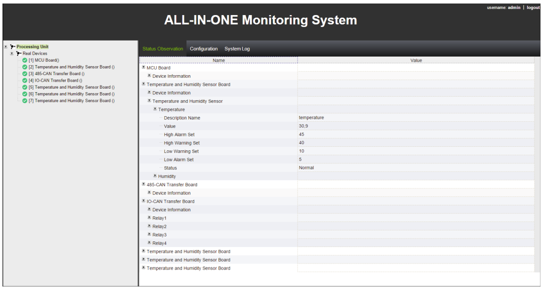

Fig. 6. Web interface of the implementation

6 Results and Discussions

A simple test environment is set up in our 80 square-meter laboratory. More than a dozen temperature and humidity sensors are deployed in each student's seat and the sensor data is collected every three seconds. Figure 7 shows the 24-h monitoring results gathered by the All-in-One monitoring system. The temperature varies from 24 °C to 29 °C, and the humidity fluctuates from 14% to 22%. From a data collection point of view, this experiment demonstrates that the proposed system can be an effective tool for environment monitoring in data center. More scenarios and monitoring parameters will be implemented in the real data center in the next few months.

To validate the performance of device's hot swap as well as the timeliness of detection alarm and commands taking effect in the All-in-One monitoring system, a few measurements are conducted. Figure 8(a) illustrates that a lost device will be detected in no more than 7 s. Figure 8(b) shows that the delay of detecting device plugged mainly concentrates between 1.5 s and 3.5 s. Moreover, Fig. 9(a) verifies that an alarm will be generated within 4 s. Figure 9(b) shows that a user command will take effect between 1 s and 2 s in most cases. In general, above indicators fully meet the needs of data center monitoring.

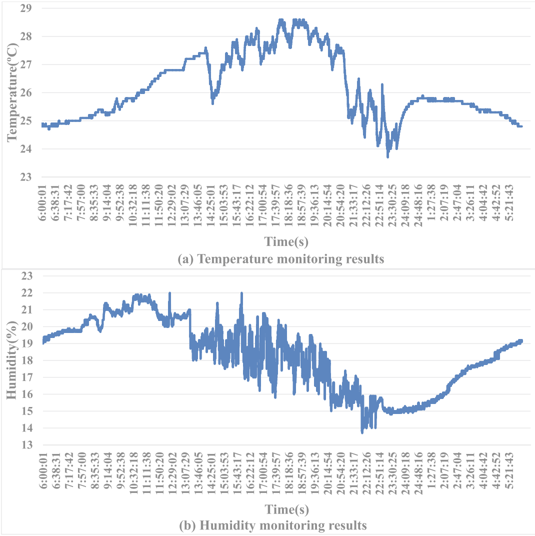

Fig. 7. Monitoring results of temperature and humidity

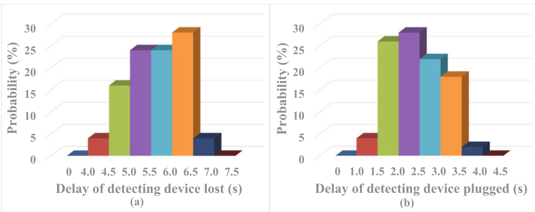

Fig. 8. Performance of device hot swap

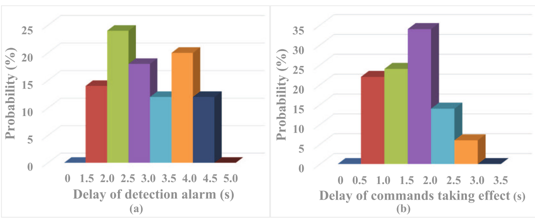

Fig. 9. Timeliness of detection alarm and commands taking effect

7 Conclusions

An All-in-One monitoring system design and implementation is proposed in this paper to solve existing problems in power and environment monitoring of data center. Based on IoT architecture, the two-level structure through CAN-BUS is devised. Then the four hardware components of the distributed sensor network are implemented respectively. Several software applications and a web interface are also developed for the All-in-One monitoring system. Test results in laboratory indicate that the proposed system can be well applied in the micro-module data center. This paper can provide essential foundation for the development of data center monitoring system in the Internet plus age and IoT era.

Data collection in order to understand a data center's environment is the first step to improve the operation and management of a data center. In the future, data analysis methods will be introduced to dynamically change the environmental conditions and energy resource allocation in data centers. Thus, the intelligence of data center could be further enhanced significantly.

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