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A Reconfigurable Smart Sensor Interface for Industrial WSN in IoT Environment

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Abstract: Wireless Sensor Networks (WSN) has been employed to collect data about physical phenomenon in various applications such as habitat monitoring. Internet of Things (IoT) has attracted a lot of attention and is expected to bring benefits to numerous application areas including industrial WSN systems, and environmental systems for data acquisition for IoT representation. A sensor interface device is essential for sensor data collection of industrial wireless sensor networks in IoT environments. Each sensor connected to the device is required to write complicated and cumbersome data collection code. To solve these problems a new method is proposed to design a reconfigurable smart sensor interface for industrial WSN in IoT environment. Thus it can read data in parallel and in real time with high speed on multiple different sensor data. The standard of IEEE1451.2 intelligent sensor interface specification is adopted for this design.

Keywords: CPLD, IEEE1415 protocol, Internet of Things (IoT), sensor data acquisition.

I. INTRODUCTION

Wireless sensor networks (WSNs) have become a hot research topic in recent years clustering is considered as an effective approach to reduce network overhead and improve scalability. Wireless sensor network is one of the pervasive networks which sense our environment through various parameters like heat, temperature, pressure, etc. Since sensor networks are based on the dense deployment of disposable and low-cost sensor nodes, destruction of some nodes by hostile action does not affect a military operation as much as the destruction of a traditional sensor, which makes the sensor network concept a better approach for battlefields. The transmission between the two nodes will minimize the other nodes to show the improve throughput and greater than spatial reuse than wireless networks to lack the power controls. Adaptive Transmission Power technique to improve the Network Life Time in Wireless Sensor Networks using graph theory we have distance comparison between the neighbor nodes and also local level connected from the nearest edges in wireless sensor networks.

A sensor is a device that detects events or changes in quantities and provides a corresponding output, generally as an electrical or optical signal; for example, a thermocouple converts temperature to an output voltage. But mercury in glass thermometer is also a sensor; it converts the measured temperature into expansion and contraction of a liquid which can be read on a calibrated glass tube. Internet of Things (IOT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure. Typically, IOT is expected to offer advanced connectivity of devices, systems and services that goes beyond machine - to- machine communications (M2M) and covers a variety of protocols, domains, and applications. The inter connection of these embedded devices (including smart objects), is expected to usher in automation in nearly all fields, while also enabling advanced applications like a Smart Grid.

A. Wireless Sensor Network

Wireless sensor network (WSN), which integrates sensor technology, wireless communication technology, embedded computing technology and distributed information management technology, has been under rapid development during recent years. A wireless sensor network is a collection of nodes organized into an interactive network. Each node consists of processing capability (one or more microcontroller's chips) and contains types of memory, with a Zigbee transceiver module and also, each node have a stable power source and the last part of a node, it is accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc method. Such systems can revolutionize the way we live and work therefore in this project we want to use WSN technology to control and manage energy in building. On the other hand, FPGA has unique hardware logic control, real-time performance, and synchronicity, which enable it to achieve parallel acquisition of multi-sensor data and greatly improve real-time performance of the system. FPGA has currently becomes more popular than MCU in multi-sensor data acquisition in IoT environment.

However, in IoT environment, different industrial WSNs involve a lot of complex and diverse sensors. At the same time, each sensor has its own requirements for readout and different users have their own applications that require different types of sensors. It leads to the necessity of writing complex and cumbersome sensor driver code and data collection procedures for every sensor newly connected to interface device, which brings many challenges to the researches. Sensor data acquisition surface device is the key part of study on industrial WSN application. In order to standardize a wide range of intelligent sensor interfaces in the market and solve the compatibility problem of intelligent sensor, the IEEE Electronic Engineering Association has also launched IEEE1451 smart transducer (STIM) interface standard protocol suite for the future development of sensors. The protocol stipulates a series of specifications from sensor interface definition to the data acquisition. The STIM interface standard IEEE1451 enables sensors to automatically search network, and the STIM promotes the improvement of industrial WSN. But, the sensors with the protocol standard have a high cost and still lack popularity in industrial WSN in IoT environment. Nevertheless, at present, examples of intelligent sensors available on the market and compliant with this standard are still limited.

To solve these problems, some dedicated hardware interfaces based on the IEEE 1451 have been recently proposed, and they are capable of interfacing with different sensor typologies. These interface devices are usually based on relatively complex dedicated electronic boards. It is obvious that such restriction should be released, and a reconfigurable multi-sensor data acquisition interface with good compatibility and normative interface standard needs to be developed in IoT environment. By focusing on the above issue, this paper designs and realizes a smart sensor interface for industrial WSN in IoT environment. This design presents many advantages as described below. First of all, FPGA is used as the core controller to release the restriction on the universal data acquisition interface, and realize truly parallel acquisition of sensor data. It has not only improved then sensor data collection efficiency of industrial WSN, but also extended the application range of the data acquisition interface equipment in IoT environment. Secondly, a new design method is proposed in this paper for multi-sensor data acquisition interface that can realize plug and play for various kinds of sensors in IoT environment.

The design system applies the IEEE1451 interface protocol standard that is used for smart sensors of automatically discovering network. For the sensors not based on IEEE1415 protocol standard, the data acquisition interface system can achieve the function of plug and play. In this paper, this design take full advantage of FPGA characteristics, such as high execution speed, flexible organization structure, IP design could reuse, etc. The design adopts IEEE1451 smart transducer (STIM) interface standards, which makes our device better compatible in the field of industrial WSN in IoT environment. IoT is a major drive to support service composition with various applications. The architecture of IoT is illustrated as in Fig. 1.

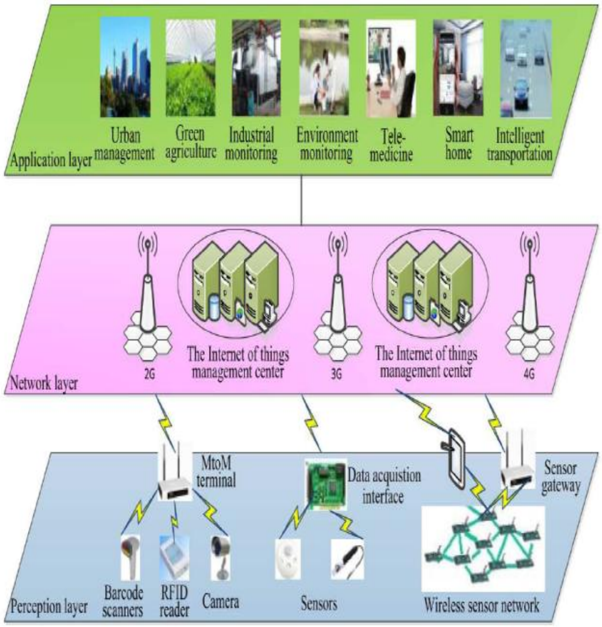

Fig.1. Architecture of IoT

II. DESIGN

Reconfigurable smart sensor interface device that integrates data collection data processing and wired or wireless transmission the device can be widely used in many application areas of the IOT and WSN to collect various kinds of sensor data in real time. The overall structure of reconfigurable smart sensor interface consists the central hub collects information from the different frequency channels and controls these channels through the ZigBee module. The central hub sends the state information to a server and then a user can monitor and control the present values using the web based user interface. This facility may create some easiness for the users. The system has been designed for measurement of temperature and LDR parameters. Important functions to the system are the ease of modeling, setup, and use. From the consumer point of view. With rapid development of IoT, major manufacturers are dedicated to the research of multisensory acquisition interface equipment. There is a lot of data acquisition multiple interface equipments with mature technologies on the market. But these interface devices are very specialized in working style, so they are not individually adaptable to the changing IoT environment. Meanwhile, these universal data acquisition interfaces is used as the core controller in mainstream data are often restricted in physical properties of sensors (the connect number, sampling rate, and signal types). Now, ARM 11 based Single board computer called raspberry pi. Raspberry pi has the advantage of low price and low power consumption, which makes it relatively easy to implement. It performs a task by way of interrupt, which makes these multi sensor acquisition interfaces parallel in collecting multi sensor data.

With the advancements in Internet technologies and WSNs, a new trend is forming in the era of ubiquity. “IoT” is all about physical items talking to each other, where machine-to-machine (M2M) communications and person-to-computer communications will be extended to “things”. Key technologies that drive the future of IoT are related to smart sensor technologies including WSN, nano-technology, and miniaturization. Since IoT is associated with a large number of wireless sensor devices, it generates a huge number of data. Sensor data acquisition interface equipment is one of the key parts in IoT applications. Data collection is the essential application of WSN and more importantly it is the foundation of other advanced applications in IoT environment. IoT is a major drive to support service composition with various applications. The architecture of IoT is illustrated as in Fig.2. It consists of three layers: 1) perception layer; 2) network layer; and 3) application layer. The design of data acquisition interface is mainly applied to the perception layer of IoT. The perception layer of IoT is mainly composed of sensors, RFID readers, cameras, M2M terminals, and various data collection terminals. The data acquisition interface is responsible for the integration and collaboration of various environments and collection of sensor data.

III. INTERNET OF THINGS (IoT)

With the advancements in Internet technologies and WSNs, a new trend is forming in the era of ubiquity. “IoT” is all about physical items talking to each other, where machine to- machine (M2M) communications and person-to-computer communications will be extended to “things”. Key technologies that drive the future of IoT are related to smart sensor technologies including WSN nanotechnology, and miniaturization. Since IoT is associated with a large number of wireless sensor devices, it generates a huge number of data. Sensor data acquisition interface equipment is one of the key parts in IoT applications. Data collection is the essential application of WSN and more importantly it is the foundation of other advanced applications in IoT environment. IoT is a major drive to support service composition with various applications. The architecture of IoT is illustrated as in Fig.2. The data acquisition interface is responsible for the integration and collaboration of various environments and collection of sensor data. Examples of such a workflow include a environment monitoring system that adopts sensors to temperature and light. Environment monitoring is one of the IoT application fields, where complex water quality information, is used to determine the environmental quality at the same time. However, currently, there are few data collection device that are dedicated to quality monitoring on the market. Such devices can ensure high speed of data acquisition for multiple sensors and adapt to complex and various sensor types well. Thus, we design and implement a WSN data acquisition interface that can be used for environmental monitoring.

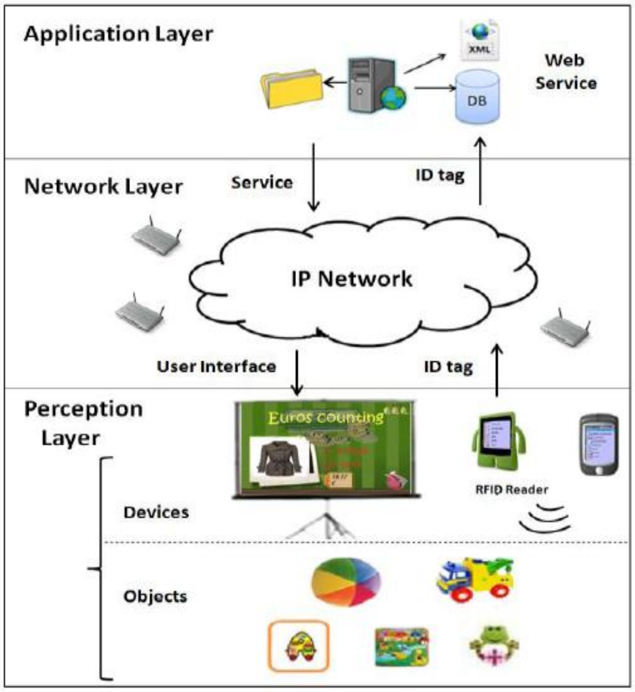

Fig.2. Architecture of IoT

It consists of three layers: 1) perception layer; 2) network layer; and 3) application layer. The design of data acquisition interface is mainly applied to the perception layer of IoT. The perception layer of IoT is mainly composed of sensors, Zigbee, M2M terminals, and various data collection terminals.

A. Microcontroller

The Spartan-3(XC3S200) is a mini-module composed of a FPGA device and a configuration memory with a PAL/GAL compatible 24 pin DIL footprint. The overall structure of smart sensor interface consists of FPGA Spartan- 3(XC3S200 chip), crystals and peripheral circuit, communication circuit for turning USB to serial port (PL2303HXC chips and peripheral circuits), power supply of 1.8 and 3.3 V (LM1117 chip, voltage regulator and filter circuit), an SRAM memory (TC55V400 chip), high-speed 8-channel ADC (ADS7870 chip and peripheral circuit), LED indicator light, an analog extended interface, and three digital extended interfaces. Every extended interface among them can connect eight independent sensors, namely, the reconfigurable smart sensor interface device can access eight analog signals and 24 digital signals. Fig.3 shows the FPGA hardware block diagram. The hardware system can also send and receive data besides the basic sensor data acquisition. It can send data to the control center via USB serial port or Zigbee wireless module. Zigbee wireless communication module can be connected with the board through the mini-USB interface or the extensible GPIO interface on the device. It can be used as wireless data transceiver node when the main controller receives trial or executive instructions. After the data control center finishes further processing for the received data, it needs to feedback related actions to sensor interface device. Data communication function can also control the running status of corresponding peripheral device.

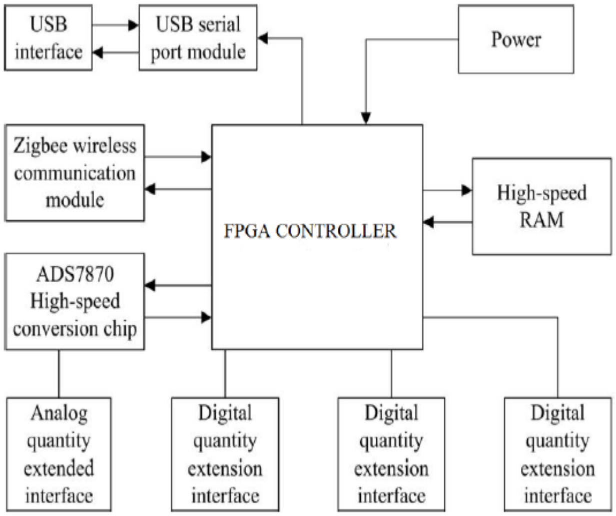

Fig.3. FPGA Hardware Block Diagram.

B. Sensor

A sensor is a device used for the detection of changes in quantities and it provides a corresponding output, generally as an electrical or optical signal. In everyday, sensors are used in objects such as touch-sensitive elevator buttons and lamps which dim or brighten by touching the base. With advances in micro machinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the more traditional fields of temperature, pressure or flow measurement. A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. Making the sensor smaller often improves its performance of measuring and it can be designed to have a small effect and also introduces many advantages. The smallest change it can detect in the quantity that it is measuring is the resolution of a sensor. Various sensors used here are for measuring temperature, gas, humidity, light intensity and pressure.

C. ZigBee

ZigBee is a specification for a suite of high-level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard. Though its low power consumption limits transmission distances to 10–100 meters line-of-sight, depending on power output and environmental characteristics, ZigBee devices can transmit data over long distances by passing data through a mesh network of intermediate devices to reach more distant ones. ZigBee is used in applications that require low data rate, long battery life and secure networking. ZigBee has a data rate of 250 kbit/s, best suited for intermittent data transmissions from a sensor or input device applications include wireless light switches, electrical meters with in-home-displays, traffic management systems, and other consumer and industrial equipment that require short-range low-rate wireless data transfer. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other wireless personal area networks such as Bluetooth or Wi-Fi. ZigBee protocols are intended for embedded applications requiring low data rates and low power consumption.

IV. IMPLEMENTATION

A. The Introduction of the Hardware Architecture

The overall structure of reconfigurable smart sensor interface consists of CPLD chip (XC2C256 chip), crystals and peripheral circuit, communication circuit for turning USB to serial port (PL2303HXC chips and peripheral circuits), power supply of 1.8 and 3.3 V (LM1117 chip, voltage regulator and filter circuit), an SRAM memory (TC55V400 chip), high-speed 8-channel ADC (ADS7870 chip and peripheral circuit), LED indicator light, an analog extended interface, and three digital extended interfaces. Every extended interface among them can connect eight independent sensors, namely, the reconfigurable smart sensor interface device can access eight analog signals and 24 digital signals. Fig. 3 shows the CPLD hardware block diagram. The hardware system can also send and receive data besides the basic sensor data acquisition. It can send data to the control center via USB serial port or Zigbee wireless module. Zigbee wireless communication module can be connected with the board through the mini-USB interface or the extensible GPIO interface on the device. It can be used as wireless data transceiver node when the main controller receives trial or executive instructions. After the data control center finishes further processing for the received data, it needs to feed back related actions to sensor interface device. Data communication function can also control the running status of corresponding peripheral device.

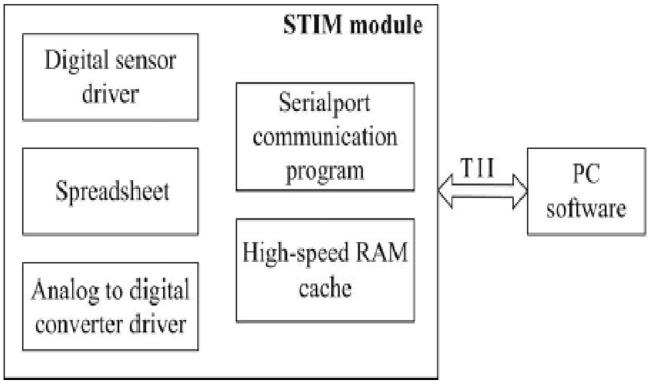

Fig.4. Overall structure diagram of VHDL part of the system

B. VHDL Design

Very-High-Speed Integrated Circuit Hardware Description Language (VHDL) design of the system includes two parts. One part to uses the VHDL language as the basic tool and write related features of the reconfigurable smart sensor interface device by referring to the standard of IEEE1451.2 agreement. It reflects the difference between reconfigurable smart sensor interface device and general data acquisition card, which has a great effect in intelligently collecting sensor data. The other part is programming the interface driver based on VHDL hardware description language. It mainly covers programming of each hardware chip driver and sensor driver on the device. Fig. 4 shows the overall structure diagram of

VHDL part of system. IEEE1451.2 Protocol Based on VHDL Language Design: The designed reconfigurable smart sensor interface device can not only be used to collect sensor data, but it has also added sensor compatible IEEE1451.2 protocol standard features. This design has been written into the IP core module of IEEE1451.2 corresponding protocols in CPLD. Through this, the ordinary sensors (these sensors do not have the function of IEEE1451.2 protocol) can be connected to the device interface with specific functions of IEEE1451.2 protocol. This model is suitable for the application that different kinds of sensors access to different occasions. This model also solves the bottlenecks on lacking IEEE1451.2 agreement applications and the high cost of intelligent sensor.

Overall Design of the Intelligent Transmitter STIM: The design of STIM is the key to realization of the smart sensor data acquisition part. Functional design refers to the design framework of smart sensor data acquisition put forwarded by the standard of IEEE1451.2. STIM overall design structure diagram is shown in Fig. 5. STIM contains the following four functions: 1) the spreadsheet Transducer Electronic Data Sheet (TEDS); 2) the data transmission module (the part of transducer independent interface (TII)); 3) channel trigger module; and 4) registers management module. Realization of the functions of intelligent transducer is mainly controlled by three state machine modules, which are master state machine, data transmission state machine, and channel trigger state machine. Another data signal cache is also included in it. Relationship among each other is shown in Fig. 6. In Fig. 6, the master state machine is responsible for scheduling each function module of the acquisition system, and also has comprehensive control effect on the other two state machines. The data transmission state machines are used for data communication between the upper levels; the channel trigger state machine is responsible for collecting sensor data of each channel, and the data can be shared by caching between them.

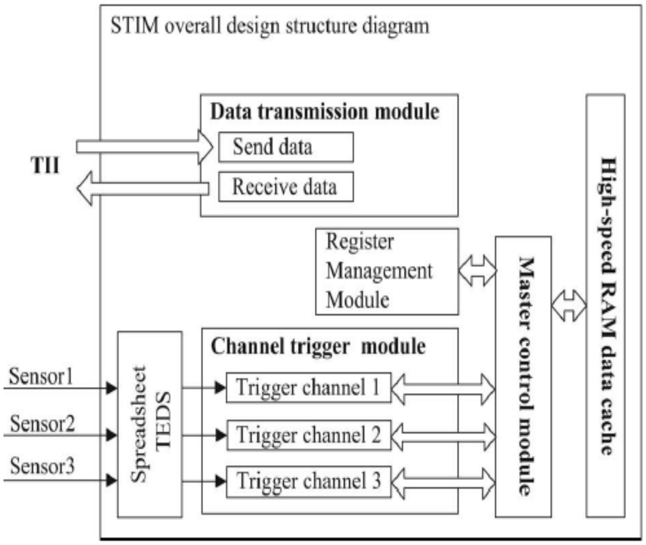

Fig.5. STIM overall design structure diagram

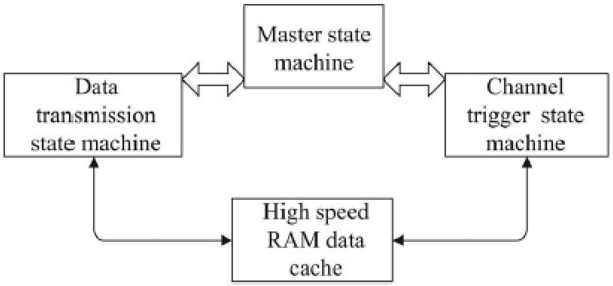

Fig.6. STIM state machine design structure diagram

The master state machine manages the switching process between each STIM state, including data transmission, triggering the sensor channel, control of data storage, etc. According to related characteristics of IEEE1451.2 protocol, the master state machine switches operations of the process as shown in Fig. 7. The signal marks of “Tri_Sig” and “Tra_Sig” determine when the state machine changes into each function module. Data transmission state machine transmits bit data through the TII. The upper layer application software sends control signals to start the state machine. The state machine can encode or decode the memory address of the corresponding sensor of each channel, and drive different types of sensors. The channel trigger state machine is responsible for reading data from the sensors in different channel. Every STIM channel has its corresponding controller of independent channel trigger state machine. These independent channel trigger state machines hidden in the sensor channel’ trigger state machine. Fig. 8 shows each channel data reading state machine. These independent channel trigger machines can be started through the corresponding trigger signal. Otherwise, they will be dormant. Each independent sensor channel’ trigger state machines possess the same structure, and its implementation process can be executed in parallel. It ensures minimum delay, real-time performance and reliability of data collection in the process of multiple sensor data collection. The differences of different channel types are just reflected in the independent channel types, and the last transmitted data are previously stored in the cache.

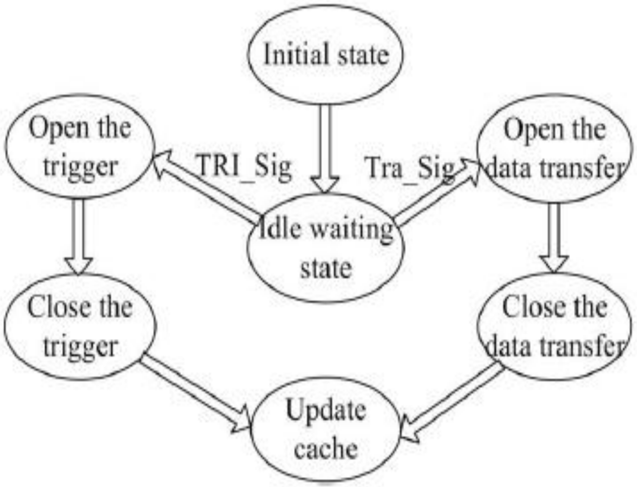

Fig.7. STIM main state machine processes diagram.

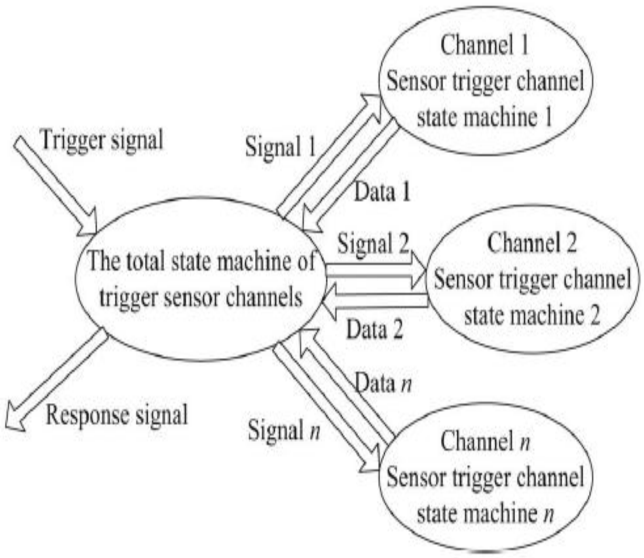

Fig.8. Data reading channel state machine.

Module Design of the Spreadsheet TEDS: Spreadsheet is an independent IP core module existing in CPLD in the form of circuit. Its main function is to operate various kinds of sensor data to be normatively collected by trigger sensor channel, and make some corresponding modifications by filtering out invalid or false sensor data according to the characteristics of a variety of sensors. Schematic diagram of TED's state machine is shown in Fig. 9. Initial state of the system is defined by its idle state. When the start signal ranges from state 0 to 1, the state will jump from the idle state to the reading state of spreadsheet. Data can be saved to the register through serial and parallel transformation. The state updated to the contrast state of data format after reading a set of data. At the same time, the status flag pos will automatically adds 1 and prepares for contrasting the next message. At this point, the internal sensor data information that has been defined at the initialization time will compare it with the data read from the external. Otherwise, the contrast state of data format will return to idle state. If comparative success, it will automatically start the next data comparison.

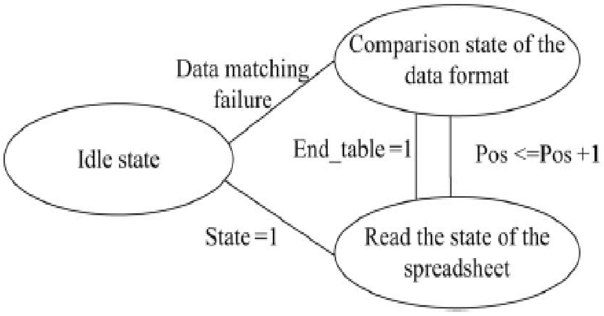

Fig.9. TEDS state machine's schematic diagram.

In our design, the sensor channel trigger state machine is assigned with a specific ID number. At the same time, the ID also represents the priority of data collection. There are numerous methods to define priority, such as sensor conversion rate data length etc. Data length is used as the standard to set priority. When data has different length, the "short data priority" principle can effectively guarantee the overall time consumption of the whole data collection, so as to enhance real-time character of acquisition system.

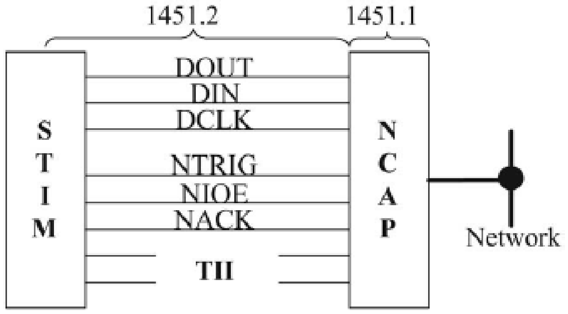

Fig.10. Independent sensor interface functional schematic.

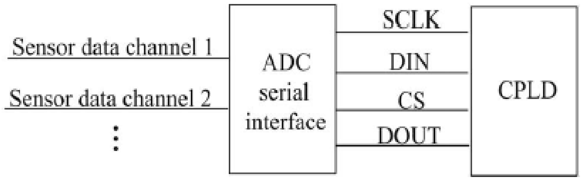

Fig.11. Data and control signals of ADS7870 schematic diagram

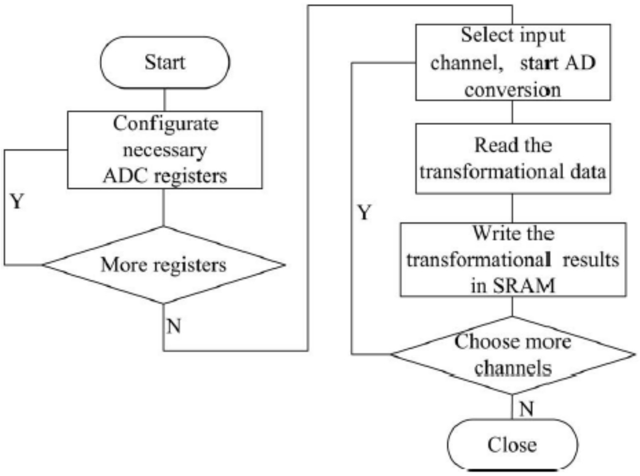

Fig.12. Configuration ADS7870 program flowchart.

Module Design of the Sensor Independent Interface TII: Sensor independent interface TII is the communication part of the smart transmitter STIM and network capable application processor (NCAP). Fig. 10 is the TII interface function diagram. TII is not complicated in concept. It interconnects with NCAP through the synchronous serial interface. TII usually includes data output (DOUT) and data input (DIN), which are used to shake hands for data and communication, DCLK is used to make data synchronization, and other signal lines such as special function signals are used as alternative choices. RS232 communication protocol is adopted in design to support the TII interface. The feature of RS232 is completely in accordance with the TII. Function of the interface owns good versatility and usability. As slave device in the system, STIM remains in the standby state, until awaking notification is received from the master device. The notification message is sent from the main equipment, NCAP, or network equipment connected to NCAP. NCAP can communicate with STIM through TII's NIOE line and activate the specific channel of sensors through TII's NTRIG line. STIM makes response information through NACK line. This system sends or receives the corresponding control or feedback signals through DIN cable and DOUT cable, so as to finish communication between STIM and the upper application software.

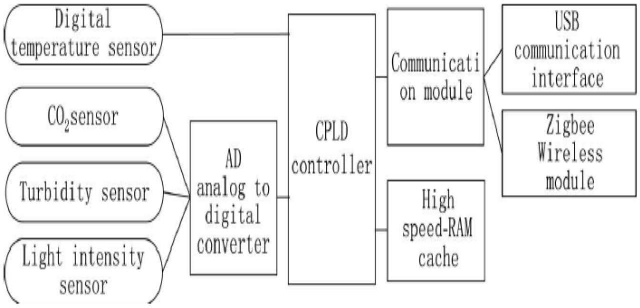

Fig.13. System's block function design.

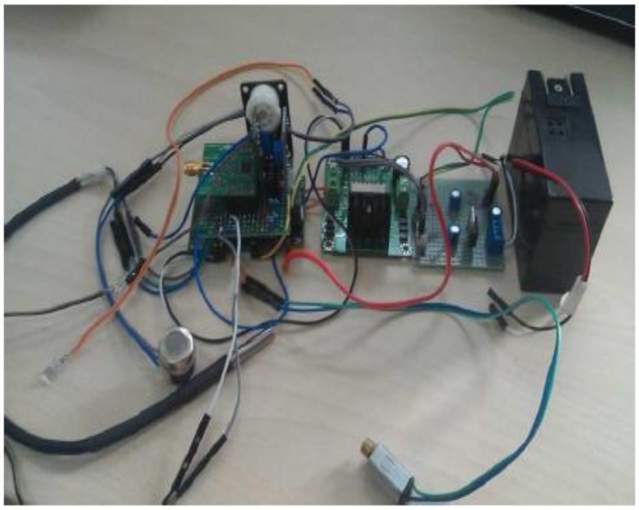

Fig.14. Water quality monitoring hardware physical map the reconfigurable smart sensor interface device is on the left side and we expand a Zigbee module on it. We use these wires around the device to attach sensors that we have used. Power of the whole system is on the right side. The two pieces of circuit boards are some corresponding configuration circuit in the middle of the figure.

The Design of the Interface Device Driver: CPLD is used as the main control unit in the device. Therefore, hardware programming language is needed to write complete drivers for every used chip. In this paper the modulus conversion chip is taken as an example. The modulus conversion chip plays a key role in the system and introduces how to write chips driver via hardware description language VHDL when the analog sensor signal accesses the system under the standard of IEEE1451.2. In our design, ADS7870, a modulus conversion chip produced by TI Company is adopted. ADS7870 is connected to CPLD processor through four serial interfaces, including clock line (SCLK), serial DOUT, serial DIN, and line selection (CS). These interfaces can implement ADS7870' function of reading or writing data in this system, the data and control signals of the modulus conversion chip are shown in Fig. 11. In our system, the ADC is mainly controlled mainly by writing signal DIN from the connected CPLD to operate registers inside the chip. First, the system controls ADC to collect analog signals of sensor input. These digital signals after conversion are first stored in the internal registers of ADC. Then, these digital signals are sent to the CPLD through DOUT port. In this system, DOUT port is set to automatically send ADC conversion results on the SCLK clock rising edge. CPLD controls initialization of the ADC, sensor data collection, and data conversion during the whole process. The flowchart is shown in Fig. 12. After finishing ADC configuration, we implement the function of collecting analog sensor signals. This process is accomplished by sending collection command circularly.

V. CONCLUSION

This paper describes a reconfigurable smart sensor interface for industrial WSN in IoT environment. The system can collect sensor data intelligently. It was designed based on IEEE1451 Ethernet protocol by combining with ARM 11 and the application of wireless communication. It is very suitable for real-time and effective requirements of the high-speed data acquisition system in IoT environment. The application designed using ARM 11 greatly simplifies the design of peripheral circuit, and makes the whole system more flexible and extensible. In this system, all the measurement is sent to the analog channel of the ATmega328p microcontroller and displayed. The performances of the channels are distinguished on the basis of its accuracy. The accuracy indicates how closely the sensor can measure the actual or real world parameter value. The more accurate a sensor is, better it will perform. Then temperature displayed in LCD is compared with the standard temperature .This system is time saving, portable, affordable, consumes less power and can be made easily available so that the user can use this system whenever and wherever.

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