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# Wireless Sensor Networks and Their Applications to the Healthcare and Precision Agriculture

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## Abstract

Wireless connection based smart sensors network can combine sensing, computation, and communication into a single, small device. Because sensor carries its own wireless data transceiver, the time and the cost for construction, maintenance, the size and weight of whole system have been reduced. Information collected from these sensor nodes is routed to a sink node via different types of wireless communication approaches.

Healthcare systems have restricted the activity area of patients to be within the medical health care center or residence area. To provide more a feasible situation for patients, it is necessary to embed wireless communication technology into healthcare systems. The physiological signals are then immediately transmitted to a remote management center for analysis using wireless local area network. Healthcare service has been further extended to become mobile care service due to the ubiquity of global systems for mobile communications and general packet radio service.

It is important that using sensors to detect field-environment signals in agriculture is understood since a long time ago. Precision agriculture is a technique of management of large fields in order to consider the spatial and temporal variability. To use more sophisticated sensor devices with capabilities of chemical and biological sensing not only aids the personnel in the field maintenance procedure but also significantly increases the quality of the agricultural product.

In this chapter, we examine the fields in healthcare and precision agriculture based on wireless sensor networks. In the application of healthcare systems, a System on a Chip (SoC) platform and Bluetooth wireless network technologies were combined to construct a wireless network physiological signal monitoring system. In the application of precision agriculture, an SoC platform was also used combining the ZigBee technology to consist a field signals monitoring system. In addition to the two applications, the fault tolerance in wireless sensor networks is also discussed in this chapter.

Keywords: wireless sensor networks; healthcare; precision agriculture; Bluetooth; ZigBee.

## 1. Introduction to the wireless sensor networks

Owing to the rapid development of new medicines and medical technologies, the aged population have been resulted in a speed-up increase. Thus, more rehabilitation centers are created for the requirements of homecare as well as more medical personnel is needed to offer medical treatments and to prevent accidents for aged patients. To provide a more humane environment for these aged patients' physical and physiological health care, monitoring and recording of their physiological status is very important [1-16]. It occupies a large portion of center's human resources to regularly observe and record the physiological status of patients. It still cannot guarantee to obtain the necessary patients' status information on time and to prevent accidents from happening even if we have sufficient professional nursing staff who works very carefully. In order to reduce the nursing staff's loading and prevent sudden situations that cause accidents, a physiological signal acquiring and monitoring system for the staff to collect the physiological status information of patients to the nursing center with physiological sensors module is essential.

Several technologies were used in the precision agriculture such as remote sensing, global positioning system (GPS), geographic information system (GIS), microelectronics and wireless communications [17, 18]. Most GPS and GIS with satellite systems provide images of great areas. Alternatively wireless sensor networks (WSNs), used for precision agriculture, give better spatial and temporal variability than satellites, in addition to permit collection of others soil and plant data, as temperature, moisture, pH, and soil electrical conductivity [19, 20].

Currently three main wireless standards are used namely WiFi, Bluetooth and ZigBee, respectively. Wi-Fi networks, a standard named IEEE 802.11, is a radio technology to provide reliable, secure, fast wireless connectivity. A Wi-Fi network can be used to connect computers to each other, to the Internet, and to wire networks. Wi-Fi networks work in the unlicensed 2.4 GHz and 5 GHz radio bands, with a data rate of 11 Mbit/s or 54 Mbit/s. They can provide real-world performance similar to that of the basic 10BASE-T wired Ethernet networks. Unlike a wired Ethernet, Wi-Fi cannot detect collisions, and instead uses an acknowledgment packet for every data packet sent.

Bluetooth is a protocol for the use of low-power radio communications over short distance to wirelessly link phones, computers and other network devices. Bluetooth technology was designed to support simple wireless networking of personal consumer devices and peripherals, including PDAs, cell phones, and wireless headsets. Wireless signals transmitted with Bluetooth cover short distances, typically up to 10 meters. Bluetooth devices generally communicate at less than 1 M bps in data transmission. The wireless Bluetooth technology is popularly used in several technique fields. Many researchers have used Bluetooth technology to their monitoring system [12]. Wireless mobile monitoring systems for physiological signal not only increase the mobility of uses but also improve the quality of health care [13].

ZigBee is a low-power, low-cost, wireless mesh networking standard. The low power allows longer life with smaller batteries, the low cost allows the technology to be widely developed in wireless control and monitoring applications and the mesh networking provides high dependability and larger range. ZigBee operates in the industrial, scientific and medical radio bands with 868 MHz, 915 MHz, and 2.4 GHz in different countries. The technology is intended to be simpler and less expensive than other WPANs such as Bluetooth.

Of those, ZigBee is the most promising standard owing to its low power consumption and

simple networking configuration. The prospective benefits of using the WSN technologies in agriculture resulted in the appearance of a large number of R&D projects in this application domain. The job of the sensor network in this Chapter is to provide constant monitoring of field-environment factors in an automatic manner and dynamic transmitting the measured data to the farmer or researchers with WSN based on Zigbee and Internet. The real time information from the fields will provide a solid base for farmers to adjust strategies at any time.

Beside to develop a low cost, high performance and flexible distributed monitoring system with an increased functionality, the main goal of this chapter is to use a fault detection algorithm to detect fault sensing nodes in the region of fields. In the proposed strategy, wireless sensors send data via a Microprocessor Control Unit (MCU) and a wireless-based transmitter. The receiver unit receives data from a receiver and an SoC platform. And, these data are transmitted to the Internet through the RJ-45 connector. A remote data server stores the data. Any web browser, smart phone or PC terminal with access permission can view the data and remotely control the wireless network.

The rest of this chapter is organized as follows. Section 2 introduces the application to the healthcare technology, in which the system architecture of the monitoring system for the physiological signals including wireless-network acquiring unit and receiver unit with an SOC platform are discussed; The detail circuit of wireless-network acquiring unit and receiver unit for the application to the precision agriculture are mentioned in Section 3; The application scenario for the ZigBee based networks were demonstrated in Section 4; Section 5 describes the fault tolerance in WSN to detect the fault sensing nodes; Finally, the conclusions and the future work are indicated in Chapter 6.

## 2. The Application to the Healthcare technology

This Section proposed a wireless network physiological signal monitoring system which integrates an SoC platform and Bluetooth wireless network technologies in homecare technology. The system is constituted by three parts which include mobile sensing unit, Bluetooth module and web-site monitor unit. Firstly we use acquisition sensors for physiological signals, an MCU as the front-end processing device, and several filter and amplifier circuits to process and convert signals of electrocardiogram (ECG), body temperature and heart rate into digital data. Secondly, Bluetooth module was used to transmit digital data to the SoC platform with wireless manner. Finally, an SoC platform, as a Web server additionally, to calculate the value of ECG, the values of body temperature and the heart rate. Then, we created a system in which physiological signal values are displayed on Web page or collected into nursing center in real-time through RJ-45 of an SoC platform. The results show our proposed wireless network physiological signal monitoring system is very feasible for future applications in homecare technology.

Because of the fast development and wide application of Internet, homecare applications to provide health monitoring and care by sending personal physiological signals to Internet have become highly feasible. However, the health care systems have restricted the activity area of patients to be within medical health care center or within residence area. To provide more feasible manner for patients, it is necessary to embed wireless communication technology into healthcare systems. The physiological signals are then immediately transmitted to a remote management center for analysis by using wireless local area

network. Homecare service has been further extended to become mobile care service due to the ubiquity of global system for mobile communications and general packet radio service. There are many researchers have used personal digital assistant (PDA) to monitor the patient's status remotely and accurately [14]. In 2006, Lin *et al.* [15] proposed a wireless physiological monitoring system named RTWPMS to monitor the physiological signals of aged patients via wireless communication channel and wired local area network. Body temperature, blood pressure, and heart rate signals are collected and then stored in the computer of a network management center in Lin's system. A wireless patch-type physiological monitoring microsystem was proposed by Ke and Yang [16] in which the skin temperature, ECG signals, and respiration rate are measured and shown by computer information center. In this section, we propose a wireless physiological signal monitoring system which integrates an SoC platform, Bluetooth wireless, and Internet technologies to home-care application to collect the heart rate, ECG, and body temperature into nursing center respectively. In the proposed monitoring system, we used an SoC platform to create a Web server that can reduce the device size significantly. In the proposed physiological monitoring system, we designed and implemented all of the application programs and hardware modules.

## 2.1 System architecture

Fig. 1 shows the architecture of the proposed wireless-network physiological signal monitoring system that includes mobile sensor units, Bluetooth transceiver module and Web server monitor system. The Bluetooth module is integrated into mobile unit as a transmitter as well as the SoC platform in monitor system worked as a receiver for physiological signals with a wireless manner. In order to get stable physiological signals, some amplifiers and filters are added into acquiring circuits. Finally, the physiological signal values can be displayed on Web page or collected into nursing center through RJ-45 of the SoC platform. According to the proposed architecture, a wireless network physiological signal monitoring system is implemented.

## 2.2 Mobile Physiological Signal Acquisition Unit

The main parts of this unit are mainly including the sensors of thermistor, ECG electrodes; acquiring circuit of heart rate, ECG, and body temperature; and MCU circuit respectively. In order to remove noise and amplify the physiological signals, filter and amplifier circuits are also added into the mobile unit. For the purpose of processing the heart rate, ECG, and body temperature signals and transferring them to Bluetooth module, an MCU named PIC16F877 is used.

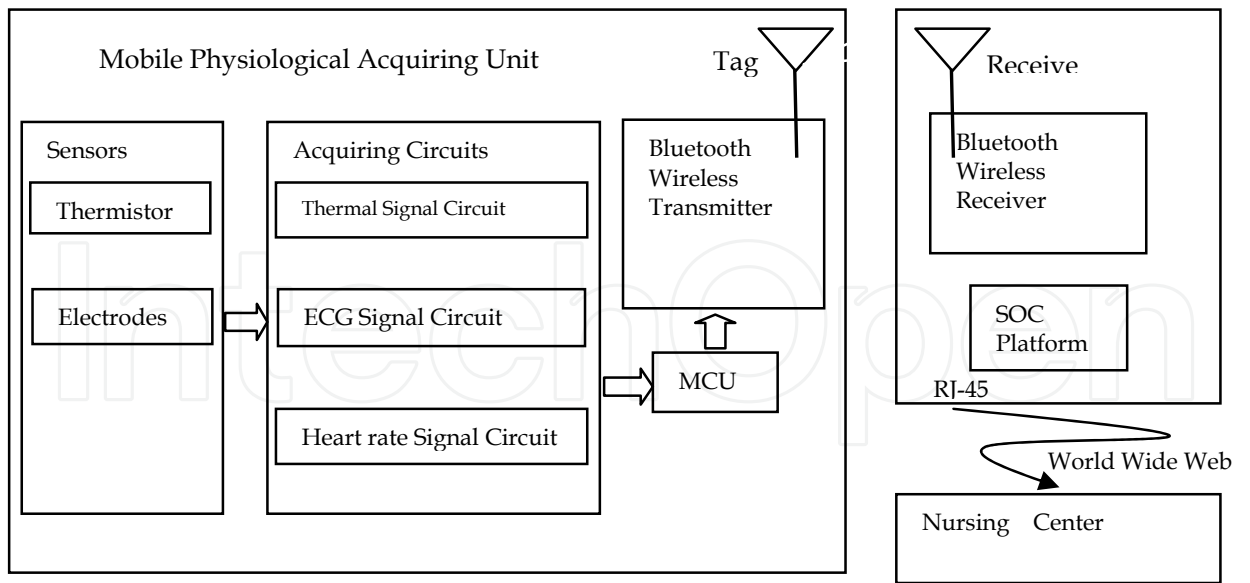


Fig. 1. The proposed architecture of wireless physiological signal monitoring system.

The body temperature is converted by an AD590 temperature sensor. The AD590 is a two terminal device that acted as a constant current element passing a current of 1 mA/°C. AD590 is particularly useful in remote sensing applications. The nominal current output of AD590 is 298.2μA at +25°C (298.2°K) and temperature coefficient is +1 μA/°K. After converting the output current of AD590 into a voltage signal, we change the temperature coefficient to +100 mV/°K by using an amplifier circuit and then send the signal to the ADC of MCU. The block diagram and circuit for body temperature acquisition system are shown as in Fig. 2.

In the proposed acquisition system, an instrument amplifier cooperates with AD590 and converts temperature signal into voltage. This instrument amplifier provides an extremely high input impedance, low output impedance, and higher common-mode rejection ratio (CMRR) to reject common-mode noise. In the front buffers, the lower OP amplifier got an aligned voltage from input port as well as the upper one transferred the temperature current to a voltage value. Because the HA17324 occupies four OP amplifiers (uA 741), we organized these three OP amplifiers in Fig.2 with an HA17324.



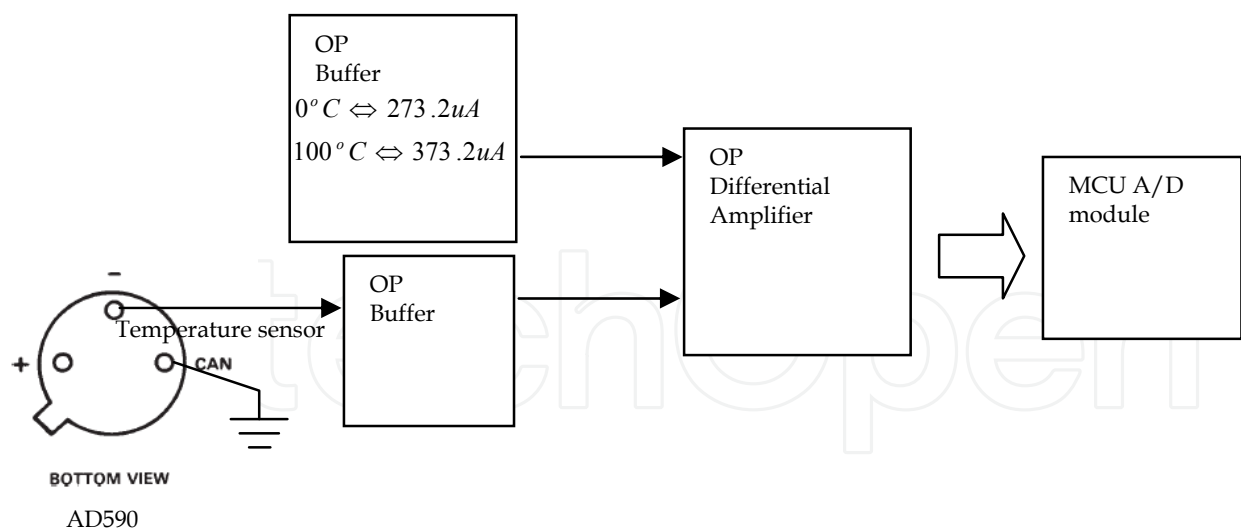


Fig. 2. The block diagram of body temperature signal acquisition system.

Electrocardiogram (ECG) is an electrical recording of the heart and is used in the investigation of heart disease. With each heart beat, an electrical impulse travels through the heart. Therefore, we can also calculate the number of heart beat with an interval to derive from the heart rate. This impulse causes the heart muscle to squeeze and pump blood from the heart. The electrical potential is an analog signal with bandwidth of 0.05 Hz to 100 Hz. It is generally around 1-mV peak-to-peak. Some of the noise can be cancelled with a high-input-impedance instrumentation amplifier (INA). Because of CMRR will result in greater rejection, we use AD620 as an INA in our signal acquisition circuit, which removes the AC line noise and amplifies the remaining unequal signals present on the inputs. In order to make signal lie in 0.05-100 Hz, we used a high-pass filter and a low-pass filter with the cut-off frequencies 0.0482 Hz and 106.103 Hz respectively. For the DC electrode, we used a high-pass filter to solve DC offset problem in which the cut-off frequency is 0.723 Hz. For the purpose of sending the analog signal to the A/D converter module in MCU, a clamping circuit was used to remain signals lie in 0 to 5 volts. The block diagram and circuit for ECG signal acquisition module are shown as in Fig. 3.

The final part of the mobile physiological acquiring unit is the MCU in which the MicroChip PIC16F877 is used. The PIC16F877 features 256 bytes of EEPROM data memory, self programming, an In Circuit Debug (ICD), 2 comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, and 2 capture/compare /PWM functions. The synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART). To integrate Bluetooth communications module directly from the USART pins of the PIC microcontroller, the details of the complex Bluetooth protocol were not needed.

Fig. 4 displays the input and output interfaces of the MCU. In the MCU PIC 16F877, we used analog input ports RA0/AN0 and RA0/AN0 to extract the ECG and body temperature signals as well as a 4-MHz crystal was mounted on pins of oscillator1 (OSC1) and oscillator 2 (OSC2) as the system clock of the MCU. Then, the digital signals of ECG and body temperature are forward sent to the Bluetooth transmitter through data output (TX) on MCU.

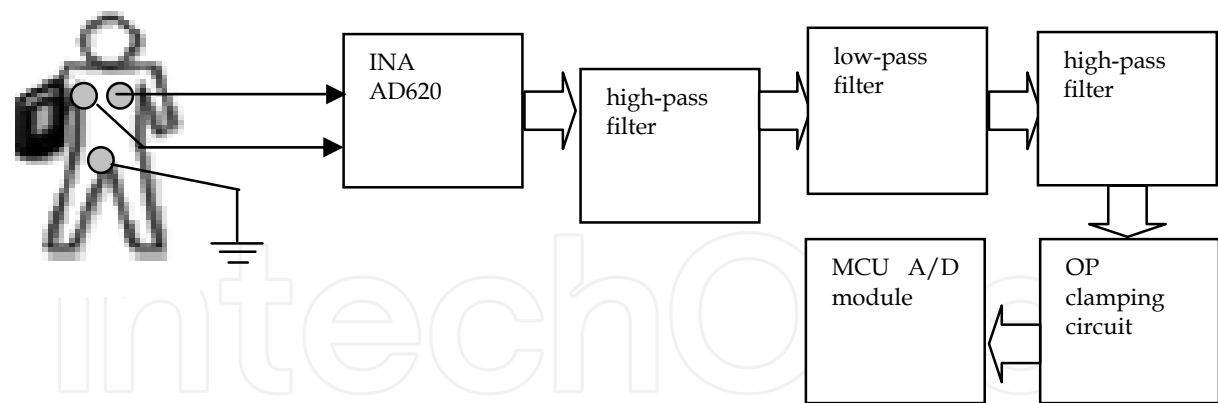


Fig. 3. The block diagram for ECG signal acquisition process.

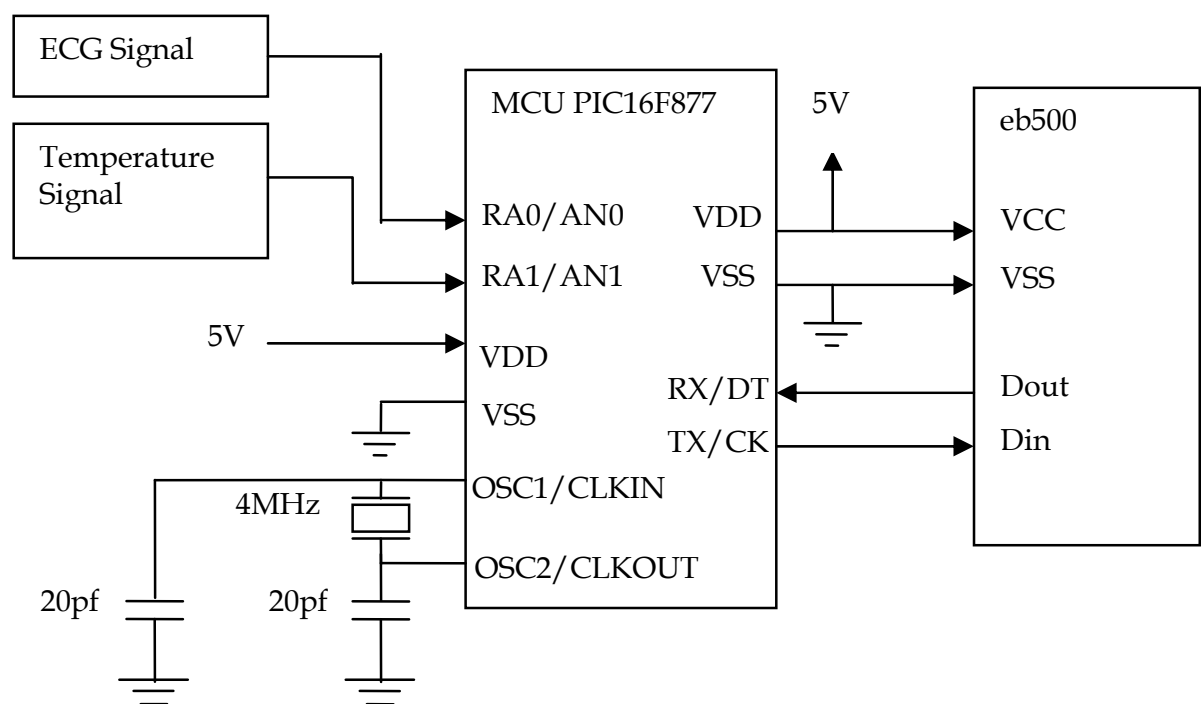


Fig. 4. The diagram of input and output signals on MCU PIC 16F877.

Fig. 5 shows the picture of the designed mobile physiological acquiring unit. In order to implement the trend of commercializing, we finished the layout of our mobile device that reduces its volume significantly. The heart rate, ECG, and body temperature signals can be acquired by physiological signal sensors. The signals were processed by amplifier, filter, and comparator circuits, and sent them out through eb500 module. In order to acquire physiological signals efficiently, we also use general battery to offer 5v for DC-DC regulator as the power supply for the mobile unit.



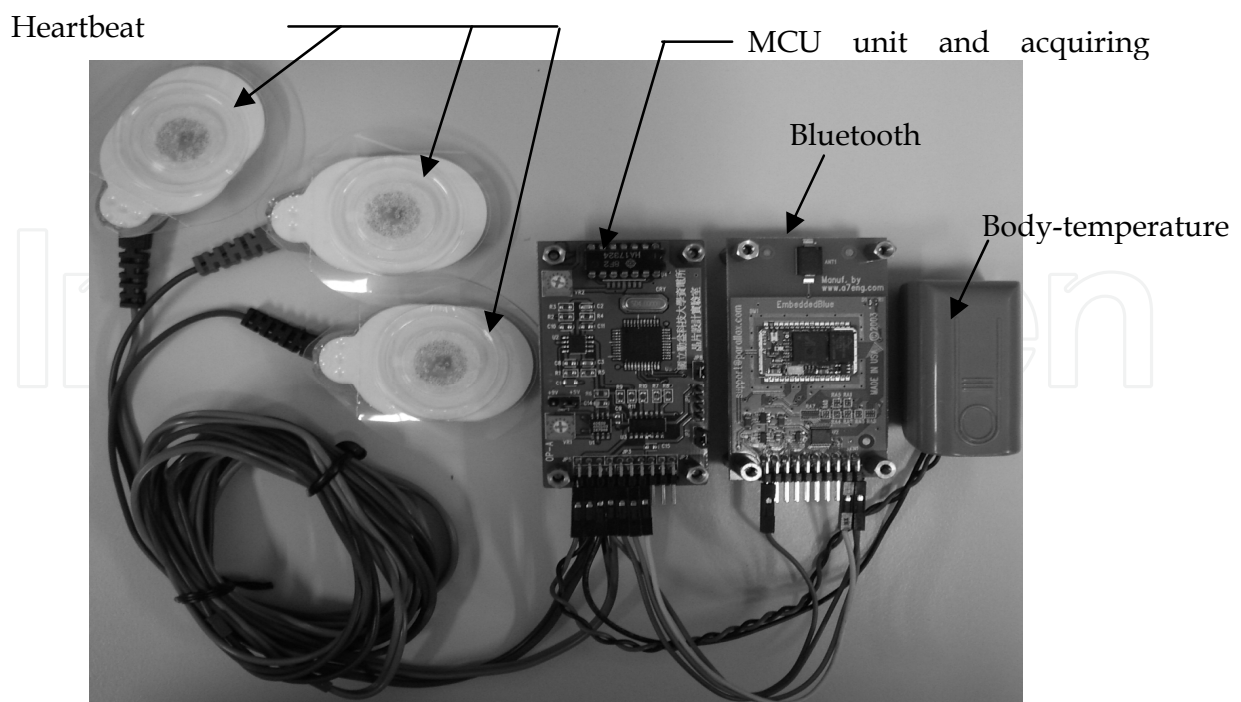


Fig. 5. The diagram of mobile unit with a Bluetooth transmitter

### 2.3 Bluetooth module

The used Bluetooth module in the proposed system is EmbeddedBlue 500 (eb500). EmbeddedBlue is a trademark of A7 Engineering. The eb500 module provides a point to point connection much like a standard serial cable. Connections are made dynamically and can be established between two eb500 modules or an eb500 module and a standard Bluetooth v1.1 or v1.2 device. Bluetooth utilizes frequency hopping in the 2.4GHz radio band and hops at a relatively fast pace with a raw data rate of about 1 Mbps. This translates to about 700 kbps of actual useful data transfer. The eb500 module supports a maximum sustained bidirectional data rate of 230.4 kbps.

In order to let two Bluetooth devices communicate each other, they must share at least one common profile. If a pocket PC is used to communicate with an EmbeddedBlue radio, it needs to make sure that they both support the same profile. The eb500 devices support the Serial Port Profile (SPP) which is one of the earliest and most widely supported profiles.

The eb500 module implements the SPP profile which enables it to appear like a traditional serial port. This virtually eliminates the need for the user to have specific Bluetooth knowledge and allows the radios to be integrated into applications very quickly. The eb500 module is a Class 2 intelligent Bluetooth module which communicates up to 10-meters that can make use of effectively at home environment. The eb500 supports two operating modes including command mode and data mode. Upon power up, the eb500 enters command mode and is ready to accept serial commands for modifying the baud rate and flow control settings. In command mode there are many commands that can be sent to change the baud rate, locate other devices, check the firmware version, etc.

## 2.4 Web Server Unit

Owing to the wide application of Internet, to access physical signals by using Internet through an embedded system is popular more and more. Using an embedded system not only can realize the equipment remote control, but also the system size can significantly be reduced. An external interface is essential to carry on the monitoring through the network. The users can manage and monitor the far-end system through Web browser which can simplify the design of human-machine interface.

We used an SOC platform built in XILINX SPARTAN-3 (SP3) [21] as a Web server and digital signal processing (DSP) unit which was implemented by using C language in order to transmit the physiological information to Web page or nursing center through the TCP/IP with a cable RJ-45. The SP3 FPGA uses eight independent I/O banks to support 24 different single-ended and differential I/O standards and allows you to easily migrate different densities across multiple packages. In the SP3 SOC platform, a built 10 base-T/100base-TX/FX IEEE 802.3u fast Ethernet transceiver named BCM 5221 is used as Ethernet PHY to transmit data to the Internet through RJ-45. The BCM 5221, designed by Broadcom Company, builds on a DSP PHY and full custom circuit design techniques to create a highly integrated and well-define physical layer solution. This development platform integrates many IP (Silicon Intellectual Property) modules including RS-232, RJ-45, USB, expand I/O pin etc. The Web server in SP3 SOC platform was developed by the Xilinx Embedded Development Kit (EDK), in which the Platform Studio (XPS) and IP cores (including a 32-bit soft- RISC-CPU MicroBlaze) are supported. The physiological data, received from Bluetooth receiver, are sent to and processed by the CPU (MicroBlaze) through a General Purpose Interface (GPI) IP. In addition, we organized off-chip memory with a 16Mega-byte SDARM as well as a hyper terminal through an internal IP named UART Lite. The architecture of the Web server and DSP unit constructed by an SOC with SP3 is shown as in Fig. 6. In the development platform, we use C language in the Xilinx's development platform and EDK version 8.1 to implement the Web server and DSP unit. Finally, SP3 platform combines eb500 to receive digital signal from mobile physiological acquiring device and calculate the heart rate, ECG, and body temperature values in the platform to transmit them to the Web page or nursing center.

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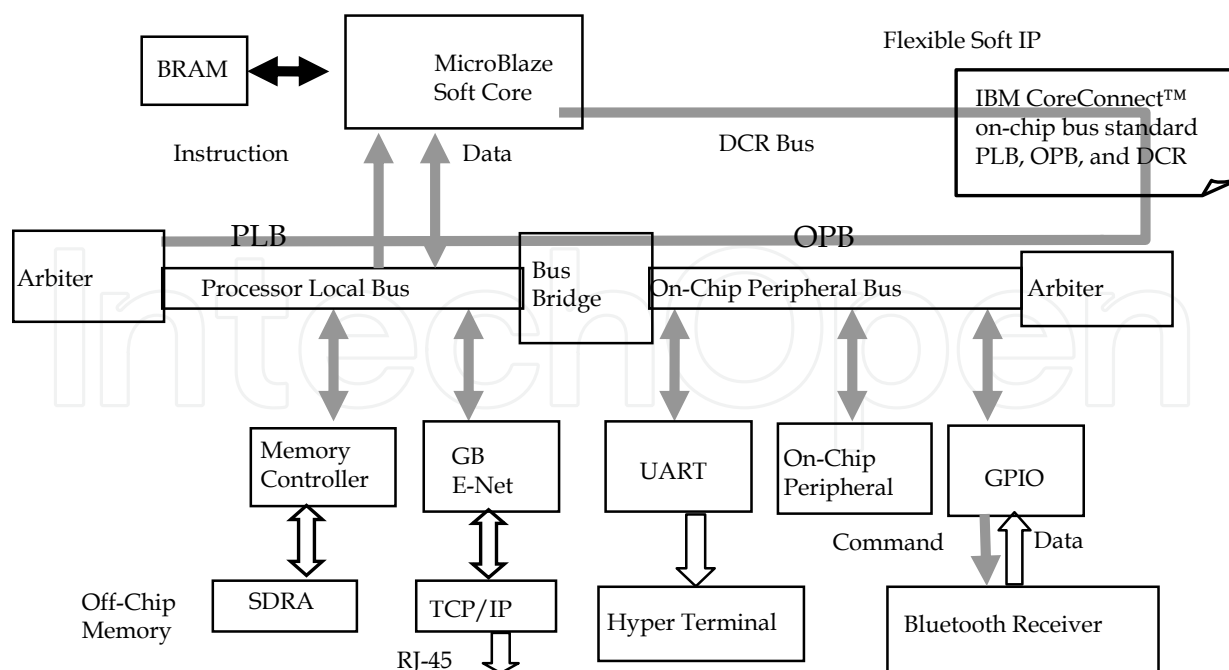


Fig. 6. The architecture of the Web Server Unit

The ECG signal was acquired through the AD620 with several millivolts. Then, the weak ECG signal was sent to the high-pass and low-pass filters, in which some noise signals are removed. In the real circuit, the drift problem for the base line of the ECG signal appeared in the frequencies between 0.0482 Hz and 106.103 Hz. Therefore, we added a clamping circuit to resolve the drift problem based line in the ECG signal. The clamped ECG signal can then be transmitted by the mobile unit and display on the Web page.

The heart rate signal can also be extracted from the intervals from a range of ECG signal. All of the above indicated hardware devices and application software have been integrated into a completed real-time wireless network physiological monitoring system. And, we use general battery solve the power supply problem of mobile device to simulate the mobile device. The front-end mobile monitoring device is light with a compact size.

The whole system has been successfully designed and tested. The physiological signals can then be accessed and stored into the physiological information database in information management system of the nursing center by a terminal or a computer in the Internet shown as in Fig. 7. Finally, the physiological signals can be displayed on the computer window through the Internet in nursing center like showing in Fig. 8. In Fig. 8, we extracted the physiological signals with a time interval about 20 ms. For the body temperature, we showed the recent 48 values with a curve manner and their average value (36.7 degrees). In addition, we also displayed the hard rate and the ECG curve about 270 points.

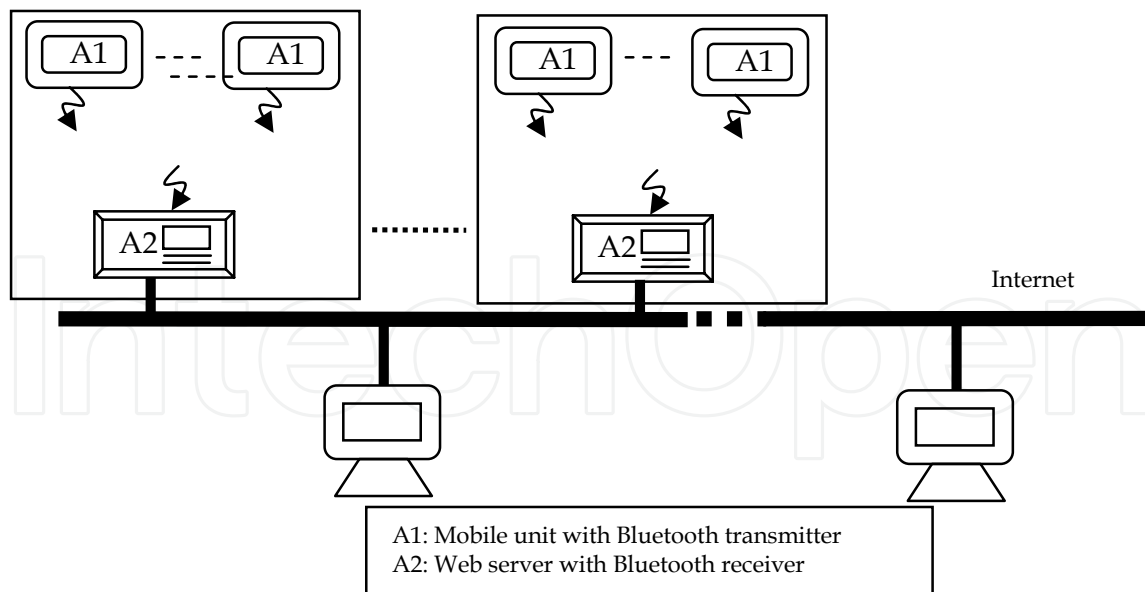


Fig. 7. Physiological signals monitoring system based on wireless and Internet Architecture.

### 3. The Application to the Precision Agriculture

This Section proposed a field signals monitoring system with wireless sensor network (WSN) which also integrated an SoC platform and Zigbee wireless network technologies in precision agriculture. The designed system is constituted by three parts which include field-environment signals sensing units, Zigbee transceiver module and web-site unit. Firstly we use acquisition sensors for field signals, an MCU as the front-end processing device, and several amplifier circuits to process and convert signals of field parameter into digital data. Secondly, Zigbee module was used to transmit digital data to the SoC platform with wireless manner. Finally, an SoC platform, as a Web server additionally, to process field signals. Then, we created a system in which field signal values are displayed on Web page or collected into control center in real-time through RJ-45 with the SoC platform. The experimental results show our proposed field-environment signals monitoring system is very feasible for future applications in precision agriculture.

In the initial effort, Alves-Serodio *et al.* [22] showed several concepts on technique for the supervision and control of agricultural systems such as greenhouse and animal live stocks-claim for the use of computer systems. The method basically focused on control of the environmental parameters in a low-cost way to generate the best agricultural product or animal living conditions. In [23] a web server based strategy was used where sensor nodes are setup with a web server to be accessed via the internet and make use of wireless LAN to provide a high speed transmission. The application of a web server assists to analyze distant agricultural fields over long periods of time whereby the whole dataset is accessible to general public. A pilot sensor network deployment in precision agriculture was proposed by Langendoen *et al.* [24]. In his algorithm the sensor nodes in the field measured relative humidity and temperature once per minute. They encoded ten samples in a single packet which was directly send or through multiple hops to a Wi-Fi gateway at the edge of the field. Wang *et al.* [25] discussed wireless sensors for agriculture and food industry in recent development and future perspective. In [26] an approach based on web server was used

where sensor nodes were organized with a web server to be accessed via the internet and make use of wireless LAN to supply a high speed transmission.

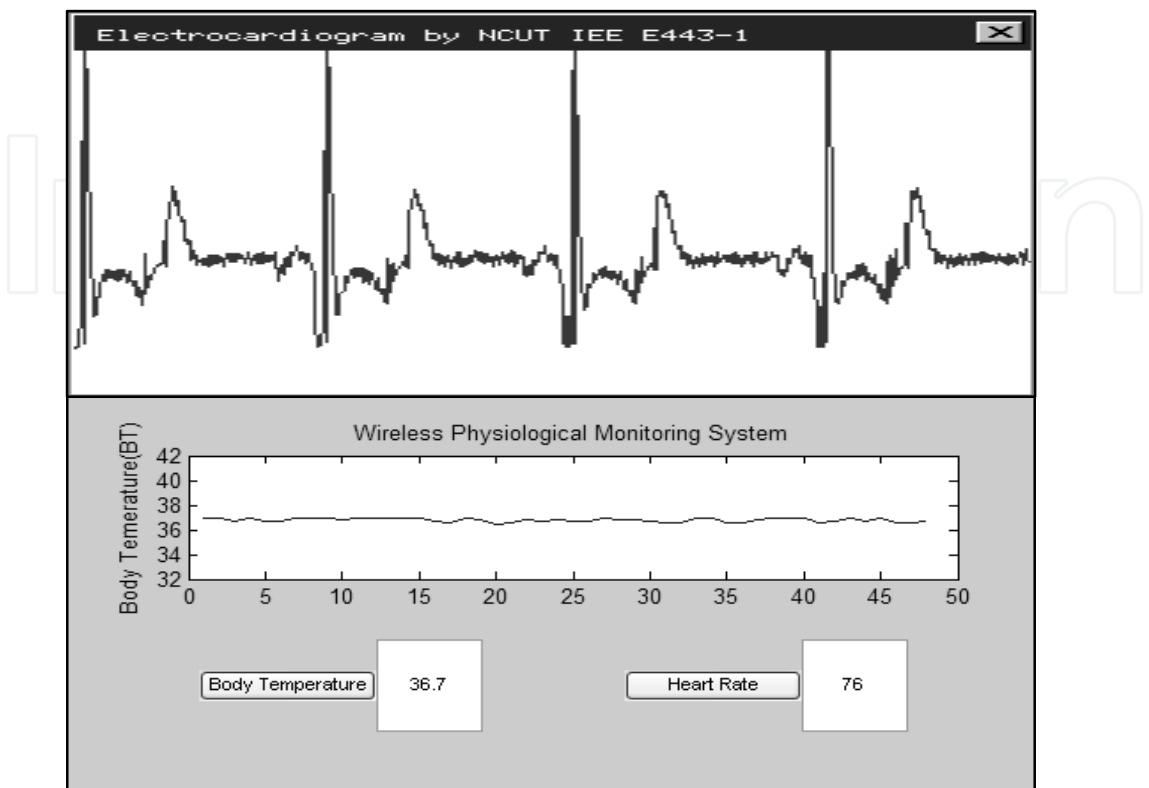


Fig. 8. Physiological-signal display window in nursing center

**3.1 System Architecture**

The advance of technology in wireless communications has developed small, low-power, and low-cost sensors. Sensor networks are developed to construct and control these sensor nodes, which have sensing, data processing, communication and control capabilities. Collecting information from these sensor nodes is routed to a sink node via different types of wireless communication approaches.

Fig. 9 shows the architecture of the proposed wireless-network monitoring system that includes sensors unit, Zigbee transceivers, an MCU, An SoC platform, and Web server. The MCU is a communicator and controller between sensors and Zigbee transmitter. The SoC platform in monitor system worked as a web server to receive the field-environment signals from a Zigbee receiver and transmit those signals to the Internet through RJ-45 interface. In order to get stable signals, some amplifiers are added into acquiring circuits. Finally, the field-environment signals can be displayed on Web page or collected into control center through RJ-45 on the SoC platform.

**Acquisition Unit and Receiver Unit**

The main part of the Wireless-Network Acquiring unit is mainly including the sensors of temperature and moisture in air and soil, CO<sub>2</sub>, and illumination. In order to amplify the field-environment signals, amplifier circuits are also added into acquiring unit. For the purpose of processing these signals and transferring them to ZigBee wireless transmitter, an MCU named SPCE061A [27] is used. Firstly, the A/D converter bound on the MCU converts

the analog signal into digital manner. And, MCU calculates and organizes the data to desired format, and writes them to ZigBee wireless transmitter. Then, the ZigBee Transmitter sends these field-environment signals to the ZigBee receiver through a handshaking protocol. Finally, these signals are transmitted to the Receiver Unit. The Receiver Unit is consisted of a ZigBee wireless receiver and an SoC platform. The field-environment signals, received by the ZigBee wireless receiver, were directly sent to the field information database on the Internet through a RJ-45 connector and Web server built on the SoC platform.

WatchDog 3667 [28], products of Spectrum Technologies, Inc. including a 6 foot cable that is connected to an external port on a WatchDog Data Logger, was used as s sensor of soil temperature. Watermark 6450WD [29-31] (Spectrum Technologies, Inc.) was used to measure soil moisture. It consists of two concentric electrodes embedded in a reference matrix material, which is surrounded by a synthetic membrane for protection against deterioration. A stainless steel mesh and rubber outer jacket construct the sensor more durable than a gypsum block. The measured temperature range is  $-30 \sim 100^{\circ}\text{C} \pm 1^{\circ}\text{C}$  for the WatchDog 3667 while the detected moisture range is  $0 \sim 200$  cbars for the Watermark 6450WD.

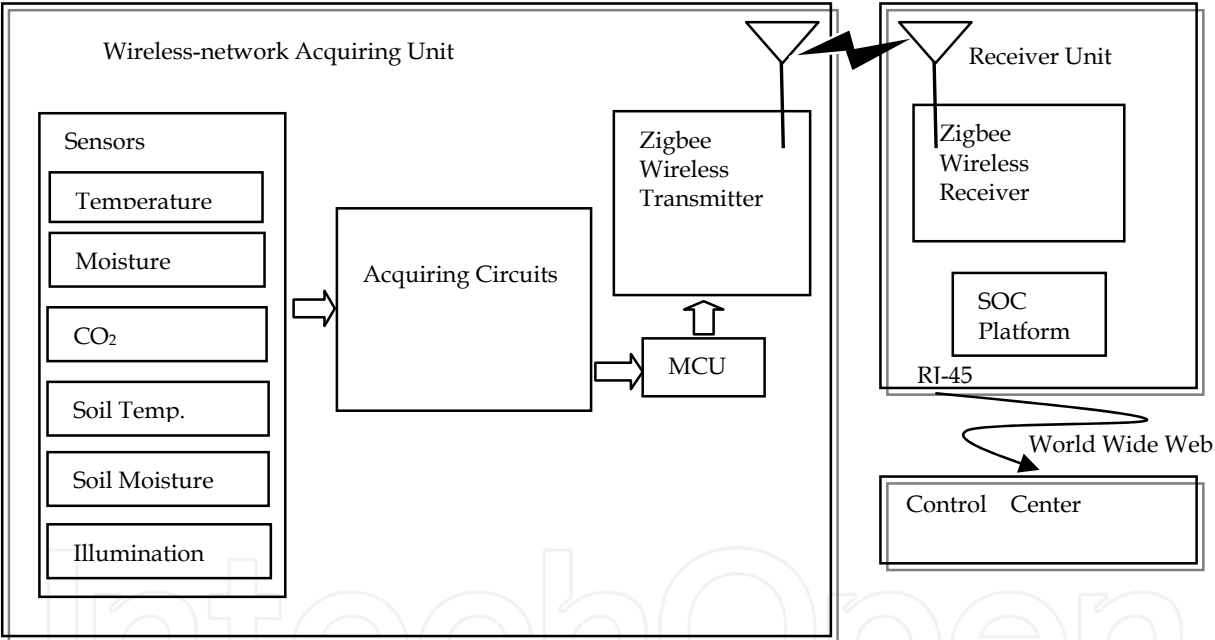


Fig. 9. The proposed architecture of wireless field signals monitoring system.

The module RHU-300M, products of Decagon Devices, Inc., was used in order to measure the temperature and moisture in the air. The range of measured temperature is  $0 \sim 60^{\circ}\text{C} \pm 1^{\circ}\text{C}$  while the range of detected moisture is  $10 \sim 95\% \text{RH}$ . For the purpose of detecting  $\text{CO}_2$ , the sensor REHS-135 [32], in which the operating humidity range is less than  $95\% \text{Rh}$ . And, the illumination was measured by using of the CDS photo-resister [33]. The completed hardware diagram of the acquiring system for these sensors to measure signals in the field-environment is shown as in Fig. 10.

The final part of the wireless-network acquiring system is the MCU in which the Sunplus SPCE061A is used. The SPCE061A features 2K words of SRAM and 32K words of Flash ROM data memory, 32 programmable input/output ports, 2 ports of 16-bit timer/counter, 7



channels of 10-bit Analog-to-Digital (A/D), 2 channels of 10-bit Digital-to-Analog (D/A) converters, and an In-Circuit-Emulation (ICE) port. Fig. 10 also displays the input and output interfaces of the MCU. In the MCU SPCE61A, we used analog input ports I/O A0 ~ A5 to extract the moisture, temperature and CO<sub>2</sub> in the air, soil temperature and moisture, and illumination. A crystal is mounted on pins of oscillator 1 (XI/R) and oscillator 2 (XO) as the system clock of the MCU. Then, the digital signals of field-environment are forward sent to the ZigBee transmitter through programmable I/O ports outputs I/O B7 and B10 respectively. To further improve communication, the nodes are enclosed in a small box while the sensors are also installed at a box with a height of 20, 40 or 60cm or embedded into soil for the soil temperature and moisture.

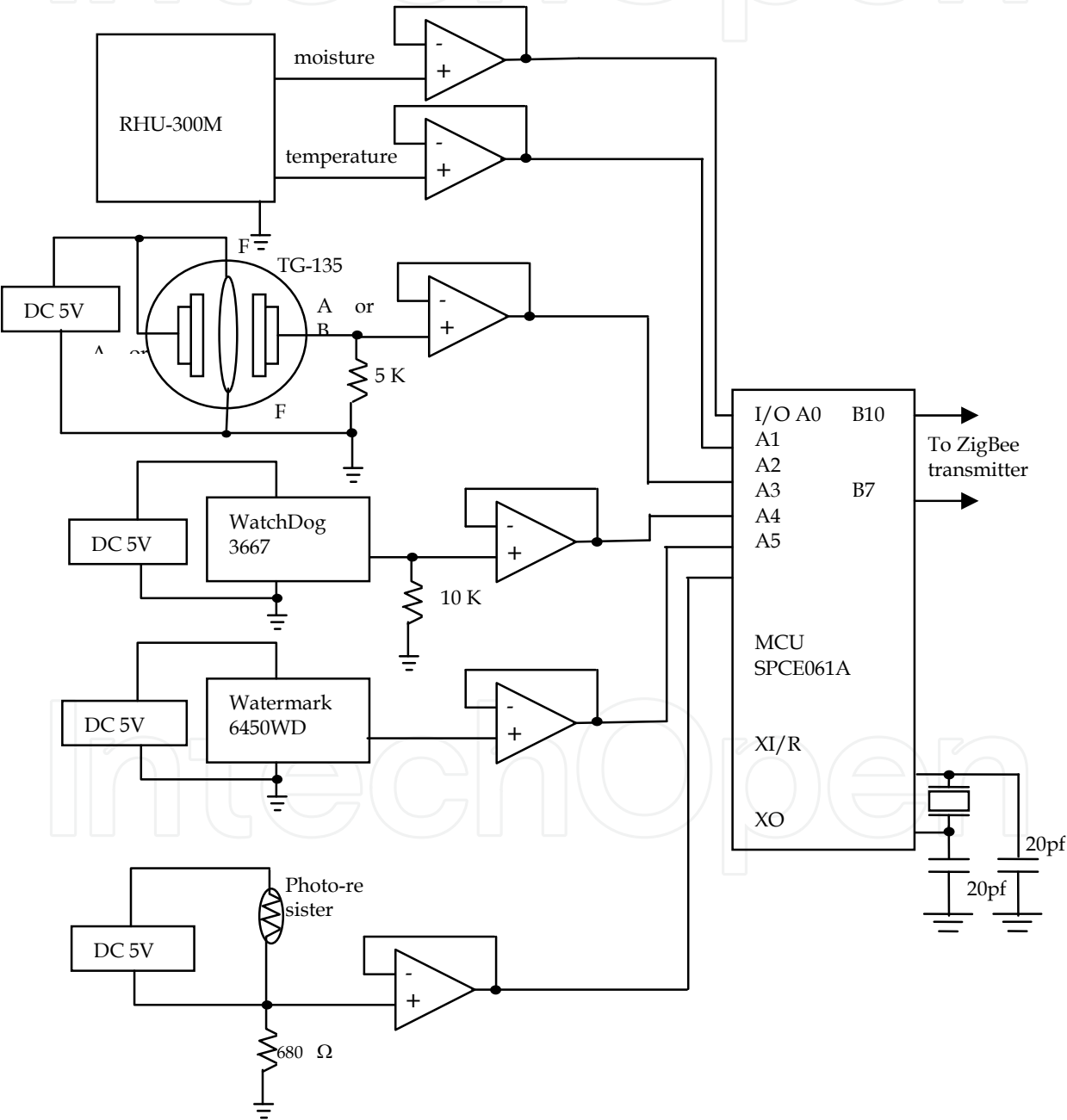


Fig. 10. The hardware diagram to measure signals in the field.

### 3.3 ZigBee Module

The used ZigBee transceiver module in the proposed system is module 3160 produced by Ready International Inc [34]. The 3160 modules provides a point to point connection much like a standard serial cable. Connections are made dynamically and can be established between server 3160 module and sensor module or between several sensor modules and a server module. ZigBee utilizes frequency hopping in the radio band and hops at a relatively pace with a raw data rate of about 250Kbps and a transmitting distance of about 200 m.

### 3.4 Web Server Unit

Owing to the wide application of Internet, to access field-environment signals by using Internet through an embedded system is popular more and more. In the web server unit, we also used an SOC platform built-in XILINX SPARTAN-3 (SP3) like the architecture shown as in Fig. 6, but Bluetooth receiver was changed as ZigBee receiver.

## 4. Application Scenario

ZigBee technology based wireless sensor can be used in a diverse, high volume sensor system. It can significantly save space and improve the reliability. Fig. 11 shows an application scenario in precision agriculture. As we know, to monitoring the real-time status of a wide field needs high-density sensors. As shown in the figure, each ZigBee receiver has quite mounts of sensors installed. MCU can poll each sensor quickly to get the sensing data. Since every sensor has a unique identification number, MCU can easy know the sensing data comes from which sensor and do respective operation.

The whole system has been successfully designed and tested. The field signals can then be accessed and stored into the field information database in the information management system of the control center by a terminal or a computer in the Internet like shown as in Fig. 11.

## 5. Fault Tolerance in Wireless Sensor Networks

### 5.1 Introductions to the Fault Tolerance in WSNs

WSNs have become a new data collection and monitoring system for different applications. The impressive advances in wireless communication have enabled the development of low power, low cost, and multifunctional wireless sensor nodes which consist of sensing, data processing, and communication components. These tiny sensor nodes can easily be deployed on a large-scale area to extract useful information from harsh or hostile environments, such as fire or rain etc. However, the character of these applications and network operational environment has also put strong impact on sensor network systems to maintain high service quality. In order to guarantee the network quality of service, it is necessary for the WSNs to be able to detect the faults and take actions to avoid further degradation of the service. Fault detection is an identifying scheme, in which an unexpected failure should be properly recognized by the network system. The fault detection approaches in WSNs can then be divided into centralized and distributed approaches [35].

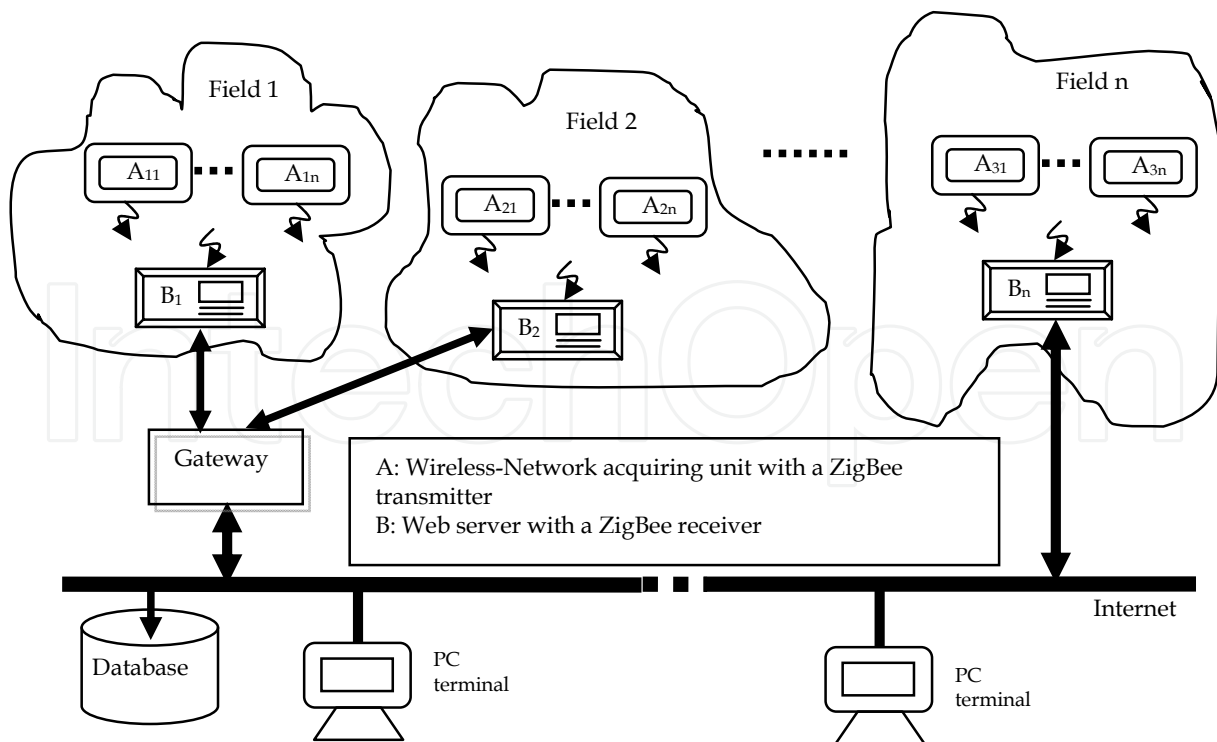


Fig. 11. The architecture of Field signals monitoring system in the precision agriculture based on wireless network and Internet.

In the centralized approaches, a geographically or logically centralized sensor node including a processing unit (PU) was used to take responsibility for monitoring and tracing failed or misbehavior node in a WSN. In several applications, a base station was used as a PU. In [36], the base station used marked packets which contained geographical information of source and destination locations to investigate sensors. It depends on nodes' response to identify and isolate the apprehensive nodes on the routing paths when an unnecessary packet drops or compromised data has been detected. Although the centralized approach is efficient and accurate to identify the network faults, resource-constrained sensor networks can not always periodically collect all the sensor measurements and states in a centralized manner. Additionally, this approach is not only extremely inefficient and expensive in consideration of a large-area sensor network, but multi-hops communication manner will also increase the response delay from the base station to faults occurred in the network. It is very expensive for the base station to collect information from every sensor and identify faulty nodes in a centralized approach. Therefore, a distributed strategy is highly preferred in WSNs.

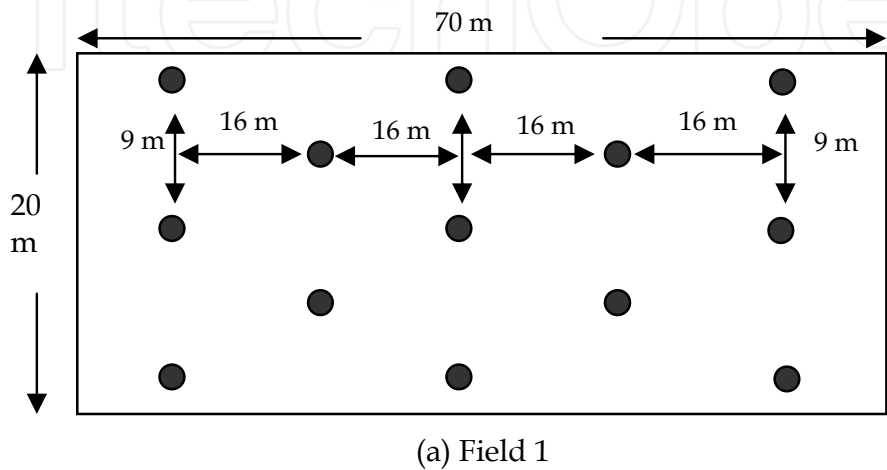
Distributed approach emphasizes the local decision-making concept to allow a local node making certain decision before communicating with the central controller. The central controller should not be informed unless there is a fault occurred in the network in order to save delivering time. Harte *et al.* [37] proposed a node self-detection model to monitor the malfunction of the physical components of a sensor node through both hardware and software interface.

Clustering approach [38] has become an emerging strategy for constructing scalable and energy-balanced applications for WSNs. Tai *et al.* [39] built a cluster-based communication hierarch to split the entire network into different clusters and subsequently fault distribute manager into each region.

Distributed detection algorithm is used to have each node make a decision on faults. Clouqueur *et al.* [40] used fusion sensors to coordinate with each other to assure that they get the same global information about the network before making decision. Fault detection through neighbor coordination is another strategy of fault management distribution, in which the network faults are detected and identified by nodes coordinate with their neighbors. Ding *et al.* [41] proposed a localized algorithm to identify doubtful node whose sensor readings have large difference against the reading value from the neighbors. Chen *et al.* [42] improved such localized algorithm to remove the node physical position.

5.2 The used Fault Detection algorithm in these two applications

In this chapter, Chen’s algorithm [42] was applied in the WSN to monitor field signals for precision agriculture. Like shown as in Fig. 11, every field was considered as an interested area for the localized algorithm in distributed fault detection. Chen’s algorithm was simulated under different number of faulty sensors in an example area and showed the simulation results with 97% faulty sensor detection accuracy with 25% faulty sensors. In this chapter, we assume that all system software as well as application software are already fault tolerant. We just focus on the hardware faults. On an interesting area, each node sends its measured value to all its neighbors. In the algorithm, a test value  $c_{ij}$  is generated by sensor  $S_i$  based on its neighbors  $S_j$ ’s measurements using measurement difference between  $S_i$  and  $S_j$  during a time interval with two predefined thresholds. The fault status of a node was determined to be likely good or likely faulty by using test value from its neighboring sensors. Finally, the good sensors are indicated in accordance with constrains in this approach. In the simulation scenarios, we constructed two 13node sensor arrays shown as in Fig. 12 to detect moisture and temperature in the air and soil, illumination, and CO<sub>2</sub> on  $70 \times 20m^2$  and  $72 \times 18m^2$  fields. The threshold values for these six parameters are predefined. The experimental results proved that the localized fault detection algorithm can achieve high detection accuracy and low false alarm rate [39]. And, in the experimental environment we can easily detect the faulty sensor nodes.



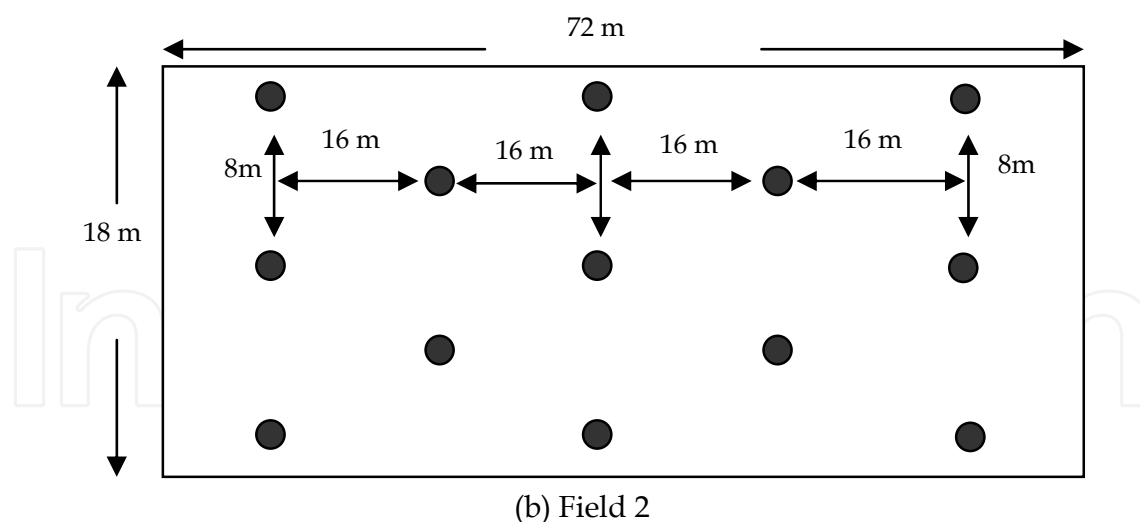


Fig. 12. Two simulation scenarios by using sensor node arrays with different distances.

## 6. Conclusions

A wireless network physiological signal and field signal monitoring systems in homecare technology and precision agriculture were proposed in this chapter. We have finished monitoring physiological signals such as heart rate, ECG, and body temperature as well as temperature and moisture in air and soil, CO<sub>2</sub>, and illumination signals in the field. We used Bluetooth technique to solve wireless transmission problem and to finish physiological signals transceiver between mobile unit and Web server that might be useful in replacing cables of physiological signal monitoring system. Additionally, we also used ZigBee technique to finish field signals transceiver between acquiring unit and Web server that might be useful for field signal monitoring. Most of healthcare-monitoring and field-monitoring systems applications use mobile device and PC as main monitoring device in their system. We used an SOC platform as the Web server that can effectively to reduce cost and the physical size significantly. Because of the popularization of the internet that displays the physiological and field signal values on the Web page in real-time through RJ-45 of SP3 platform, the doctors or patient's family can easily take care of the patient's health status while the researchers or farmers can easily look out of the product's status in the precision agriculture anytime and any place through the Web page. Additionally, we also embedded the faulty sensor detection algorithm into sensor nodes on the two simulation fields and obtain feasible faulty sensor detection accuracy.

Although the fault detection algorithm can be implemented in the wireless sensor networks on the field to detect the faulty sensor nodes, we are still persecuted by the power supply with batteries for the sensor nodes. Low power consumption is one of the advantages of the Zigbee networks, but we must change batteries when the power were exhausted. Owing to the sunlight being sufficient on the field, the solar cell will be used to support the power for sensor nodes in the future.

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