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Designing an industrial real-time measurement and monitoring system based on embedded system and ZigBee

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ABSTRACT

With the increasing automation of factories, factory floors are being covered with machinery. Spaces crowded with machinery are more difficult and dangerous for personnel to operate in. This system attempts to uses the ZigBee embedded system to improve industrial safety quality. In addition to performing existing typical monitoring functions, this system utilizes ZigBee wireless transmission technology for remote monitoring. The measurement items of the industrial applications of this system platform include length filtering, ground vibration sensing, weight grading, electricity sensing, energy monitoring, temperature monitoring, and carbon dioxide concentration. Our application of ZigBee combined with an embedded system to industrial real-time measurements represents an innovative technology. In addition to discussing the system platform in this study, we also discuss statistics and analysis of measurement data. Performing wired and wireless synchronized measurement and monitoring using this system can achieve correct and efficient industrial monitoring operations.

1. Introduction

Increasing numbers of factories have been constructed due to industrial development. However, problems of safety have also increased, e.g. equipment malfunction, human error, and natural disasters are just a few examples. The harm and damage caused by these factors is increasingly common, so factory safety has become a topic of consistent emphasis in recent years.

Performing investigation surveys of the safety attitudes of personnel emphasizing the "human factors" and recognizing characteristics and improving communication between personnel and superiors cannot completely solve the safety problem. In this study, we converted the analog signals received by multiple sensors into multiple digital signals using signal processing and then standardized the signals. DAQ was used to perform wired transmission and LABVIEW program design was used for function monitoring; ZigBee was used for wireless transmission to integrate all independent sensor signals in interfaces that allowed for centralization and real-time control. Central management can save labor, increase efficiency, and greatly reduce costs in industrial safety; remote monitoring and processing is achieved through network transmission to improve the safety and efficiency of industrial safety.

2. Literature survey

Miroslav Sveda (Ou, Chung, Sung, & Chung, 2006) introduced industrial sensor applications using local area networks as a basis, and then integrated case-based reasoning (CBR) to use this concept to protect equipment. Giuseppe (2002) believed that product quality needed to be consistent and that different assumptions determine the central value ranges of measurement. As a result, he asserted that additional measurements needed to be performed and all range distributions considered so as to standardize and internationalize these effective processes and reach clear conclusions. Stuchly and Bassey (1998) presented an industrial measurement concept using microsensors and discussed the basic electromagnetic wave characteristics and principles of industrial use for transmission wires equipped with sensors. In addition to presenting DAQ applications, Kochan, Kochan, Sachenko, and Turchenko (2005) also presented experimentation results for noise elimination and ADC processing industrial measurements. Wirandi, Kulesza, and Lauber (2004) presented a reliable online industrial automated measurement system, improving the side-removal process as well as product quality analysis and showing that human factors cannot be ignored but that the measurement process can be completely automated. Misgra, Panda, and Das (2005) presented a simpler method to design and develop an LVDT-based sensor system primarily intended to expand the linear adjustment range and to be used in conjunction with a neural network to overcome the difficulties of manual adjustment; Mishra

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also used computers to produce actual simulation data. Ford, Weissbach, and Loker (2000) considered the difficulties of commercial use of LNDT due to complexities in signal processing, and so developed a communications system using a double sideband suppressed carrier (DSBSC-AM) to improve the problem. Ford et al. used SIN wave inputted to LVDT to transmit signals and received signals through a platform used for processing such signals into digital signals. Signals were processed into optimal signals through this system, resolving the complexity of signal processing and also increasing the linear adjustment range, thereby reducing the difficulties of manual adjustment. Drumea, Vasilem, Comes, and Blejan (2006) believed that LVDT can be used in measurements of hydraulic, pressure, and electronic machinery as well as in displacement of power; LVDT has a fairly broad range of use and is also relatively accurate (0.1% error) and low-loss. However, the signal processing method of inputting a 5 kHZ SIN wave from a square-wave generator and then outputting the signal for synchronous demodulation is relatively complicated. As a result, Drumea and Vasile suggested the use of an MSP430F149 chip as a signal adjuster for LVDT to improve on this problem; this chip also has additional functions, such as providing serial communication and malfunction testing. Saxena and Lal seksena (2000) presented a type-dependent compensatory LVDT. Experimental results showed that changes produced in the production of highly-sensitive and higher linear changes while being subject to external environmental impacts are not excessive; the system actually provides temperature compensation to maintain relatively good data transmission quality even in poor environments. Flammini, Marioli, Sisinni, and Taroni (2007) suggested the use of LVDT for speed and acceleration evaluations. Using this method overcomes the limitations of more traditional conversion processes; this method also facilitates understanding of calculation functions and is now used in the field of digital signal processing module operations (DSP). Kano, Hasebe, and Huang (1989) presented a type of location detection using LVDT as a linear motor; the structure is also simpler than those typically used in location detection.

3. System structure

This system can be divided into three parts according to the operation process: sensor terminal (LVDT, temperature and humidity, energy monitoring, CO_2 concentration, electricity sensing), routing node (GIO-ZM), and network server mainframe of the central monitoring system. The system framework of this study is shown in Fig. 1.

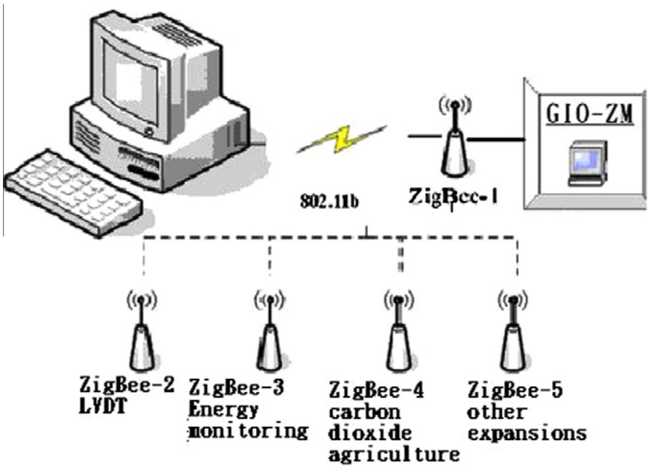


Fig. 1. System framework of this study.

Different sensors can be equipped on the sensor terminal to realize monitoring of needed data and exert the effects of the ZigBee platform. The central data management terminal is composed of the central main node GIO-ZM mainframe and a PC; the two can actualize data transmission through Bluetooth or other wireless transmission methods.

4. Description of integrated ZigBee embedded system

1. ZigBee characteristics
   ZigBee is a short-distance, simple-structured, low power, and low-transmission rate wireless communications technology. It has a transmission range of 100 m and uses the free 900 MHz and 2.4 GHz transmission frequencies. ZigBee has a transmission rate of 20 Kbps to 250 kbps; its network structure has Master/Slave attributes and can provide the function of two-way communication. Currently, ZM03 uses the 2.405–2.480 GHz frequencies; in addition, due to the low transmission rate and small amount of data transmitted, the sending and receiving time is kept low. In non-work mode, ZigBee is placed in sleep mode. In the conversion time between work and sleep modes, only 15 ms are needed for normal sleep activation time and only 30 ms are needed in the equipment search time, making ZigBee fairly power-saving. The MAC level of ZigBee utilizes a talk-when-ready collision prevention mechanism: data is transmitted immediately when there is need, and each transmitted data packet is confirmed to be received by receiver and is responded to with a confirmation message; if a confirmation message is not received in response, then a collision has occurred and the data packet is transmitted again. This method greatly increases the reliability of the system's data transmission. In addition, a ZigBee network can include a maximum of 255 nodes, making it highly expandable (Lin, Liu, & Fang, 2007a).
2. ZigBee standard-setting
   ZigBee software and hardware standards are primarily set by, respectively, the IEEE 802.15.4 and ZigBEE Alliance organizations. Development of the physical layer (PHY), media storage control layer (MAC), and the data link layer is led by IEEE, while the ZigBee Alliance is responsible for determining logic networks, data transmission encryption mechanisms, application interface specifications, and communication specifications between system products. ZigBee agreement structure diagram is revealed in Fig. 2.
   On the network layer, ZigBee supports the three network frameworks of Star, Cluster Tree, and Mesh; the roles of nodes can be divided into full-function device (FFD) and reduced-function

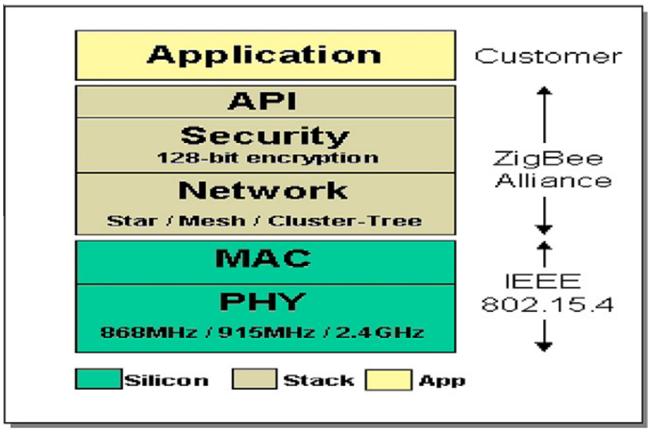


Fig. 2. ZigBee agreement structure.

device (RFD). Compared to FFD, the circuits of RFD are simpler and have less memory. FFD nodes are equipped with controller functions to provide data exchange, while RFD can only transmit data to or receive data from FFD (Lin, Liu, & Fang, 2007b).

3. Comparison of ZigBee with other wireless communications services

   In comparing ZigBee with other wireless communications technologies (Fig. 3) in terms of the wireless communications technology faces of area networks and personal networks, 802.11-series technologies (Wi-Fi) are centered on wireless local area networks (WLAN) for use in data transmission. On the other hand, Bluetooth, UWB, and ZigBee are wireless personal area networks (WPAN) technologies. The Bluetooth standard has a transmission rate of hundreds of Kbps and is thus appropriate for data transmission; it also has the QoS mechanism for voice applications. The UWB (ultra wideband) has high-speed and QoS, making it appropriate for multimedia applications. Characteristics of the ZigBee standard include low power and low-cost, so it fits the control and sensing needs in industry, family, and medicine; ZigBee does not have high requirements for data transmission rate and QoS. In addition, in comparing the currently-popular Bluetooth technology and ZigBee, Fig. 4 shows that ZigBee consumes far less power than Bluetooth; due to its low power consumption, ZigBee has a lower transmission rate compared to Bluetooth. In terms of the expansion flexibility of network node quantity, ZigBee has very strong capability in range expansion due to its support of mesh topology.

   Fields of application for ZigBee include family automation, family security, overall medical care in hospitals, and industrial automation. ZigBee can be used in conjunction with products such as home appliances, consumer electronics, PC peripherals, and sensors, providing functions such as home appliance sensing, wireless PC peripheral control, and home appliance remote control (Lin & Liu, 1997).

5. Research method for sensor components

1. LVDT components

   LVDT (Linear Variable Differential Transformer) is composed of three rings, primary ring N1 and secondary rings N2 and N3. A moveable rod-shaped iron core is inserted between the primary ring and the secondary rings; applying AC voltage to the input end of primary ring N1 produces magnetic flux with secondary rings N2 and N3. With the movement of the iron core, N2 and N3 will sense voltages of different strengths but of identical phases.

   LVDT is the type of sensor device most commonly applied in quality control. LVDT's high sensitivity, high accuracy, small size, light weight, and durability make it appropriate for use in any situation that requires accurate measurement; its range of applications is expanded due to its lack of temperature and humidity limitations. In addition, LVDT is also used in displacement distance measurements, making use of good linearity to perform distance measurement. Pressure LVDTs also exist, converting pressure into distance movements and then using LVDT principles in sensing voltage magnitude to express the size of applied pressure. Fig. 5 shows LVDT structural diagram and sensor circuitry.

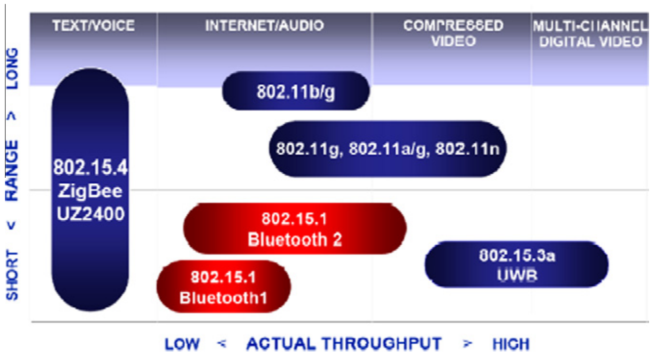
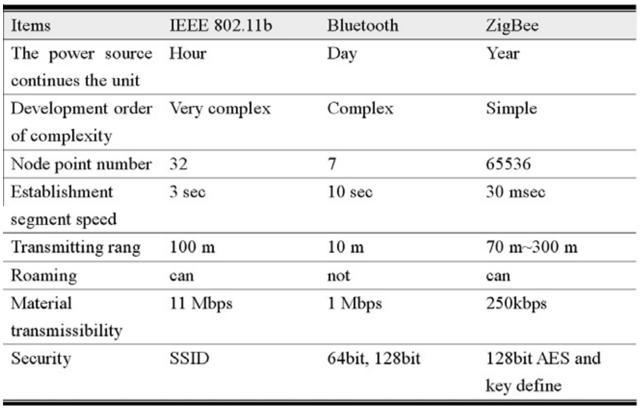


Fig. 3. Comparison of different wireless service networks.



Items	IEEE 802.11b	Bluetooth	ZigBee
The power source continues the unit	Hour	Day	Year
Development order of complexity	Very complex	Complex	Simple
Node point number	32	7	65536
Establishment segment speed	3 sec	10 sec	30 msec
Transmitting rang	100 m	10 m	70 m~300 m
Roaming	can	not	can
Material transmissibility	11 Mbps	1 Mbps	250kbps
Security	SSID	64bit, 128bit	128bit AES and key define

Fig. 4. Comparison of ZigBee with WLAN and Bluetooth.

   Our system uses the signal equivalent to the changes produced which is produced when the iron core of the LVDT measures a certain length or vibration; the signal is passed through an amplification circuit for amplification, inputted into a wired or wireless device, and then used in a precise grading system for length and depth measurements or vibrations. In addition, because this device does not need to apply additional voltage to the LVDT itself, inputting ±12 V voltage to the amplification circuit is sufficient for use; this allows for fairly small volume installations following precision manufacturing.

2. Current sensing components

   The sensor component used in this study was a current sensor formed by connecting a LEM HAS 50-S, a type of Hall component, with a differential amplification. Physicist Edwin H. Hall directed current into a *Y*-direction conduction board, and then applied a magnetic field to direction *Z* (facing oneself), perpendicular to the direction of the current. At this point, charged particles are offset by the magnetic force perpendicular to their movement of direction *X*; a stronger magnetic field leads to more serious offsetting. The results of offsetting cause charged particles to accumulate on the edges of the conduction board, forming a potential difference referred to as Hall voltage. This Hall voltage prevents further offsetting of charged particles, causing them to continue moving in a straight line. According to Ohm's law, dividing horizontal Hall voltage by vertical voltage is referred to as Hall resistance. A larger magnetic field leads to greater Hall resistance. In addition, as Hall components are basically four terminal components, same-phase voltage will accumulate in Hall components. Consequently, one must connect a differential amplifier behind the components to remove the voltage and to amplify outputted signals for ease of observation. This system can be used in measuring the presence of current or in controlling the size of the current. We set the measurement value of this current sensor device to be 0–2 amps, a measurement range which can be increased or decreased as needed (Chen, Tu, & Weng, 1990).

   In this study, we used current sensing devices to convert sensed current into voltage signals through Hall components; signals were then inputted to wired and wireless devices after being

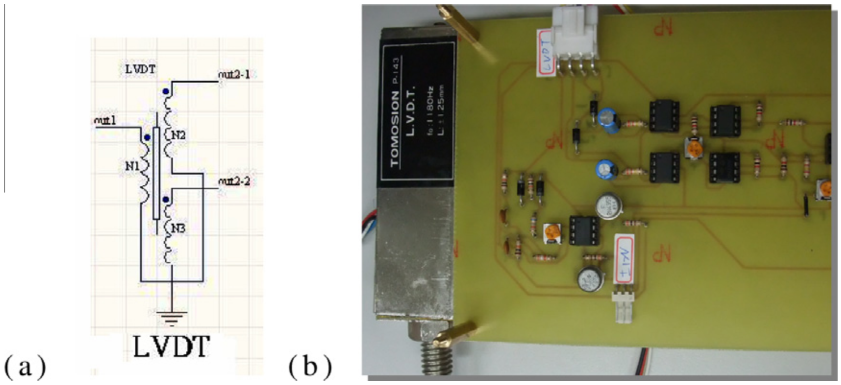


Fig. 5. (a) LVDT structural diagram. (b) LVDT sensor circuitry.

amplified using an amplification circuit. A power supply was used to produce a current so that the Hall component HAS 50-S could sense 0–2 amps of current, causing it to apply sensor voltage within a certain range. The sensor voltage was amplified to 1–5 V using an amplification circuit (Chung, Hsieh, & Yeh, 2001).

Fig. 6 depicts a current sensor formed by connecting a Hall component (LEM HAS 50-S) with a differential amplifier. The Hall component is basically four end components; same-phase voltage accumulates in the Hall component. Consequently, a differential amplifier must be connected in the back to remove the voltage and to amplify the output signal for ease of observation.

3. ZM04 component

ZM04 is typically applied in machine-to-machine wireless communications devices. In terms of hardware, ZM04 provides industrial-standard digital signal output and Darlington output as well as −10 V to +10 V analog signal input. Standard 802.15.4 is used for wireless transmission; network reliability is improved using Mesh, Star, and Cluster-tree flexible network topology, thereby satisfying wireless application needs at different distances. Fields of application for ZM04 include lighting, heating and cooling controls, industrial construction and automation, medical treatment, curfew enforcement, and RFID.

The ZM04 used in this study was built with temperature, humidity, and CO_2 sensors and could be connected to different types of sensors outputting 0–5 V signals; analog-to-digital conversion signal processing was performed, after which data was transmitted to the GIO-ZM receiver. Fig. 7 illustrates the ZM04 component, GIO-ZM component, and energy monitoring component.

4. GIO-ZM component

GIO-ZM specifications are: Geode ™ integrated processor by AMD pcs and CC2430; it integrates an embedded system control platform and ZigBee wireless transmission technology and information control system. GIO-ZM utilizes the Windows XP Embedded operating system and supports Ethernet network connection functions. The GIO-ZM can be applied to network functions such as remote-end data collection, logic control/scheduling control, and rear-end webpage databases. It can also utilize different topologies or point-to-point methods to perform short-distance network connections and data transmission. GIO-ZM can combine Ethernet connections and wireless functions to perform long-distance wireless data transmission and integration, forming an overall wireless framework. This study used GIO-ZM to receive the data transmitted by ZM04 and then display the data on an LCD monitor.

5. Energy monitoring component

After connecting the load to the energy monitor, the energy monitor can display sensed current voltage; power efficiency percentage and power factor are also displayed and outputted. Labview was then used to develop firmware for monitoring. With load voltage current and power factors observation capabilities, the LabView monitoring screen can be used to switch the load on and off (Ou, Chung, & Sung, 2006).

6. Research method

1. System block diagram

After passing the sensor (LVDT, current sensing, CO_2 concentration, energy monitoring) through linear IC amplification and

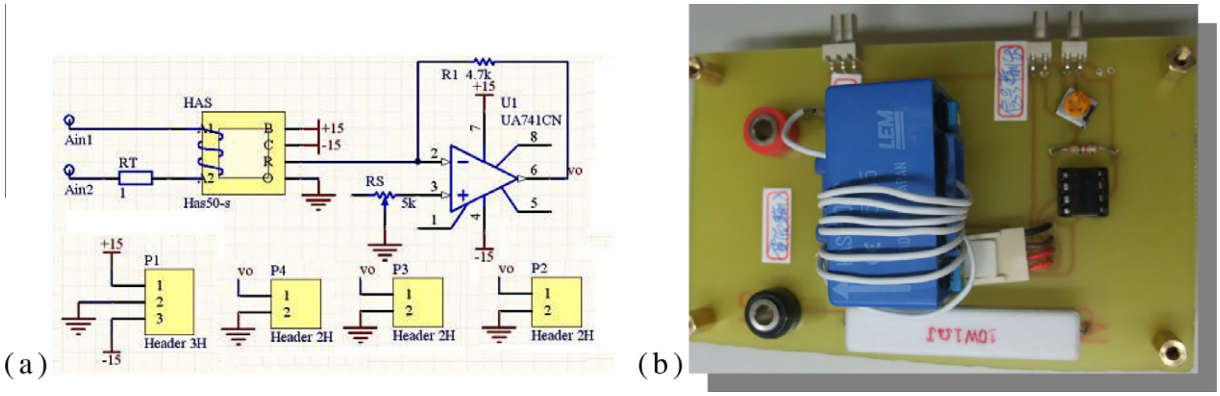


Fig. 6. (a) LEM HAS 50-S current sensing circuit analysis. (b) LEM HAS 50-S current sensing circuit.

Fig. 7. (a) ZM04 component; (b) GIO-ZM component and (c) energy monitoring component.

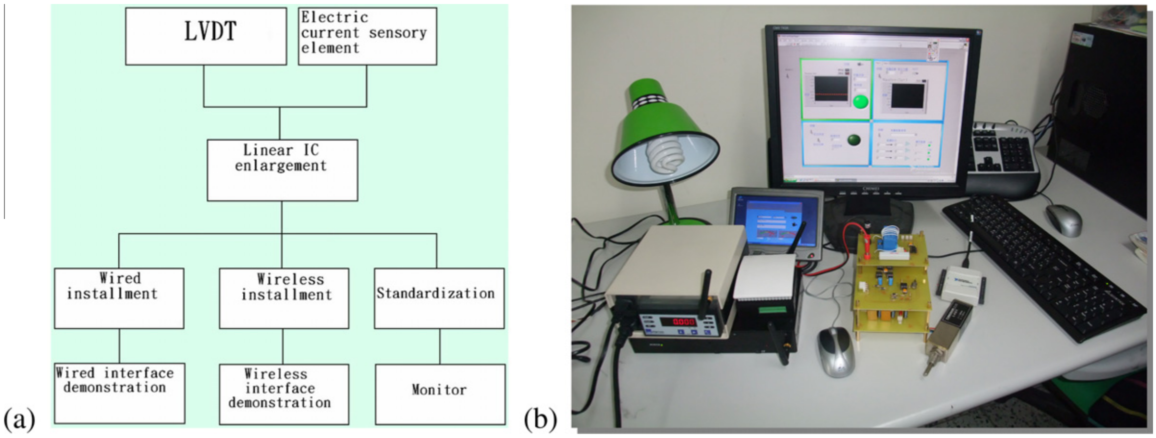


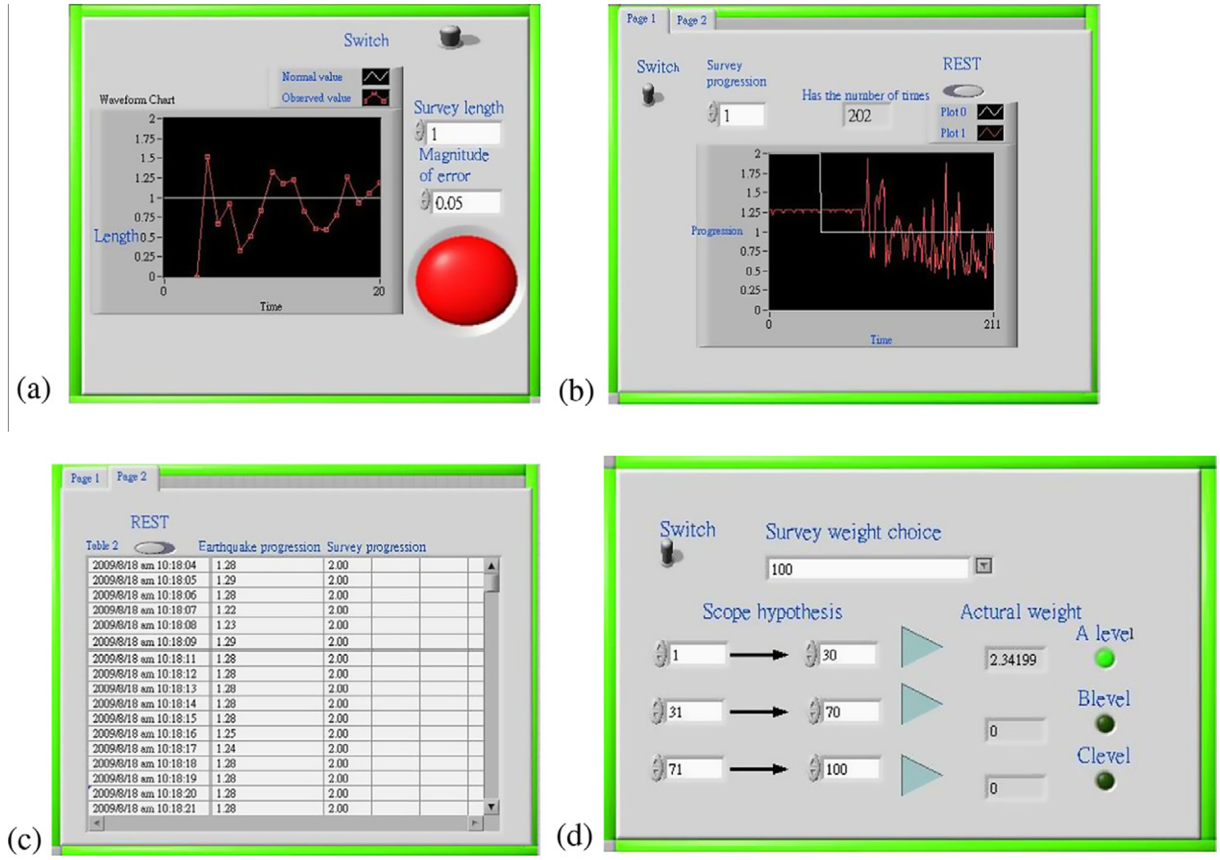
Fig. 8. (a) System block diagram and (b) wired and wireless synchronous and integrated experimental platform of this study.

extracting the signal using wired devices (DAQ) and wireless devices, LabView was used to develop, design, and integrate the ZigBee embedded system. We then performed monitoring using wired and wireless interfaces and were then able to display and output the signal after standardization using a seven-stage display. Fig. 8 depicts the system block diagram and integrated experimental platform of this study.

2. Thickness filtering
   This sensor component was developed using LVDT and was applied to thickness filtering of industrial measurement items. This filtering function can primarily be used for thickness measurements of goods on conveyor belts to serve as a basis of quality control. The meter in Fig. 9(a) displays two sets of data: the standard thickness (cm) and the thickness of the item measured. When the measured thickness exceeds the standard thickness the light in the figure will turn red, indicating rejection; otherwise, the light will be green. The function on the right side of Fig. 9(a) is used for setting standard thickness.
3. Ground vibration sensing
   This sensing component was developed using LVDT; the function is applied to measurement of factory machinery vibration strength (gal) as a factory safety reference. The meter in Fig. 9(b) displays two sets of data: the safe vibration strength of the measured machinery and the actual machinery vibration strength. When the measured machinery vibration strength in the meter exceeds the set safe vibration strength, the light in Fig. 9 (c) will turn red, indicating the current machinery vibration strength poses a threat to safety; the function will also record the time of occurrence as well as vibration strength and number of occurrences.
4. Weight grading
   This sensing component was developed using LVDT. This function is applied to weight grading and can primarily be applied to industrial grading of goods according to weight. The range settings in Fig. 9(d) are configured so that, after measured weight ranges (kg) are set, when a measured good's weight falls within a certain set range, the grade associated with that range will light up, providing a basis for categorization.

7. Experimental results and analysis

1. Thickness filtering experiment
   The thickness to be filtered in Fig. 9(a) is 1 cm, with an error of 0.05 cm. The white line displayed in the meter is a standard thickness to be filtered of 1 cm. The red dots are the thicknesses of the goods actually measured; a thickness in excess of the standard thickness (1 cm) will cause the light to turn red. It can be seen from the figure that the thicknesses of the goods measured between 56 and 71 s exceeded the standard, so the light turned red to indicate that these goods had exceeded the standard and should be rejected.
   Data analysis was performed for this study. Analysis was performed for the data collected from a thousand instances of thickness filtering measurements. There are many existing length filtering scenarios, each of which may have differing standards; some scenarios may emphasize standard deviation, while others may emphasize variance. Consequently, we performed data analysis for the 1000 sets of data to obtain the data needed in each scenario. Fig. 10(a) shown the length filtering data, and figure (b) indicated the data statistical analysis (1000 sets of data) in various experiment items.
2. Ground vibration experiment
   The set measurement grade shown in Fig. 9(b) was d gal. The white line in the meter shows that the measurement grade is 2 dal, while the red line displayed actual machinery vibration strength. In the figure, the indicator light turned red between



Survey length 1

Magnitude of error 0.05

Survey progression 1

Has the number of times 202

Table 2

	Earthquake progression	Survey progression			
2009/8/18 am 10:18:04	1.28	2.00			
2009/8/18 am 10:18:05	1.29	2.00			
2009/8/18 am 10:18:06	1.28	2.00			
2009/8/18 am 10:18:07	1.22	2.00			
2009/8/18 am 10:18:08	1.23	2.00			
2009/8/18 am 10:18:09	1.29	2.00			
2009/8/18 am 10:18:11	1.28	2.00			
2009/8/18 am 10:18:12	1.28	2.00			
2009/8/18 am 10:18:13	1.28	2.00			
2009/8/18 am 10:18:14	1.28	2.00			
2009/8/18 am 10:18:15	1.28	2.00			
2009/8/18 am 10:18:16	1.25	2.00			
2009/8/18 am 10:18:17	1.24	2.00			
2009/8/18 am 10:18:18	1.28	2.00			
2009/8/18 am 10:18:19	1.28	2.00			
2009/8/18 am 10:18:20	1.28	2.00			
2009/8/18 am 10:18:21	1.28	2.00			

Survey weight choice 100

1 → 30

31 → 70

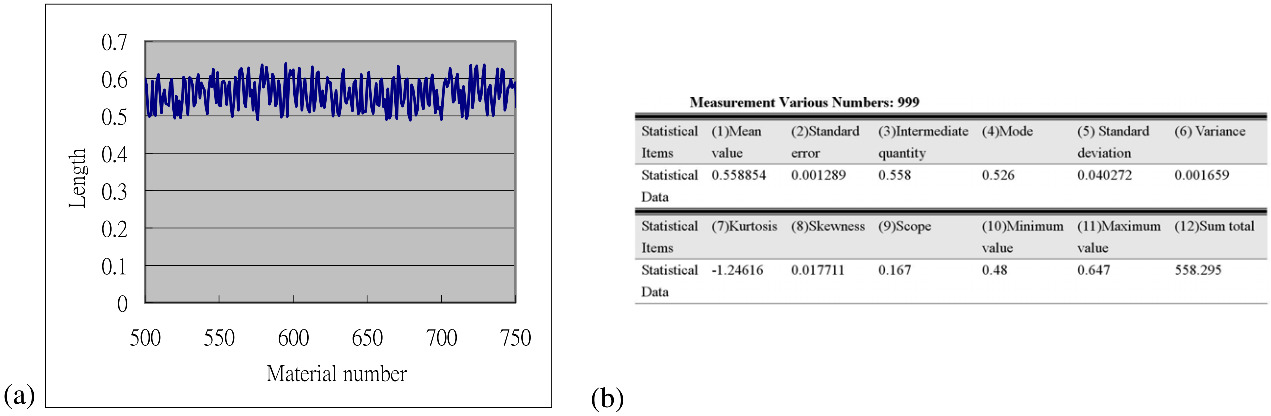
71 → 100

A level 2.34199

Blevel 0

Clevel 0

Fig. 9. (a) Thickness filtering interface, (b) ground vibration sensing interface, (c) machinery vibration data record and (d) weight grading.



Measurement Various Numbers: 999

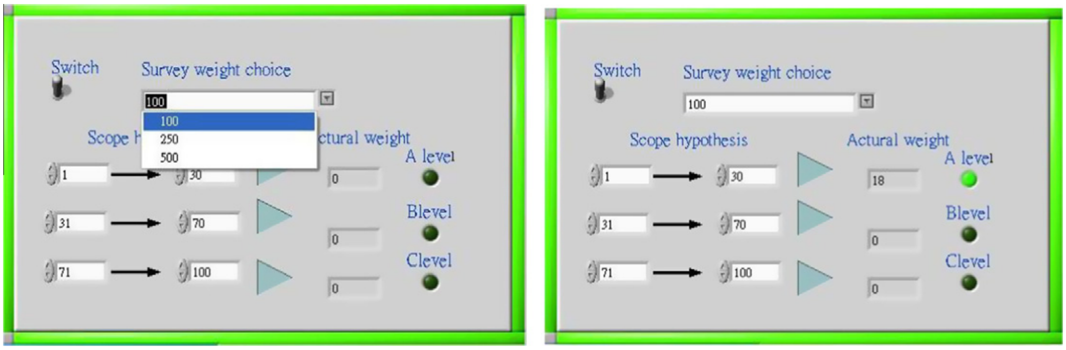
Statistical Items	(1)Mean value	(2)Standard error	(3)Intermediate quantity	(4)Mode	(5) Standard deviation	(6) Variance
Statistical Data	0.558854	0.001289	0.558	0.526	0.040272	0.001659

Statistical Items	(7)Kurtosis	(8)Skewness	(9)Scope	(10)Minimum value	(11)Maximum value	(12)Sum total
Statistical Data	-1.24616	0.017711	0.167	0.48	0.647	558.295

Fig. 10. (a) Length filtering data and (b) data statistical analysis (1000 sets of data).

22 and 131 s because actual machinery vibration exceeded the standard vibration strength. The number of occurrences of machinery vibration strength exceeding the standard was recorded, representing the number of times current machinery vibration could be a threat to the safety of the machinery and operation personnel. Fig. 9(c) depicts the recording of the time points and strength at which machinery vibration exceeded the standard. For example, a vibration strength greater than the standard (1 dal) occurred at 3:32 PM on 16 January 2008.

3. Weight grading experiment
   The measured weight selected in Fig. 11 was within 100 kg. A, B, and C grades were set, in order, as 1–30 kg, 31–70 kg, and 71–100 kg. The actually measured good was 27 kg, falling within the 1–30 kg range; it was thus determined to be A-grade and caused the light next to Grade A to light up.
   In performing signal processing for the signal extracted by DAQ, this program block includes hexadecimal conversion, range limitation, table completion, and logic design circuitry, as shown in Fig. 12, the LabView program block (Hsiao, Wang, & Chu, 1996).
4. Energy monitoring experiment
   Through plugging in home appliances, e.g. a heater, into the energy monitor's sockets, we can observe whether there is a danger of excess supply during the operating process based on sensed voltage and current changes. This system also achieves remote monitoring through wireless transmission; appliances can be directly switched off even if they are not nearby.



Switch
Survey weight choice: 100

Fig. 11. Weight grading – grading settings and determination.

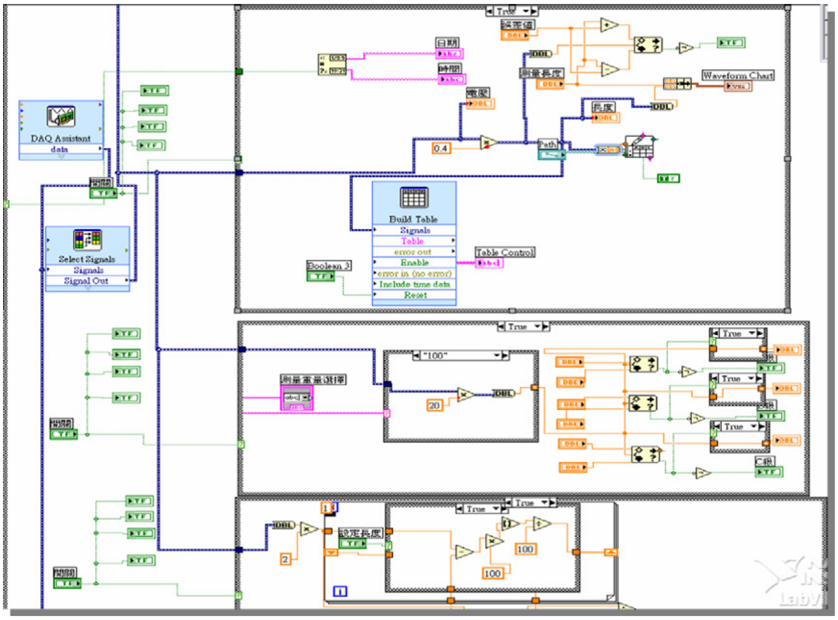
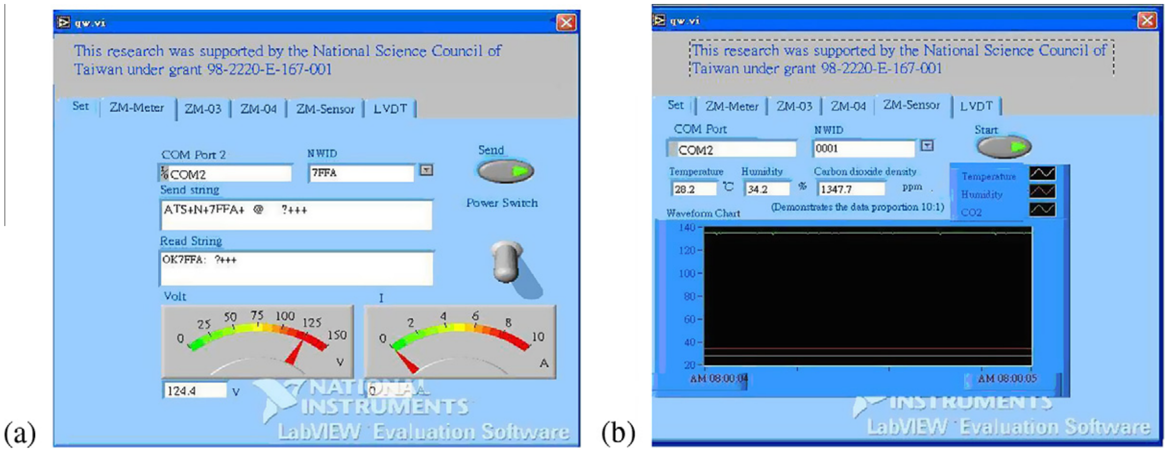


Fig. 12. LabView program block.



(a)

qw.vi

This research was supported by the National Science Council of Taiwan under grant 98-2220-E-167-001

COM Port 2: COM2
NWID: 7FFA
Send string: ATS+N+7FFA+ @ ?+++
Read String: OK7FFA: ?+++
Volt: 124.4 V
I: 0 A

(b)

qw.vi

This research was supported by the National Science Council of Taiwan under grant 98-2220-E-167-001

COM Port: COM2
NWID: 0001
Temperature: 28.2 ℃
Humidity: 34.2 %
Carbon dioxide density: 1347.7 ppm

Fig. 13. (a) ZigBee wireless transmission – energy monitoring. (b) ZigBee wireless transmission – temperature and humidity as well as CO_2 sensor system.

5. Temperature/humidity and CO_2 sensor system experiment

   The top of the interface in Fig. 13 shows the current temperature, humidity, and CO_2 concentration, while the meter on the bottom graphically displays temperature, humidity and CO_2 concentration. CO_2 concentration is displayed with a green line,[1] temperature is displayed with a white line, and humidity is displayed with a red line.

6. Wired and wireless transmission integration experiment

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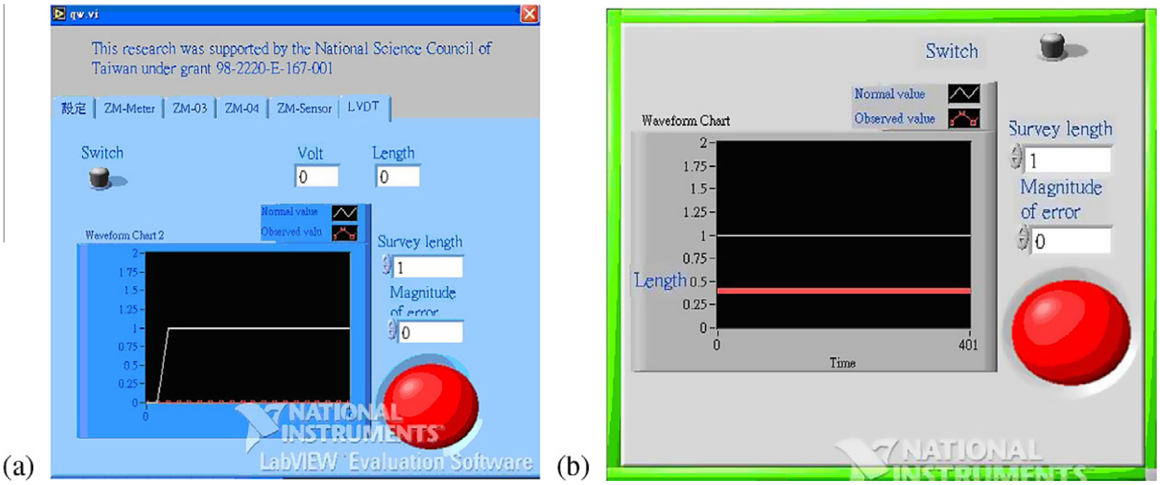
[1] For interpretation of colour in Figs. 1 and 2–14, the reader are referred to the web version of this article.



This research was supported by the National Science Council of Taiwan under grant 98-2220-E-167-001

Volt 0

Length 0

Survey length 1

Magnitude of error 0

Survey length 1

Magnitude of error 0

Fig. 14. (a) LVDT wireless control interface (b) LVDT wired control interface.

When wired data changes, wireless data changes at the same time in order to perform wired/wireless synchronous monitoring. In addition to increasing efficiency, synchronous monitoring can also perform real-time processing due to the synchronicity; synchronous monitoring can thus increase factory personnel and equipment safety. Fig. 14 shows LVDT wireless control interface and LVDT wired control interface.

8. Conclusion

As automation in factories is becoming increasingly commonplace, more machinery is being installed on factory floors. Neither machinery nor layouts are easy to operate in some places; these places are also more dangerous. Consequently, by integrating a ZigBee embedded system (LVDT, current sensing, CO_2 concentration, energy monitoring) for unified monitoring and with the real-time processing capabilities provided by synchronous wired and wireless measurements, we can greatly increase efficiency and safety. The control interface was developed using LabView (Lin, Chuang, Han, & Hsiao, 1994). LabView is widely accepted in the industry due to its ease of use. We performed data analysis for this system. There are many different scenarios for length filtering, but each scenario emphasizes different aspects. Some scenarios emphasize standard deviation while others emphasize variance. As a result, we obtained 1000 sets of data for this system and then performed data analysis; we listed the aspects used in each scenario to provide additional choices. This system used an integrated ZigBee embedded system as a basis.

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