The Design and Implementation of Real-Time Environment Monitoring Systems Based on Wireless Sensor Networks

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Abstract. This research focuses on the implementation of a real-time environment monitoring system for environment detection using wireless sensor networks. The purpose of our research is to construct the system on the real-time environment with the technology of environment monitoring systems and ubiquitous computing systems. Also, we present the monitoring system to provide a faster solution to prevent disasters through automatic machine controls in urgent situations. As the purpose of this study, we constructed simulation nodes with wireless sensor network devices and implemented a real-time monitoring system.

1 Introduction

The context-aware technology which is a core technology to construct a ubiquitous computing environment has recently become a growing interest. The representative technology of the context-aware is the Radio Frequency Identification and Ubiquitous Sensor Network (RFID/USN)[3][14][15]. In ubiquitous sensor network systems, the wireless node devices are installed on objects or places. The collected data through self-communication among them are transmitted to central nodes such as pan coordinators or sink nodes. Pan coordinators gather and analyze the data, send a control signal to control nodes such as actuators over threshold values, and adjust control conditions automatically. The USN system can be an automated network based on objects in all situations[8][9].

The USN has been utilized in robot control systems and monitoring systems, automatic temperature control systems and illuminate control systems in agricultural fields as well as other locations such as tracking system, smart homes, system, intrusion detection systems in applied applications. The research into the USN systems has proceeded through projects at universities in the U.S.A. For instances, the ecological system which has been developed by the Great Duck Island Project of U.C Berkeley installed sensor nodes at habitats of petrels and track their locations and moving paths[13][14]. Also, much research of monitoring system which can analyze crack states of buildings and bridges with sensor nodes has currently proceeded.

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Recently, USN systems can be applied to environmental problems and prevention of disasters there is overpopulation or in larger cities. In this paper, we will design and implement a real-time environment information system based on the USN to solve environmental problems that might cause large scale of disasters. Also, we will evaluate the performance of the presented system.

This paper is organized in the following manner. In the next section, we describe the basic technologies of ubiquitous computing and the real-time environment monitoring systems. In section 3, we present the hierarchy architecture of real-time environment control systems and explain their components. Also, we will experiment on the performance and the durability of sensor nodes in Section 4. Finally, we will summarize this research and will describe future work.

2 Related Research

2.1 Technologies of Ubiquitous Sensor Networks

The core technologies to implement ubiquitous sensor networks are classified into sensors, processors, communications, interfaces, and security[12][14]. First, sensors are the most important devices to sense variations of the environment as devices substituted by five senses of humans. The sensors devices are a core technology deriving objects-oriented computing environment from what has been human-oriented. Secondly, processors, which are devices corresponding to the human brain, process and analysis measured data by sensors. Processors in sensor networks can be implemented with only micro control units (MCU) executing essential functions. The low electricity-based MCU is an essential component to sustain durability of nodes. Next, communications and interfaces have interactions transmitting measured data to objects or humans through wire or wireless. Finally, ubiquitous computing systems have weaknesses in the information security. The security of USN has been researched in order to solve the weaknesses by using authentication and integrity of information[12][13].

2.2 Real-Time Environment Monitoring Systems

The goal of the environment monitoring systems is to minimize damages from disasters by monitoring and analyzing various environmental data on the real-time. However, in existing environmental information systems, humans who were expert in measuring gathered the data with analogy measurements at certain time intervals [8]. The data was dependant on the time it was measured, not data of fixed quantity with minimized errors in the real-time. For example, humans obtained data with measuring devices in the case of measuring exhaust gas from factories, and the collected data are time-dependant values and is not considering environmental variations. Therefore, environment monitoring systems which collect and analyze data on the real-time with sensor networks is required in the age of rapid variation.

3 Design and Implementation of Real-Time Environment Monitoring Systems

We constructed a real-time environment monitoring system based on the USN with the following four advantages. Our presented system has embedded operating systems executing the simple tasks, which ensures self communications between nodes. It is implemented as low electricity, and has operations of stable nodes. Also, we implemented control and monitoring application module. Fig. 1 shows the hierarchical architecture of the real-time environment system.

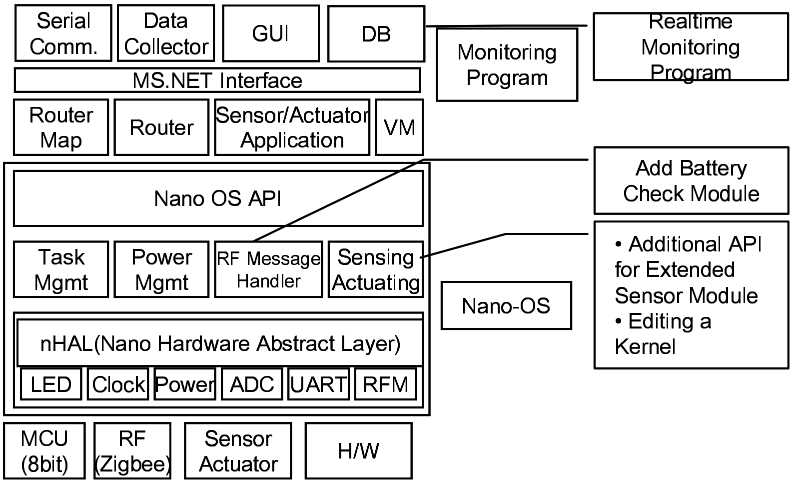


Fig. 1. The Hierarchical Architecture of the Real-time Environment System

3.1 Hardware Systems

We constructed the Nano-24 Development Kit Hardware System, which was developed by Electronics Telecommunications Research Institute in Korea (ETRI) and Octacomm Inc.[5][15]. The Nano-24 USN Kit is composed of the Main Board including RF module, the Sensor Board including gas, illuminate, temperature and

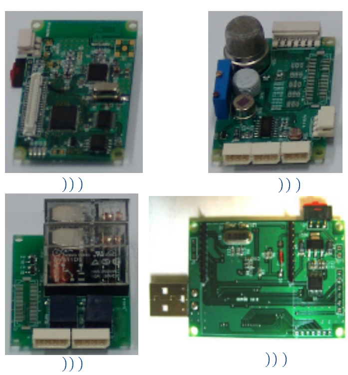


Fig. 2. Nano-24 Development Kit (a) Main Module (b) Sensor Module (c) Relay Module (d) Interface Module

humidity sensor, The Actuator Board can control machines by AC/DC relays, and the Interface Board which communicates with PC or monitoring systems using RS-232C standard interfaces. Figure 2 shows the four modules of the Nano-24 Development Kit.

3.2 Nano Real-Time Operating System with A/D Conversion Algorithm

Real-time embedded operating systems with simple task functions are used in USN systems[13][14]. We use a Nano-Q+ 1.5.1e version developed by ETRI. The Nano-Q+ is an operating system (OS) supporting hard real-time kernel and is being developed. In this paper, we reduce OS modules and add battery check modules to construct the effective monitoring system.

Analog to Digital (A/D) Conversion Algorithm. The A/D Conversion of sensors is executed by using registers related with ATMega128L made by the ATMel company. The procedures of the A/D conversion are follows:

(1) The value of An ADMUX register and an ADCSRA register must be fixed. The ADMUX is a register variable for setting analog channels and standard voltages, and control ADC data registers to save results of A/D conversion. The ADCSRA is a register variable for setting pre-scalar, free running mode, and ADC-enabled.
(2) A/D ending interrupt must be established for an interrupted type of A/D conversion. The ADIE bit of the ADCSRA variable is set up 1, and one bit of the SREG variable, which is an interrupt bit allowed, is set up 1.
(3) The ADSC bit of ADCSRA variable is set up 1, and ADSC bit is set up 0 in the case of free running mode.
(4) Wait for the interrupt occurrence of the A/D conversion ending
(5) Read contents of the A/D data register

The results of ADC conversion have 0x0000~0x03FF(0~1023). The maximum value 0x03FF means ATMega128 has 10 bits of ADC address space.

```
SIGNAL(SIG_ADC){        //Get data from ADCL and ADCH
  adc_low_data=ADCL;
  adc_high_data=ADCH; }
void Init_ADC(void){    //Initialize ADC
  ADMUX=BM(REFS1)|BC(REFS0);
  ADMUX|=BM(MUX0);
  ADCSRA=BM(ADEN)|BM(ADSC)|BM(ADIE)|BM(ADPS0); }
```

Fig. 3. A/D Conversion Algorithm

3.3 Node Construction

We constructed a Pan Coordinator, one or more Sensor Nodes, and Actuator Nodes. Fig. 4 shows interactions between nodes.

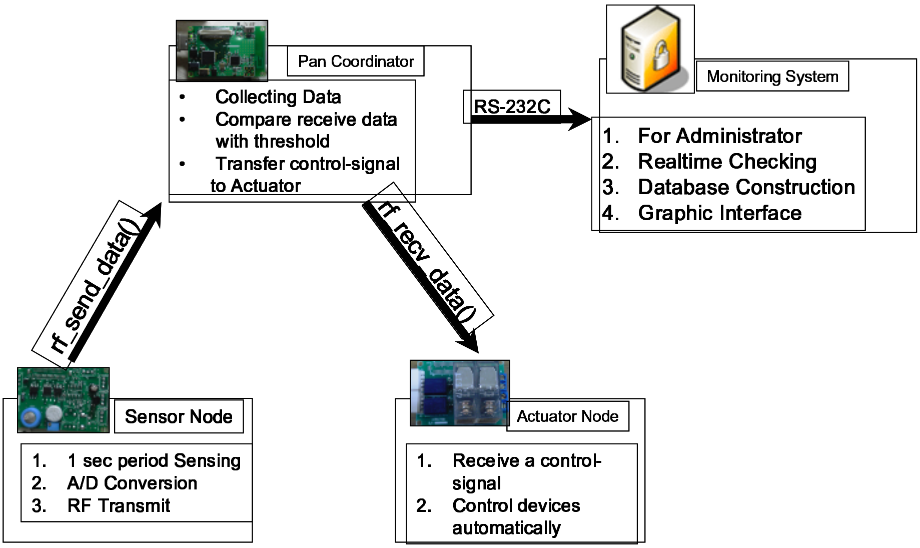


Fig. 4. The Construction of Nodes

```
/* initialize system values and then start multi-tasks. */
void *start(void *arg);
...
pthread_create(NULL,&attr,rf_net_scheduling(void *)0);
void *rf_net_scheduling(void *arg); /* network scheduling */
qplusn_tx_packet_queue_processing();  //Send Packet

/* receive task(rf-interrupt) */
void rf_recv_data (ADDRESS *srcAddr, INT8 nbyte, BYTE *data);
...
decode_indirect_packet(data,&route)  // handling received message
/* send task */
void *rf_send_data (void *arg);
...
// Transfer a control-signal
if((int_data>250) && (MAIN_GAS_VALUE_STATUS==TURN_OFF)
    direct_actuator_op_cmd_transmit(1,GAS_VALUE,TURN_ON);
    MAIN_GAS_VALVE_STATUS = TURN_ON;85
```

Fig. 5. The Algorithm of the Pan Coordinator Nodes

Pan Coordinator Node. The pan coordinator node, which is located in the center of networks, collects data[4][14]. The transmitted data is compared with fixed threshold values and sends control signals to actuator nodes. Fig. 5 shows the algorithm for constructing the pan coordinator node.

Sensor Node. Sensor nodes are inputted into values extracted from the periodic sensing and transmit A/D conversion process and the data into pan coordinator nodes by wireless[4]. In this paper, we constructed nodes with gas and illuminate sensor. Fig. 6 (left) shows the algorithm of sensor nodes.

Actuator Node. Actuator nodes receive control signals from pan coordinator nodes and set relays to ON/OFF[14]. Fig. 6 (right) shows the core algorithm of actuator nodes.

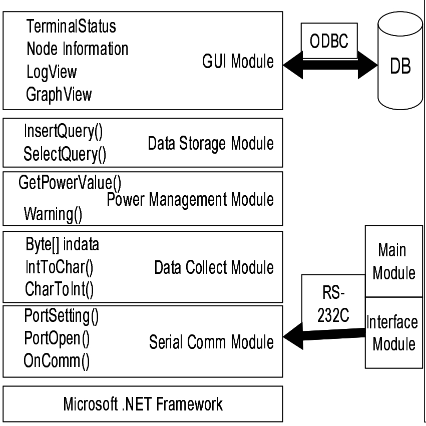
```
void *rf_net_scheduling(void *arg)
GAS_SENSOR_POWER_ON(); /* sensor power on */
LIGHT_SENSOR_POWER_ON();
while(1)
if (second_cnt==0)
pthread_create(NULL,&attr,rf_send_data,(void *)0);
//second_cnt= SENSOR_ADC_PERIODE;
  second_cnt= 10;
 /* switching */
 pthread_ms_delay(1000);
second_cnt--;
void rf_send_pkt(void)
int_data = get_gas_adc_raw_data();
sensor_gas = int_data;
int_data = get_light_adc_raw_data();
sensor_light = int_data;
nano_rf_send_pkt(&global_my_coordAddr,
  index+2, pBuffer,,TX_OPT_ACK_REQ);
halWait(50000);
```

```
void   nlde_node_incomming_data_indication(ADDRESS *srcAddr,
         UINT8 nbyte, BYTE *pMsdu)
...
if (packet_type == ACTUATOR_COMMAND_PACKET)
  actuator_type    = (BYTE)(pMsdu[index]);
  actuator_op_mode = (BYTE)(pMsdu[index+1]);
  ...
  if (LIGHT_LAMP == actuator_type)
    /* LAMP Satatus Check */
    actuator_operation(LIGHT_LAMP,actuator_op_mode);
    //rf_actuator_status_transmit(LIGHT_LAMP,actuator_op_mode);
   LED1_BLINKING();
 .....
 else if (GAS_VALVE == actuator_type)
   /* LAMP Satatus Check */
 if (MAIN_GAS_VALVE_STATUS != actuator_op_mode)
    MAIN_GAS_VALVE_STATUS = actuator_op_mode;
    actuator_operation(GAS_VALVE, actuator_op_mode);
```

Fig. 6. The Algorithm of Sensor Nodes (left) and Actuator Nodes (right)

3.4 Real-Time Monitoring Implementation

The real-time monitoring is a user interface program to express data extracted from RS232C standard serial communication interface based on the wireless sensor networks. The monitoring program consists of five modules which are serial communication module, data collection module, power management module, and data storage module, and GUI module. The modules are developed by on the Microsoft Visual Studio .NET 2003. Fig. 7 shows the structure and the algorithm of the monitoring system.




```
private void InitComPort()
  com.CommPort = userport;
  if (com.PortOpen)
  com.PortOpen = false;
  com.RThreshold = 1;
  com.Settings="9600,n,8,1";
  com.DTREnable = true;
  com.Handshaking = MSCommLib.HandshakeConstants.comNone;
  com.InputMode = MSCommLib.InputModeConstants.comInputModeText;
  com.InputLen = 0;
  com.NullDiscard = false;
  com.OnComm +=new System.EventHandler (this.OnComm);
  com.PortOpen = true;
private void OnComm(object sender, EventArgs e)
  if (com.InBufferCount>0) ProcessComData((string) com.Input);
  //Char printing//
  //byte[] indata = (byte[]) com.Input;              //Binary printing //
  //foreach (byte b in indata)
  //char[] ch = Convert.ToChar(b);
  //rtfTerminal.AppendText(b+ " ");
```

Fig. 7. The Monitoring System and Algorithm

Serial Communication Module. This module presents values extracted from RS-232C port. We implement the module by marshaling an ‘AxMSCommLib.lib’ file in the Visual Studio 6.0 tool because of without the library for controlling serial ports on the Microsoft .NET.

Data Collection Module. This module extracts data from sensors using characteristic function and expresses the collected values into following record structure.

SourceID	LightValue	GasValue	Voltage	Time	Reserved	Reserved	Padding

Power Management Module. This module presents voltage values, and warning beeps if its values drop.

Data Storage Module. This module connects with the database systems to register sensor data and manage the related log data. The values extracted from the data collection module are executed with SQL query language.

GUI Module. This module is to support user friendly-forms.

4 Experiment Results

4.1 The Experiment of Threshold Values in Sensor Nodes

We defined the threshold values by extracting an upper and a lower value from sensor nodes. We experimented with an illuminate sensor A9060 and a Nap-55AE gas sensor to attain threshold values. The results which are attained from the outdoor and indoor with varied lighters as the defined time variation are showed in table 1.

Table 1. The A9060 Illuminate Sensor

Time	Outdoor	Indoor (fluorescent)	Indoor (fluorescent +lamp)
10:00 a.m.	772	703	820
15:00 p.m.	821	822	835
18:00 p.m.	355	790	822
21:00 p.m.	257	790	821

We experiment with lighter gas, butane gas, and LPG gas using a gas sensor NAP-55A. Table 2 shows values in normal and pouring gas as the types of gases.

Table 2. The NAP-55A E Gas Sensor

NAP-55A	Values in Normal	Values in Pouring Gas
Lighter Gas for a time	67	415
Butane Gas	66	633
LPG Gas in a Can	67	335

4.2 The Experiment of Sensor Performance

We experimented on an urgent imitation situation and measured time taken in controlling machine by relays using a timer module to attain more accurate results. We interrupt the illuminate sensor from light completely and attain the time taken until actuator node's switch is in ON state. In the gas sensor, we pour into gas and describe the ON/OFF state of the motor and the ON state of the buzzer. The results are showed in Table 3. We knew our system can perceive the urgent values over threshold values.

Table 3. System Performance Results

Sensor	Illuminate Sensor	Gas Sensor
Machine State	Light On	Motor Off
Minimum Required Time	About 3.65 sec	About 4.7sec
Maximum Required Time	About 4.77 sec	About 8.5sec

4.3 The Experiment of Nodes Duality

We experimented on the sleep mode which provides the electric power for driving only basic MCU and RF circuit, and the active state mode which happens the periodic sensing to test the duality of nodes.

Fig. 8 shows results on the sleep mode (left) and on the active state mode (right). Nodes in the sleep mode are preserved to more than 15 hours, but are not preserved **for** more than 7 hours in the active stat mode. The result is analyzed because the power consumption quantity of the NAP-55A gas is about 30(mA) and the much power taken for deriving sensors needs.

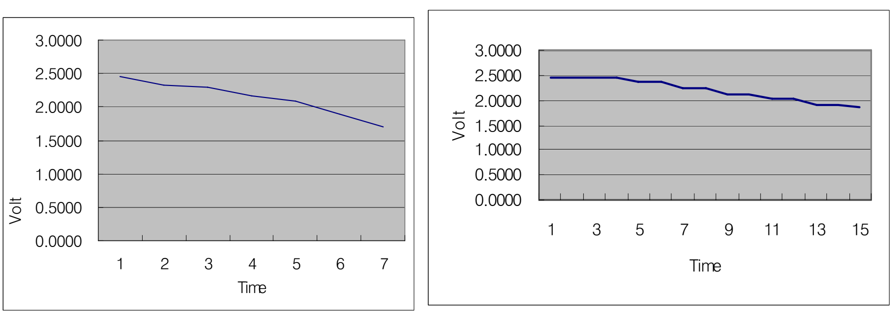


Fig. 8. Nodes Duality in Sleep Mode(left) and in Active State Mode(right)

5 Conclusion

We designed and implemented a real-time environment monitoring system based on the USN environment using wireless sensor networks. The system operates on the premise that pan coordinate node collects data extracted from sensor nodes, compares the collected date with fixed threshold values, and control the machines automatically if the data is over the fixed threshold values. The advantages of our system include: (1) the independence of roles between nodes, (2) the automated system by self-communication function between nodes, and (3) the user-friendly monitoring system to access the environment information and to process the urgent situation more easily.

It needs some improvements in order to apply our system to a real field. First, there are some problems with the amount of electrical power consumption caused from driving sensors and causing low data integrity transmitted by wireless. Especially, this happens in the case of sensor networks that need many sensor nodes. Secondly, we know that it takes a long time when driving actuator nodes and controlling machines are using gas sensors. As a result, we need to develop an algorithm to lessen the time complexity. As future work, we are planning to apply the monitoring system to a real field and to continuously improve the performance of the system.

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