REMOTE BACKGROUND RADIATION MONITORING USING ZIGBEE TECHNOLOGY

Hamisu A. Adamu 1, M. B. Muazu 2

1 Centre for Energy Research and Training, Ahmadu Bello University, Zaria
2 Department of Electrical and Computer Engineering, Ahmadu Bello University, Zaria

Abstract-In this paper, a solution of remote background radiation monitoring, based on the concept of Wireless Sensor Network (WSN), is presented. Radiation dose rate measured by the sensor node is sent to the monitoring station through ZigBee wireless network operated on 2.4 GHz unlicensed Industrial Scientific Medical (ISM) band. The system is calibrated for use for ionizing radiation dose rate range of between naturally occurring background radiation and 1.02 mSv/h. Power consumption of the sensor node is kept low by operating the node ZigBee radio with low duty cycle: i.e by keeping the radio awake only during data transmission/reception. Two ATmega8 microcontrollers, one each for sensor node and the monitoring station, are programmed to perform interfacing, data processing, and control functions. The system range of coverage is 124m for outdoor (line of site) deployment and 56.8m for indoor application where 5 brick walls separated the sensor node and the monitoring station. Range of coverage of the system is extendable via the use of ZigBee router(s).

Keywords:- ZigBee, Atmega8 microcontroller, WSN

I. INTRODUCTION

Ionizing Radiation plays many roles integral to the existence of life. However, it can be, and has been demonstrated to be, dangerous to biological systems [1], [2]. A number of events have occurred throughout history in which people have been exposed to dangerous amounts of radiation in their living and occupational environments. These adverse effects of ionizing radiation in humans are the important considerations underlying the development of safe radiation exposure limits; 0.5µSv/h for the general public and 27µSv/h for radiation workers [3]. The monitoring of the environment background radiation will hasten the detection of heightened radiation activity in good time for prompt response.

Environmental monitoring represents a class of Wireless Sensor Network (WSN) applications with enormous potential benefits for scientific communities and society [4]. ZigBee technology finds wide application in area of environmental monitoring because the ZigBee protocol was purposely developed to provide low-power wireless connectivity for a wide range of network applications concerned with monitoring and control [5], [6]. ZigBee radio operates in one of three possible RF (Radio Frequency) bands: 868, 915 or 2400 MHz These bands are available for unlicensed use, depending on the geographical area. Although 868- and 915-MHz bands offer certain advantages, the 2400-MHz band is far more widely adopted for a number of reasons [7], [8], [9]: worldwide availability for unlicensed use, higher data rate (250 kbps) and more channels, and lower power (transmit/receive are on for shorter time due to higher data rate).
II. HARDWARE IMPLEMENTATION

The hardware implementation can be divided into two: sensor node, and monitoring station, as shown in Figure 1. The radiation sensor is a Geiger Mueller (GM) tube based detector. The sensor is calibrated against a certified radiation measuring device (Rados RDS-120 universal radiation survey meter). The calibration parameters obtained are used, at the monitoring station, to calculate the radiation dose rate measured by the radiation sensor. Both ZigBee radios are configured in AT mode using X-CTU software, a graphical user interface developed by Digi, the manufacturer of the ZigBee Pro modules used in this work. In-system programming (ISP) method was employed for the programming of the microcontrollers, and the display used is a 2 X 16 character LCD.

![Figure 1: Block diagram of Background Radiation Monitoring System](image)

A. Sensor Node-

Figure 2 shows the schematic diagram of the sensor node. Pulses from the radiation sensor are fed into the input of Atmega8 microcontroller where they are processed and forwarded to the UART input of the ZigBee radio for onward transmission to the monitoring station. Logic Level shifting circuit is used between the microcontroller and the ZigBee radio in order to compensate for the variation in the operating voltages of the two devices; 5V for the microcontroller, and 3.3V for the radio.
Figure 2: Schematic diagram of Sensor node

Figure 3 shows the flow chart of the program implemented in the Atmega8 microcontroller. The program is written in C language and compiled with avr-gcc version 4.3. The program begins with hardware setup. Two out of the three timers of the microcontroller are used by the program. ‘Timer 0’ is setup as an external event counter which counts pulses received from the radiation sensor. The following statement calls the interrupt service routine (ISR) that uses ‘Timer 0’:

```c
ISR (TIMER0_OVF_vect) {
  overflows++;
}
```
The program also declares an (ISR) for Timer1 Compare Event, which occurs every second and essentially keeps track of time for the program’s time-based tasks.

```c
ISR (TIMER1_COMPA_vect) {
    secs++;
    if (secs == 58) {
        PORTD |= _BV(WAKEUP_PIN);
    }
    else if (secs == 59) {
        PORTD &= ~( _BV(WAKEUP_PIN));
    }
    else if (secs >= 60) {
```

Figure 3: Flow chart for Sensor node Atmega8 program
processFlag = STATE_READY;

Two timing functions that ‘Timer 1’ performs are waking up the ZigBee end device just before data transmission (at the 59th second), and ensuring that processed data are sent to the ZigBee every minute. The GM tube based radiation sensor used for the detection of ionizing radiation was calibrated using a Cesium radioactive source, Ortec 775 NIM Counter, and Rados RDS-120 Universal Radiation survey Meter. Table 1 shows pulse count from the sensor as recorded against corresponding radiation dose rate measured using the survey meter.

Table 1: Sensor pulse count versus radiation dose rate

<table>
<thead>
<tr>
<th>S/no</th>
<th>Sensor data (cpm)</th>
<th>Radiation dose rate (µSv/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>11</td>
<td>1.19</td>
</tr>
<tr>
<td>2.</td>
<td>50</td>
<td>5.00</td>
</tr>
<tr>
<td>3.</td>
<td>91</td>
<td>9.35</td>
</tr>
<tr>
<td>4.</td>
<td>153</td>
<td>15.00</td>
</tr>
<tr>
<td>5.</td>
<td>186</td>
<td>20.00</td>
</tr>
<tr>
<td>6.</td>
<td>249</td>
<td>26.20</td>
</tr>
<tr>
<td>7.</td>
<td>293</td>
<td>31.44</td>
</tr>
<tr>
<td>8.</td>
<td>466</td>
<td>51.50</td>
</tr>
<tr>
<td>9.</td>
<td>909</td>
<td>104.00</td>
</tr>
<tr>
<td>10.</td>
<td>1547</td>
<td>199.00</td>
</tr>
<tr>
<td>11.</td>
<td>2131</td>
<td>308.00</td>
</tr>
<tr>
<td>12.</td>
<td>2593</td>
<td>400.00</td>
</tr>
<tr>
<td>13.</td>
<td>3655</td>
<td>512.00</td>
</tr>
<tr>
<td>14.</td>
<td>4784</td>
<td>606.00</td>
</tr>
<tr>
<td>15.</td>
<td>5456</td>
<td>703.00</td>
</tr>
<tr>
<td>16.</td>
<td>5753</td>
<td>807.00</td>
</tr>
<tr>
<td>17.</td>
<td>6089</td>
<td>905.00</td>
</tr>
<tr>
<td>18.</td>
<td>6560</td>
<td>1020.00</td>
</tr>
</tbody>
</table>

Figures 4 shows the plot of dose rate versus corresponding sensor pulse counts for two different ranges: zero to one thousand, and one thousand and above. The use of separate plots for different ranges of radiation dose rate is explained by the fact that efficiency of GM tube is dependent on the intensity of radiation. That is, the dead time of the detector is not fixed, but depends on the level of radiation the tube is exposed to [10].
Figure 4: (a) Plot for count up to 1,000; (b) Plot for counts above 1,000

Two equations,

\[ y = 0.105x \]  \hspace{1cm} (1)

and \[ y = 0.146x - 22.737 \]  \hspace{1cm} (2)

deduced from the two graphs are used in the monitoring station microcontroller program to calculate the level of radiation measured by the sensor node.

B. Monitoring Station-

Figure 5 shows the schematic diagram of the monitoring station. The ZigBee radio is configured as ZigBee coordinator. It is responsible for the initialization and formation of the wireless network. Logic level translation is not necessary in this case because signal flow is from the radio to the microcontroller, and Logic level ‘1’ for the microcontroller ranges between 2.7V and 5V.
Flow chart for the program implemented in the monitoring station microcontroller is as shown in Figure 6. The program is built around a finite state machine (FSM), such that messages from the sensor node or internal occurrences cause transitions between states. The program has two interrupt service routines: one for the ‘Timer1’ unit and the other for the USART. ‘Timer 1’ ISR is as given thus:

ISR (TIMER1_COMPA_vect) {
    counts++;
    if (counts $\geq$ TIMEOUT_SECONDS) {
        updateFlag = UPDATE_ERROR;
        bufferIndex = 0;
        STATE = STATE_IDLE;
        counts = 0;
    }
}
During every Interrupt Service cycle, the program checks to see if the number of seconds that have elapsed exceeds the timeout value (timeout value is set to 90s). If so, the finite state machine is advanced to an error state and the message on the LCD is updated to indicate the error condition. Two error conditions are defined in the program; ‘Sensor offline’ and ‘Radio out of range’. ‘Sensor offline’ message is displayed if the ZigBee node at the sensor node records no pulse count from radiation sensor such that the node transmits the figure ‘0’ and same is received at the monitoring station.
Nonexistence or disruption of communication link between the sensor node and the monitoring station initiates the occurrence of ‘Radio out of range’ error condition. When error condition occurs, the state machine remains in this state till an advance is made as a result of a change in status. Reception of character from ZigBee USART triggers the second ISR. This program portion translates markers added to information received from the sensor node to imply the beginning and the end of the data packet. Reception of complete data packet (which is a sequence of characters) will cause an advance from STATE_IDLE to STATE_ACTIVE and from STATE_ACTIVE to STATE_COMPLETE. The microcontroller processes the received data and calculates the radiation dose rate, in µSv/h, based on equations (1) and (2) obtained from the calibration of the radiation sensor. Portion of the program that implements these calibration parameters is:

```c
void DisplayData(void) {
    int pulses = atoi(buffer);
    char* unit = "µSv/hr"
    double outValue = 0.0;
    if ((pulses >= 0) && (pulses <= 1000)) {
        outValue = 0.105 * pulses;
    } else {
        outValue = (0.146 * pulses) - 22.737;
    }
}
```

The use of Finite State Machine ensures robust communications between the sensor node and the monitoring station. If the system functions without any incidence, then the error state condition will never occur because the transmission time interval of the sensor node which is set at 60 seconds would never exceed the timeout value of 90 seconds preset at the monitoring station. Figure 7 shows the picture of the radiation monitoring system.

![Figure 7: Picture of monitoring system; (a) sensor node, (b) monitoring station](image)
III. MEASUREMENTS AND RESULTS

The range of coverage of the monitoring system was determined for both outdoor (line of site) and indoor applications. Summary of results obtained is given in table 1.

Table 1: Results for Radio Link Range Tests

<table>
<thead>
<tr>
<th>S/No</th>
<th>MEASUREMENT CONDITION</th>
<th>RANGE (m)</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>Av</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Indoor (with 5 brick walls between modules)</td>
<td>56.93</td>
<td>56.68</td>
<td>56.71</td>
<td>56.80</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Outdoor (line of sight)</td>
<td>121.00</td>
<td>126.24</td>
<td>124.80</td>
<td>124.00</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Indoor (with 82.3cm-thick reinforced concrete wall between modules)</td>
<td>21.27</td>
<td>22.20</td>
<td>21.77</td>
<td>21.75</td>
<td></td>
</tr>
</tbody>
</table>

Similarly, the stability of the system in continuous monitoring of various levels of background radiation was tested at a nuclear waste management/storage facility and the results are as given in Table 2.

Table 2: Results for system stability test

<table>
<thead>
<tr>
<th>S/No</th>
<th>DEVELOPED SYSTEM RESULTS(μSv/hr)</th>
<th>RADIATION METER RESULTS(μSv/hr)</th>
<th>PERCENTAGE ERROR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.128</td>
<td>0.126</td>
<td>+1.587</td>
</tr>
<tr>
<td>2.</td>
<td>5.017</td>
<td>5.090</td>
<td>-1.434</td>
</tr>
<tr>
<td>3.</td>
<td>82.950</td>
<td>83.254</td>
<td>-0.365</td>
</tr>
<tr>
<td>4.</td>
<td>280.780</td>
<td>271.300</td>
<td>+3.494</td>
</tr>
</tbody>
</table>

Each entry is averaged over eight readings and the results compared with corresponding dose rates obtained from Rados RDS-120 universal radiation survey meter.

IV. CONCLUSION

The Wireless Background Radiation Monitoring System was tested at a radioactive waste storage facility and the test confirmed its suitability for continuous monitoring, as results obtained from the system only show deviation within +/-4% of those obtained using a certified radiation measuring device (Rados RDS-120 universal radiation survey meter). The system range of coverage obtained for both outdoor (line of sight) and indoor application can be extended by the introduction of ZigBee router node(s) between the two units, in multi-hop peer-to-peer topology. The depth of this extension can be up to the 32 network hops allowable in ZigBee Pro wireless network.
REFERENCES