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A Development of Sub-1GHz ZigBee based IoT Sensor Network Safety Management Devices for Indoor Construction Sites

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Abstract: - **This study has been conducted for developing IoT sensor network-based safety management device. In this paper, we developed a safety management device consisting of a wearable low power safety management sensor tag integrated with temperature, humidity, triaxial acceleration, and altitude sensor and border router using Sub-1GHz ZigBee. The developed device is more suitable for indoor construction sites with longer radio reach and more obstacles than equipment using the 2.4 GHz band. In addition, the LTE network is shared by several sensor tags through the edge router, so the maintenance cost is low.**

Key words: Component, formatting, style, styling, insert.

1. INTRODUCTION

Due to various disasters in recent years, the importance of national safety is increasing. In January 2018, the Government of the Republic of Korea announced that it would focus on national safety as the central government goal and to promote industrial safety as three major projects to protect the national life [1]. In particular, the construction site is a high-risk sector, which accounts for about half of the deaths per year. However, despite the government's intensive countermeasures, according to the Industrial Accident Occurrence at the end of June 2019 announced by the Ministry of Employment and Labor, the number of deaths due to disasters increased by 3.9%. [2]. Also, various technologies such as IoT and AI have been developed in recent years, such as disaster and risk detection, but the development of such technologies does not easily apply to labor-intensive fields where small capital is invested, such as indoor construction sites. Moreover, the indoor work environment is not only significant in terms of interference factors (e.g. workers, pillars, materials, etc.) that interfere with the collection of information using sensors, but also in very poor communication environments [3]. This is not only a big obstacle to construct a sustainable IoT environment, but also cannot guarantee the quality of service of the systems being developed [3]. In previous studies, IoT sensor networks using various wireless communication technologies such as Bluetooth BLE and Wi-Fi have been proposed. However, indoor construction sites have a short line of sight and because of this, the radio waves are difficult to reach, and since it is difficult to build a power grid during construction, a wireless communication method with low power consumption and keeps long radio range will be required. In this paper, newly developed Sub-1GHz ZigBee based IoT Sensor Network Safety Management Devices for Indoor Construction Sites are proposed. Wei-Cheng et al. argues sub-1GHz radio frequency device achieves larger communication range and suffers fewer reflections in the indoor space [4]. In this manner, sub-1GHz frequency range is much more suitable for indoor construction sites. The developed devices are illustrated in Figure 1. This paper is organized as follows: In Section II our sensor tag and routers and development processes will be discussed. Lastly in we conclude in Section III.

a. b. c.

Figure 1: The Developed Sub-1GHz ZigBee based IoT Sensor tags and Routers (a. Sub-1GHz ZigBee based IoT Sensor tag, b. A safety helmet which attached with the sensor tag, c. Sub-1GHz ZigBee based IoT router)

II. THE DEVELOPMENT OF SUB-1GHZ ZIGBEE BASED IOT SENSOR NETWORK SAFETY MANAGEMENT DEVICES

In order to develop a sensor tag that can be attached and detached to a hard hat to monitor the worker's environment at the construction site, several design requirements for the development were required.

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1. Use a small MCU for small volume and low power consumption.
2. Use Sub-1Ghz based ZigBee, a wireless communication method suitable for construction sites.
3. Use accelerometer to detect falls.
4. Equipped air pressure sensor to detect dangerous situation such as explosion.
5. Add temperature and humidity sensor for safety management in working environment such as extreme cold and hot.
6. Lithium polymer battery with low power usage and rechargeable.

However, according to the research, the existing Sub 1Ghz ZigBee-based network devices are sold in the form of Evaluation Module including network chipset. Therefore, it was necessary to design and develop new manufacturable devices to reduce size and minimize power consumption. In addition, it was confirmed that the design of the housing and the connection part of the device is inevitably required to be mounted on the helmet according to the construction site.

For the development, we designed block diagram for sensor tags. It shown Figure 2.

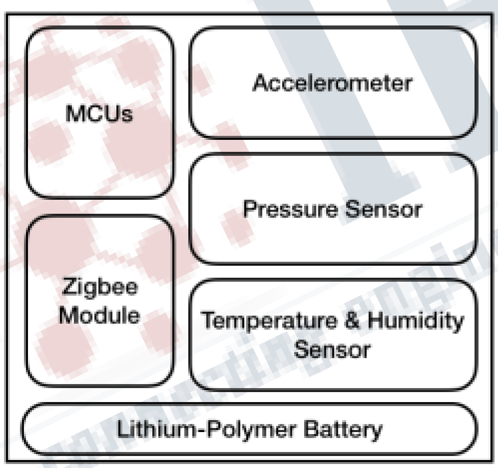

Figure 2: The Block Diagram of Our Sensor tag

Also, select proper components that meet our requirements is important. So, we chose tinyDuino, a microcontroller unit (MCU), for small volume and low power consumption. The MCU employs the Atmega328P processor and has a tiny form factor of 20mm x 20mm and 1.10g. It can also operate at a low voltage of 2.7V. Figure 3. a. is shown.

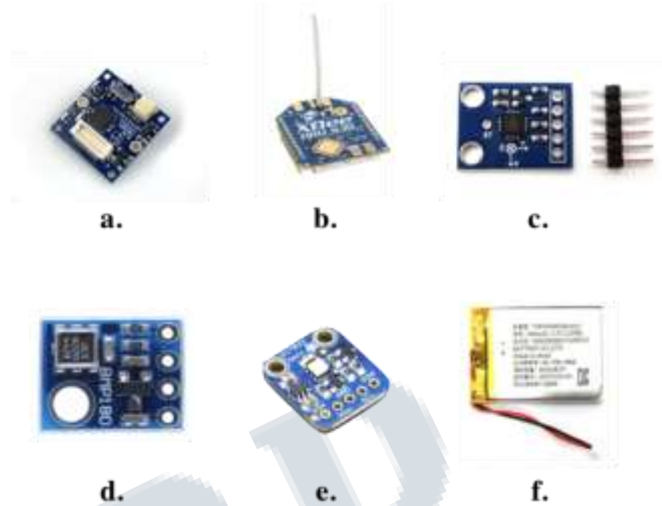

Figure 3: Components of our developed Sub-1GHz ZigBee based IoT Sensor tag

(a. Main Controller (TinyDuino), b. Sub-1Ghz ZigBee Module (XBee-PRO XSC S3B), c. 3-Axis Accelerometer (ADXL335),

d. Digital Pressure Sensor (BMP180), e. Temperature & Humidity Sensor (Adafruit Si7021)).

In addition, XBee-PRO XSC S3B module using Sub-1Ghz based ZigBee, which is suitable for indoor construction site, is adopted. It is shown in Figure 3. b. The module is capable of wireless communication using Sub-1GHz (900 MHz) and has a maximum power consumption of 250mW (Peak). It also has a built-in wire antenna and a transmission rate of 19.2 Kbps.

To overcome the shortcomings of this low data rate module, the firmware has been developed to collect data once per second. Next, the ADXL335 accelerometer is used to detect the fall. The sensor has a three-axis acceleration sensor and can transmit data to the MCU at angular velocity and acceleration. It is shown in Figure 3.c.

In order to detect sudden explosions, the BMP180 digital pressure sensor was used to measure altitude and barometric pressure. When module operate the high precision mode, the current is 15uA and it operates at low power. It also has a precise barometric resolution of 0.03hPa, which can be used to estimate the current height using altitude. Accurate altitude measurements are possible using the sea level air pressure closest to the measurement area. This sensor is shown in Figure 3.d.

In addition, Adafruit Si7021 temperature and humidity sensor is added for the safety management of workers in the harsh working environment. The humidity error range: ± 3%, and humidity measurement range: 0–80% RH. Also, temperature error range: ± 0.4° C. and temperature measurement range: -10 to +85 ° C. The interface for

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communication with MCU: Operates at 3.3V with I2C. It also has a small form factor of 17.8mm x 15.3mm x 3.0mm. This sensor is shown in Figure 3.e.

Lastly, the sensor tag is powered by a lithium-polymer battery that can be charged. The battery will be supply the power at 500mAh and 3.7V, despite its small size of 30 x 35mm. This battery is shown in Figure 3. f. The final sensor tag should look like Figure 1.a.

In addition, we devised several methods for fastening to the helmet using the existing device housing but concluded that it was impossible to use the existing housing and concluded that a new device housing must be manufactured. To do this, the housing design was carried out using Onshape, a web-based online CAD, for the production of small prototypes. The completed design is shown in Figure 4.

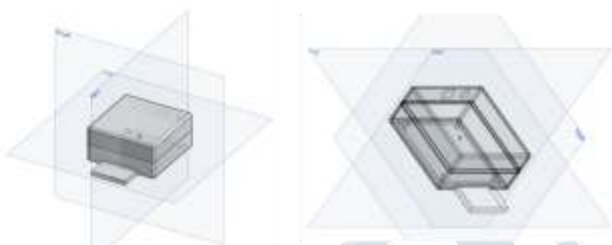

Figure 4: The Completed Design of Sensor tag Housing

This sensor tag housing is designed to be attached to the safety helmet and is also detached easily. The shape of the completed sensor tag housing is shown in Figure 5. a. The figure on the helmet is shown in b.

a. b.

Figure 5: The Designed Sensor tag Housing with Safety Helmet

In addition, we manufactured a Sub-1Ghz ZigBee-based border router using Raspberry Pi 3 model B Single Board Computer. The Raspberry Pi 3 Model B has a 1.2GHz quad-core CPU, a Broadcom VideoCore IV graphics processor, 1GB RAM, a microSD port, four USB ports, and Wi-Fi and Bluetooth. To mount the XBee-PRO XSC S3B module on this board, an ARPI600 shield was attached. The shield allows the XBee module to be mounted and the built-in real-time clock ensures that the Raspberry pi's time is not reset even when power is not supplied. This router is shown in Figure 6.

Figure 6: The Completed Design of Sensor tag Housing

III. CONCLUSION

In this paper, we developed a safety management device consisting of a wearable low power safety management sensor tag that integrates temperature, humidity, 3-axis acceleration, altitude sensors and border router using Sub-1 GHz ZigBee. The device has been shown to be able to deliver data over longer distances using frequency bands suitable for indoor construction sites. The sensor tag is also designed to be detachable from the safety helmet, with a very low power and rechargeable lithium-polymer battery. To prototype these designs, a web-based CAD program called Onshape was used to test the 3D printed housing and determine the final design. In addition, by developing a border router using a Raspberry Pi 3 model B Single Board Computer, it was possible to build a device with high efficiency at low cost. By using this device, we will monitor the safety of workers at indoor construction sites in the future and contribute to the prevention of numerous accidents and the creation of safe construction sites.

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