IoT-based Safety Recognition Service for Construction Site

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***Abstract*— In this paper, we implemented a service that supports the safety situation of the construction site using IoT sensor network that prevents the dangerous situation of workers. We built a sub-1ghz based Zigbee SensorTags and Edge Routers for sensor networks which is suitable for construction sites. Using the gyroscope and accelerometer data of the wearable device, it provides a safety service that detects worker's falls using Deep Learnings. Using Deep Learning networks falls detection performance was achieved above 94%.

Keywords*— *IoT, Deep-learing, Smart-City, Safety Recognition, Construction site, Zigbee

I. Introduction

Recently, IoT technology has enriched human life by eliminating physical constraints that require control of things directly. In addition, IoT technologies such as Smart City and Smart Factory are evolving into convergence technologies that collect and process data and monitor and manage community services using AI technology. Using the IoT monitoring system is effective in areas where it is important to secure human resources such as construction sites. The evolution of ICT has brought synergies among other industries, and the convergence of the construction industry with IoT technology is being discussed as a major issue. In this paper, we propose a system that monitors workers' situation and informs about a dangerous situation such as falls for the safety of construction site workers using sensors acquired from IoT devices based on the deep learning system implemented in previous research [1].

II. Related Works

A. IoT on Construction Site

The Internet of Things is a future Internet-based technology that can connect various objects in the real world and objects in the cyber environment through the Internet and provide various services through interworking between physical space and virtual space [2]. IoT technology is used in a variety of industries such as transportation and logistics companies' monitoring systems, smart vehicle systems, and smart meters for energy companies. Among them, Korea company Hyundai Engineering & Construction Co., Ltd. has introduced a safety management system (HIoS) using a safety helmet with IoT based sensor. Six types of safety accidents can be prevented through this system: confirmation of workers' positions, prevention of construction equipment stenosis, prevention of tower crane collision, detection of gas concentration, wind speed detection, and prevention of collapse of the earthquake [3]. Japanese company Fujitsu Ltd. has a safety management system that uses a wristwatch-type sensor to provide accurate and appropriate break instructions through objective assessment of the current situation of workers and respond promptly in the event of an accident. In addition, through the collected data, effective measures can be taken to speed up efficiency by visualizing the movements of workers in the factory that have not been quantitatively understood so far [4]. Since these companies use the Bluetooth network, there have limitations to applying a construction site it needed a wide range of communications.

The proposed system uses ZigBee used Sub 1GHz bands. It uses a lower frequency band than Bluetooth or other 2.4GHz ISM band communications, it is a more suitable technology for construction sites where there are many obstacles and difficult to build infrastructure.

B. Recent Wearable Devices for Falls Detections

2013, the Samsung Galaxy Gear was released, wearable devices market has inflated, many services for recognizing human physical activities and behaviors have appeared. In late 2018, Apple Inc. has been released the Apple watch 4 it contains a fall detection feature. The user's motion can be recognized by using the acceleration sensor and gyroscope sensor data. When the user falls down, the watch asks if the situation is okay. If the user cannot answer, the device will inform the fire station and the emergency network about the location and status of the facility so that the user can receive first aid immediately [5]. These services can help ensure the safety of users because they support appropriate first aid measures. However, since it is indispensable for Apple Watch to work with the iPhone, cost problems arise if it is necessary to purchase equipment, so it is difficult to apply it to the construction sites which has many workers. In addition, Apple watch uses LTE or Wi-fi, and when using LTE, an LTE charge is charged per Apple watch, resulting in high-cost communication costs. Moreover, Wi-fi consumes a lot of battery power and has a relatively short reach compared with Sub-1GHz wireless networks, it is necessary to install many wireless routers, and the interference between each router is increased as the number of wireless routers increases.

C. Sub-1Ghz based IoT Sensor Network

Most of recently developed IoT sensor networks are being implemented using 2.4GHz Industrial Scientific and Medical bands (ISM) such as Bluetooth or Wi-Fi. However, the power value of the transmitted signal is inversely proportional to the square of the distance and the square of the frequency. Therefore, the Sub-1GHz signal has a lower frequency than that of 2.4GHz, and more distance that can be reached when the signal is transmitted with the same power. This means that signals can be sent farther even with small power. Therefore, even a battery with very small power such as Coin cell, it is possible to secure transmission/reception distance within 2 km. In addition, since the indoor construction site has various radio interference factors such as huge equipment, steel structures, and concrete, it is suitable for the construction site to use sub 1GHz which is diffracted and permeable with lower frequency signal. As shown in Table 1, when configuring the network with Star topology, Sub-1GHz has more nodes than Bluetooth. In the case of Bluetooth, the maximum number of devices that can be connected to one router simultaneously is eight, while the sub-1GHz Zigbee network can link up to 200 devices. In this paper, temperature, humidity, pressure (altitude) and acceleration values are measured in a device acting as a node of a sensor network, and data is transmitted to a gateway at a constant period (1000ms) to a sub-1GHz based Zigbee. Multiple sensor nodes and gateways are configured as Star Topology, and data sent from each sensor node is transmitted from the gateway to the cloud at regular intervals through the LTE network. The monitoring device is able to check the connection status of the devices and the transmitted data value and recognizes the situation at the construction site to check whether the fall occurred.

TABLE I. FEATURES ACCORDING TO NETWORK TYPE

	Bluetooth	***Sub-1GHz***	***Wi-Fi***
Range	50m	2000m	100m
Max Node Number	8	200	64

III. IOT-BASED SAFETY SERVICE FOR CONSTRUCTION SITE

A. Safety Recognition Method on Construction Sites

- 1. Acquiring Environmental Data

According to data from the Ministry of Employment and Labor, there are 58 heat-related disasters caused by heat waves between 2012 and 2016, of which 11 are deaths. At the construction site, the number of disaster victims was 31, accounting for 53.5% of the total industry[6]. In order to prevent such disasters, the Korean government has established "Industrial Safety and Health Act" on construction sites. However, to properly working these acts, take into consideration the situation of the workers and the circumstances of the environment. Thus, a more appropriate safety management system is needed. In this manner, our system provides objective safety guidelines tailored to the worker's situation at the construction site, using environmental data such as temperature and humidity acquired from workers' wearable devices.

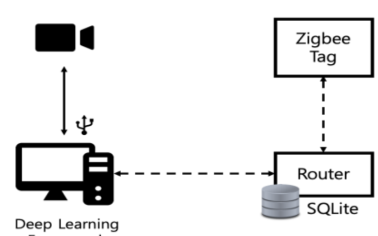
- 2. Acquiring Worker's Activity Data

According to the Ministry of Employment and Labor's analysis of the status of industrial accidents in 2017, the fall was 34.2%, which is the largest disaster type among industrial accidents[7]. Especially, there is a high possibility of finding a worker who has crashed due to a lot of noise in a construction site. Therefore, we utilize Activity data to inform the location information in case of a user crash, so that we can support quick post action.

- 3. Suggested Safety Recognition Frameworks

The sensor data is transmitted at one sampling rate per second by the implemented wearable device, in which the acceleration sensor data gather 10 times per second for accurate measurements. And the cumulative value of the difference between the X, Y and Z axes is recorded and transmitted. And Edge Router received that, and the acquired data is stored in the file type database SQLite. The transferred data is time-synchronized with the image data obtained via the camera, and it is possible to distinguish the operation corresponding to the sensor data. The data labeled via the above process is learned using the deep learning framework. Fig1. illustrated the frameworks.

FIG1. SAFETY RECOGNITION DEEP LEARNING FRAMEWORKS



IV. Experimental Results

A. Wearable Sensor Networks Systems

We categorized two situations changing heat or humidity(it related to worker's heatstroke or frostbite) and a worker's falls as the most important and usual safety issues in common construction sites. And then implemented SensorTag for detecting two features. First of all, 3-axis accelerometer is used as detecting falls accident. By using pressure sensor we obtained the height value of the worker. More accurate height measurements are possible by using closest sea level atmospheric pressure. We assumed that when workers are on a higher height on the same floor, the worker's are vulnerable to falls. Also, for efficient wireless communication in the construction site, we used Sub-1GHz based Zigbee which can transmit sensor data farther with low power consumption. Lastly, the TinyDuino board which enabled atmega328p microcontrollers made that the whole system operated with a lithium polymer battery that has 3.7V 500mAh. Fig2. shows our implemented proprietary SensorTags. And Fig3. Illustrated internal structures of the SensorTags.

Fig2. Our Proprietary SensorTags

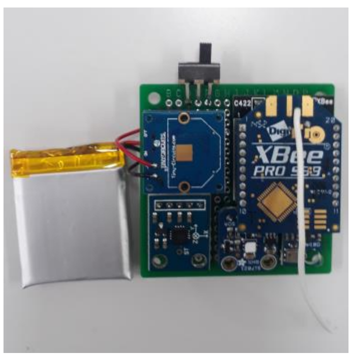
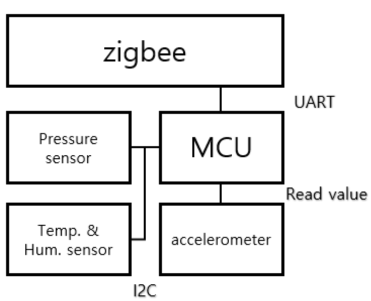


Fig3. Implemented SensorTag Structures



According to Alaneai, K., and Mishra, S. the sum of the differences from between each magnitude sample and the mean of that window divided by the number of data points. This feature was utilized in for individual acceleration axes to enhance the resolution in capturing the information captured by data points. [8] We assumed that SGAD(Sums of Gravitational Acceleration Differences) is data with more features than gravitational acceleration values only. Therefore, after taking each 3-axis acceleration value, the absolute value of subtracting previous value, we got the differences. Repeating 10-times and then the sum of those value which calculated by Equation1. The value has transmitted through our network every second. By integrating the differences we could reduce the amount of traffic data.

Equation1. Sum of Graviational Acceleration Differences

$$S = \sum_{i=0}^{9} |A_{i+1} - A_i|$$

B. Experiments

We constructed a deep learning framework for experiments and used tensorflow-gpu1.13.1 at the back end of the framework. In the neural network library, Keras 2.24 was used. For the data set used for the test, SGAD obtained from the sensor tag was divided into x, y, and z-axes and used as input. The total number of records acquired is 500. The state of falls was classified into four categories and labeled, and then it was used as input of a network of a deep neural network. For the experiments, the Intel I7 4770 CPU was installed and equipped with an NVIDIA Geforce GTX 1050TI GPU with 4 GB memory on a PC with 16 GB of memory. The structure of the deep neural network used in the experiment is shown in Fig4. The accuracy of the overall performance is 94.62%. The loss rate and accuracy graph was illustrated in Fig5.

Fig4. The configuration of deep neural network models for our experiments

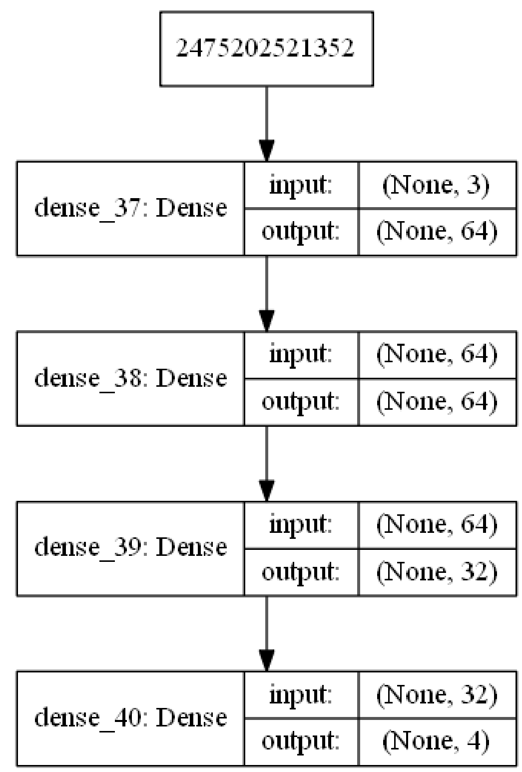
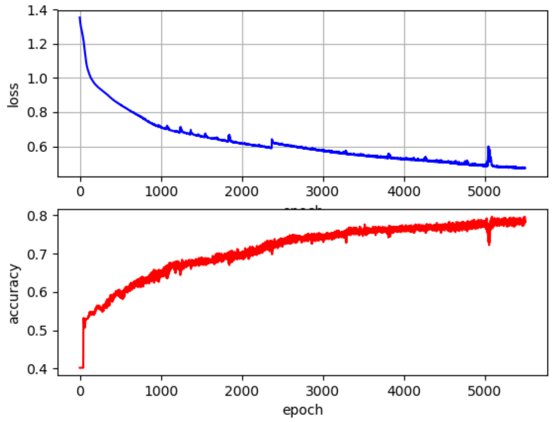


FIG5. THE SAFETY RECOGNITION ACCURACY AND LOSS GRAPH BY EACH EPOCHS.



V. CONCLUSION

The purpose of this study is to provide customized safety management services to workers at construction sites by using data acquired from wearable devices. To that end, we constructed a Sub 1 GHz sensor network which is suitable for construction sites with various radio interference factors. Based on the data obtained through this, we hope that objective safety guideline will be established to workers at the construction site using environment and activity data. In addition, we built a service that provides appropriate post-response when notified of workers' perceived dangerous movements, through worker's fall detection using deep learning. This technology is expected to be a safety guards for people in an environment where not only construction sites but also Smart Factories, Smart City, IoT, Big Data, and Artificial Intelligence technologies converge.

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