Application of Sensor Technology for Warning Unsafe Conditions from Moving Objects above Construction Workers

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***Abstract*— Moving objects above construction workers is one of the major causations of accidents at construction sites. The dynamic and complex nature of construction sites can lead to the above unsafe conditions. However, previous research has developed sensor system for detecting the accident which can only be applied to crane prototype in laboratory. The objective of this research is to develop a sensor warning system (SW system) for warning construction workers from unsafe conditions. This study focuses on a lifting operation of the tower crane. The SW system is developed based on the Internet of Things (IoT) concept, GPS sensor, and server. In this paper, the pilot test was conducted on testing GPS devices which could lead to determine the distance error and calibrate the system. As a result, the average of distance error was 1.96 meters for calibrating the system. Further study will continue to develop the full-scale system which can be applied to construction site.**

Keywords*— *Global positioning system (GPS); Internet of Things (IoT); Moving objects; Sensor warning system; Unsafe conditions.

I. Introduction

Construction work is a dangerous job which includes several unsafe activities and conditions. The construction accident rates represent 17.1% among other industries which has recorded as the highest accident rates in many countries and has often led to high compensation [1, 2]. Furthermore, falls and struck-by falling objects are the numerous accidents which caused injuries and fatalities in construction industry in the United States, also in Malaysia [3, 4]. As reported by OSHAcademy, struck-by falling object is one of the four major accidents (called fatal focus four) at construction site [5]. In construction sites, cranes are the most visible equipment which contribute to one-third of all construction accidents [6]. To prevent fatal and non-fatal accidents caused by this moving object, safety management and safety measures have been proposed and implemented by many researches and organizations [7-10]. Even though previous researches have revealed preventive measures to detect dropped objects from the crane, these alone are not enough to prevent accidents due to the dynamic nature of the construction site [11, 12]. 80–95 % of all accidents are caused by unsafe acts and behaviours of workers themselves [13], which need to be warned or alerted by innovative technology. Due to construction work spaces consisting of multiple resources and its dynamic nature interaction, information technology such as real-time sensor, data processing, and visualization plays an absolutely important role to deal with those safety problems [14].

II. Problem Statement

Numerous research studies have shown innovative technologies to minimize accidents from moving objects by crane. There technologies were applied to detect and monitor the potential accident on construction site. Firstly, VSMART system have been developed to visualize the virtual projectile range of falling object [15]. Secondly, Autonomous system was run on the tablet of crane operator which could visualize location of the worker toward dangerous zone [16, 17]. Thirdly, an integrated information management model of ZigBee network and automation have proposed for preventing struck-by-falling object accidents based on real-time location tracking [18]. Fourthly, a methodology has proposed to predict dangerous zone under the loads of swinging crane and monitor struck-by accidents in real time through efficient and strong algorithms of sensor system [12]. After that, a safety training have been proposed based on automation and VR system to improve behavior-based safety of workers, and automatically warns workers when they are too close to danger sources [19, 20]. Lastly, a proximity warning system based on PCMS and safety sensor CSS provided the real-time location data for assessing safety risk in terms of quantifying hazard zone [21]. Thus, previous researches mentioned above attempt to prevent the crane accidents in construction. Unlike sensor technology, monitoring work places in form of safety management through other technologies such as automation and virtual reality require permanent attention and are subject to privacy and ethical issues [22]. Therefore, this issue needs to be solved by sensor technology.

Although Bobadilla et al. (2014) have developed a sensor system for detecting workers from struck-by falling objects from crane; the extent and effect of their utilization is still in limit to construction site [12]. This is because of the low sensing range of the distance sensor. As a result, the recent research requires to seek for appropriate and high sensing range sensor which be able for developing the system. Based on literature review, there are many sensors which have been used in terms of proximity warning. In this case, ultrasonic sensor (US), infrared sensor (IR), and passive infrared sensor (PIR) have a low sensing range within 3 to 4 meters [12, 23-25]. Furthermore, Bluetooth low energy (BLE) has a large sensing range (60 to 100 meters), but it cannot be an appropriate one due to its

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pairing communication [26-28]. Global positioning system (GPS) have been used by previous researches in order to deal with proximity warning based on server control and wireless network with a wide range of communication (bucket collision during dam construction, truck with vehicle) [18, 29]. Thus, GPS sensor can be an appropriate sensor in utilization for warning unsafe conditions of moving objects.

The main objective of this research is to develop a sensor warning system (SW system) for warning construction workers from unsafe conditions. This research study focuses on unsafe conditions which are related to tower crane moved the objects above construction workers. In application, the sensor system will be attached to the load and person. The system is developed with experimental study in outdoor environment around the Chulalongkorn University campus. In this paper, the experiment of GPS device was conducted in order to define its distance error and calibration.

III. Literature Review

A. Dangerous Zone

There are many types of crane which are used to facilitate the construction progress. Especially, luffing tower crane is one of tower cranes which consists of three motions including slewing of crane's boom (0 to 0.75 rpm), luffing of crane's boom (0.025 m/s), and hoisting loads (0 to 2 m/s) [30]. Related to tower crane, dangerous zone under a loaded crane was defined based on expert interviews and OSHA's regulation [16]. By size of objects and different dangerous levels, this dangerous zone was divided into three zones including red zone (dangerous zone), yellow zone (warning zone), and green zone (safe zone). The yellow zone was created by the clearance distance which was defined from 1.52 meters to 3.05 meters.

B. Sensor System

The Global Positioning System (GPS) is a space-based radio navigation system owned by the United States government and operated by the United States Air Force [31]. By using GPS module, we can get the location (latitude, longitude) and the position (altitude) of any objects on the Earth from satellites. Currently, the GPS sensor has been developed into a microelectronic board, the so-called Arduino. This sensor can be controlled by writing the programs in order to get required information [32].

Importantly, GPS systems can be controlled through the internet by using a web server application in terms of tracking and monitoring [29]. In order to obtain GPS data from Arduino board, two software programs need to be used such as Arduino IDE (Integrated Development Environment) and WampServer. Arduino IDE is used for Arduino computing and WampServer is utilized for GPS tracking server [32, 33].

IV. Research Methodology

This research paper explains on our concept and system design. System design consists of sensor system design, preliminary study of sensor warning system, full-scale development of the system, and field experiment at construction site. However, in this paper we did only first part which is sensor system design and primary testing of GPS device.

A. Sensor System Design

1) Dangerous Zone Definition

According to thorough site observation and engineer interview, we have got the lifting height around 5 to 15 meters above the level of work platform. Height of tower can be installed up to 30 meters from the level of work platform.

In this research, sensor devices are carried by workers and attached to all corners of the object up to its shape. As a result, we have got the dangerous zone (red zone) as can clearly be seen in Fig. 1 below. In order to apply the warning system, we need the warning zone (yellow zone) which is made from a clearance distance of 3 meters. Out of these two zones, green zone around the object is the safe zone.

2) Sensor System Configuration

The system based on GPS can allow for real time warning; when persons are nearby the dangerous zone, an audible alert and a vibrate warning are triggered to alert them. Based on the Internet of Things (IoT) technology and concept, every GPS systems and web server are connected to the internet [34]. This can allow the GPS systems to continuously send data to the web server, to be accessible, and to interact directly with each other as Fig. 2 below.

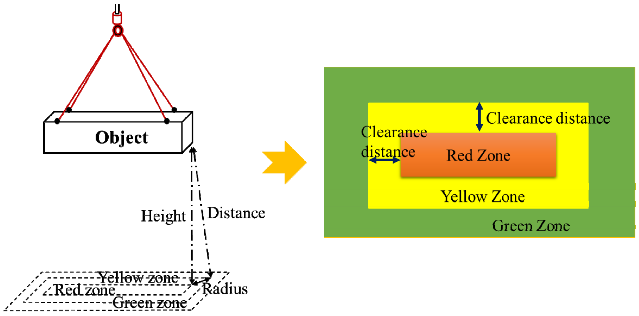

Fig. 1. Dangerous zone.

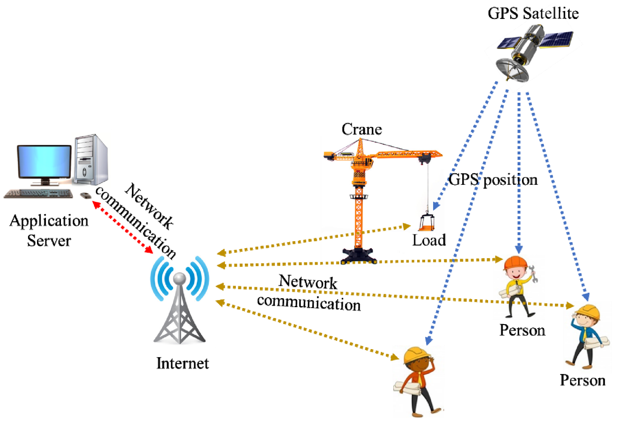

Fig. 2. Server application tracking of proximity.

a) Hardware

The warning system consists of an Arduino Uno for computation, a GPS module for obtaining GPS information (location, position) of object and worker, an OLED for displaying the information, a MicroSD card for logging the information, a 3G module for sending information wirelessly, a power bank for power supply, an active buzzer for audible alert, and a vibration motor for vibrate warning (Fig. 3).

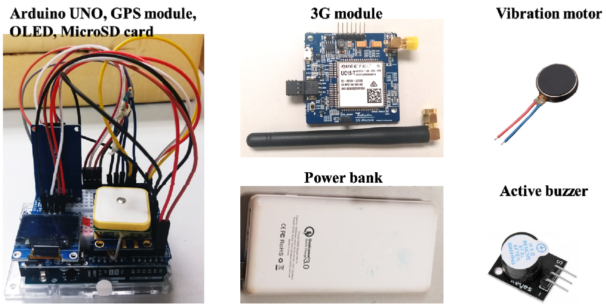

Fig. 3. Device configurations.

b) Software

There are two softwares using in this project, Arduino IDE and WampServer v3.0.6 (Fig. 4). The Arduino IDE is utilized for controlling the GPS which lead to get GPS information from satellites. Then the WampServer is used for creating a web server which be able to access the data from GPS, calculate proximity distance, make a comparison with predefined distance, and send a feedback to each GPS.

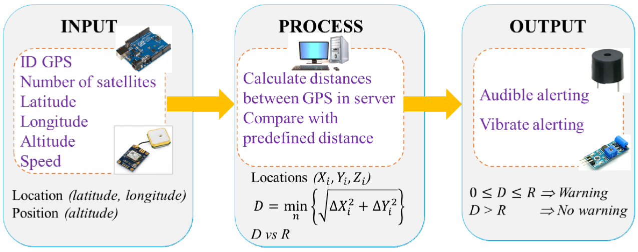

Fig. 4. Sensor warning system algorithms.

B. *Preliminary Study of Sensor Warning System*

The first step of the system development aims to test in the condition that one GPS can warn only one person who go close in proximity to dangerous zone within predefined distance.

1) *Initial Development of Sensor Warning System*

The GPS on person will be triggered by feedback from the server when the proximity distance is less than the predefined distance (Fig. 5).

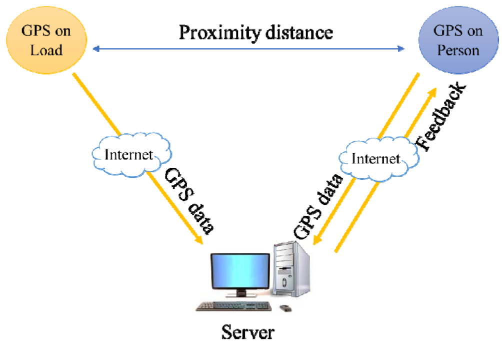

Fig. 5. One to one warning model.

2) *Experimental Study with One to One Warning*

The static and dynamic test process in this research study was designed based on a previous testbed design [35].

a) Static Test of Initial System

In this test, the crane's load is supposed to be stationary at a specific height and a person mobile toward the dangerous zone under the loaded crane (Fig. 6a). To record an accurate warning range, a measurement grid needs to be set up with size of each cell is 0.3 by 0.3 meters. The person is allowed to move towards the sensor in a row parallel to the longitudinal centerline (row) of the sensor. When the alarm is triggered at the first time, the cell is recorded on the data collection sheet. Similarly, when the alarm stopped at any cell, the last one that is just passed is recorded as the end point. During testing, the person stays at least one second in each cell. The cells between two end points are assumed as the warning range. By repeating the same scenario along with the other rows, the warning area of the system is obtained. The number of repeating in each row is 10 trials. This test presents the reliable and valid warning area.

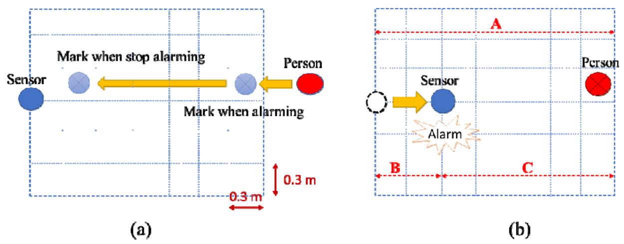

Fig. 6. Experiments: (a) static test, (b) dynamic test.

b) Dynamic Test of Initial System

This test continues from static test by reducing warning range due to dynamic conditions of the load. In this test, the crane's load is supposed to mobile at a specific height and a person is a stationary (Fig. 6b). This dynamic test is conducted to evaluate maximum warning range changes due to dynamic conditions of load and different sensor response time. This test design is developed in a basic of the theoretical warning range models in static and dynamic conditions. Distance A is maximum warning range of the sensor in the static condition, distance B is warning range reduction due to the dynamic condition, and distance C is dynamic warning range of the sensor in the dynamic condition. In this scenario, the maximum warning range A got from static test of the system regardless of sensor's response time and load's moving speed. In the dynamic test model, simple physics state that $D = V \times T$, where "D" is distance, "V" is velocity, and "T" is time. Thus, the range reduction ("D") is dependent on sensor's response time ("T") and load's moving speed ("V").

C. Full Scale Development of Sensor Warning System

1) Development of Sensor Warning System

The GPS on person can be triggered by feedback from the server when the minimum distance is less than the predefined distance (Fig. 7).

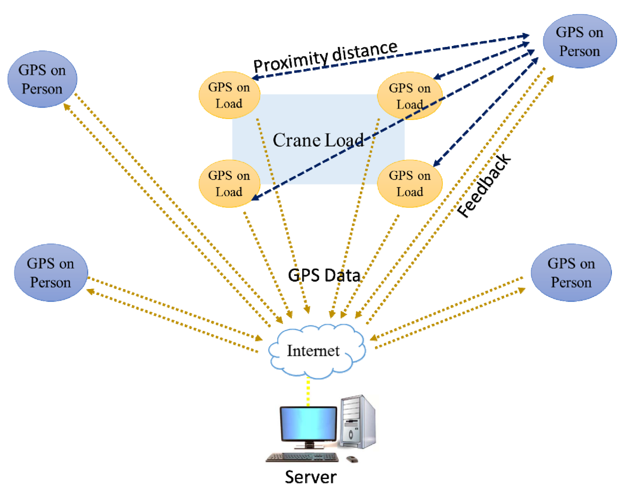

Fig. 7. Many to many warning models.

2) Experimental Study with Many to Many Warning

In this experimental study, the procedures and conditions of testing are done the same as static and dynamic test in section B. The difference is just increasing the number of sensors on the load and the number of persons with sensor.

a) Static Test of Full Scale System

In static test, four persons are allowed to move towards the load with four sensors on it simultaneously (Fig. 8a). This test presents the reliable warning area as well as warning range.

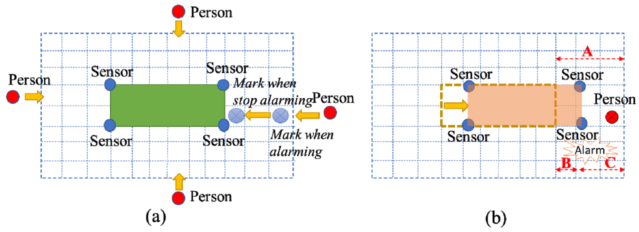

Fig. 8. Experiments: (a) static test, (b) dynamic test.

b) Dynamic Test of Full Scale System

This test continues from the static test to reduce warning range due to dynamic conditions of the load. The load with sensors is allowed to move towards a person at an extreme point of the warning area (Fig. 8b). By doing the same scenario, the dynamic test is done with another three directions.

D. Field Experiment at Construction Site

Field experiment is necessary to be conducted in order to ensure possible application of the developed system at construction work place.

1) Field Experimental Design

Firstly, the sensor systems are attached to the crane load and the person for doing experiment (Fig. 9). Then let the person walk towards the load which is moved by tower crane at construction site. When the system starts alarming by vibration or audible alarm, location of the load and person are recorded. Then the horizontal distance between load and person is calculated to check the accuracy of right way range. This experiment is done to compare the warning range got from field experiment and the predefined distance.

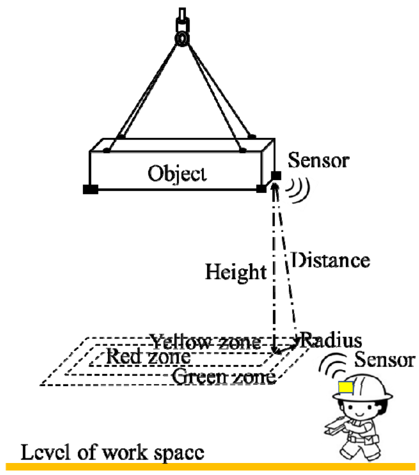

Fig. 9. Configuration of the system application.

2) Field Experimental Setting

During field experiment, data is recorded as location, then they can be calculated as the distance between load and person. Experimental data is stored in computer hard drive for analyzing in the next step.

3) Field Experimental Data Analysis

In this section, the data from field experiments is basically analyzed. The data is stored as excel file which can be imported into SPSS Statistic tool of data analysis. The analysis can be done in terms of comparison between the warning ranges got from construction site experiment and the predefined distance by using one-sample T-test in SPSS software. The system can be applicable if there isn't a significance difference of the comparison analysis.

V. PILOT TESTING

A. Case Description

The testing was performed to check accuracy of the GPS device and calibrate its distance measurement by calibration constant (C). This test was conducted to check the distance error and then whether the distance calculating in web service program needs to be added or subtracted any error. This is because of study on proximity distance which the system needs to warn workers inside the specific distance. Importantly, area of testing is necessary as selected for this test, which has a clear space and can let GPS device to communicate well with satellites.

The system was applied in a basketball field behind Civil Engineering building, at Chulalongkorn University. The testing field area was 500 m^2 which was suitable for distance testing up to 7.5 m.

B. Device Arrangement

The devices were set up for its application in the following procedure (Fig. 10). We did the test in 9 cases which one case take 1 hour. Data was recorded in every second. Testbed was prepared as a circle which 4 GPS devices (GPS1, GPS2, GPS3, and GPS4) were put on the arc of circle and 1 GPS on the center (GPS0). The GPS on the center was lifted up to three different heights of 0 meter, 2.5 meters, and 5 meters. For the 4 GPS on the arc, they were moved with three different radiuses of 2.5 meters, 5 meters, and 7.5 meters. The data collection was begun when the number of satellites in each device fixed to 12 satellites.

After experiment, the collected data was gotten as 3600 per case. Data was stored in microSD card, then copy into PC for further analysis.

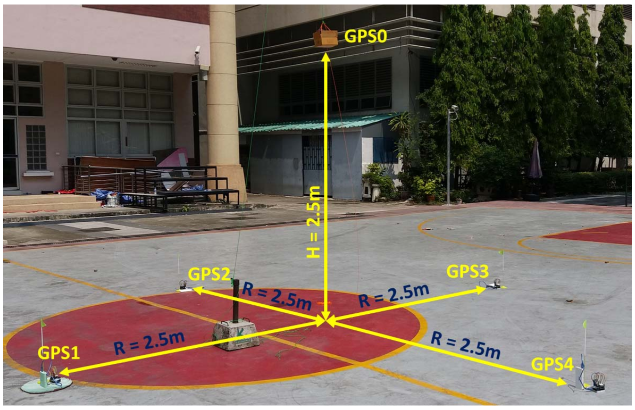

Fig. 10. Snapshots of pilot experiment.

C. Result and Discussion

Data got from experiment were in latitude and longitude values, which were necessary for calculating the distance between each two points. Firstly, its latitude and longitude were converted into UTM (Universal Transverse Mercator) coordinate system [36]. Then the distance between two points is simply calculated by using Pythagorean theorem. The distances were calculated as horizontal distance between GPS0 and GPS1, GPS0 and GPS2, GPS0 and GPS3, and GPS0 and GPS4. There were three measurement cases for each pair of GPS device such as 2.5 meters, 5 meters, and 7.5 meters. Thus, comparison between distance measurement and real distance were done for each pair.

Table I shows the results from testing which are the comparison between distance measurement by each pair GPS device and real distance. The results got from this experiment were not affected by the number of satellites because after a several minutes of power on the device, this number was fixed within 12 satellites. The whole table was divided into two sides. First side shows the average distance of each pair device. The other side shows the average distance error of each pair.

From the result table, we saw that the distance error was decrease with the real distance was increase in each column of the pair. Thus, the result can state that the distance error is decrease when the distance of two objects is increase. However, we got the average distance error of 1.96 meters among the four devices.

This error value will be used as calibration constant for developing the sensor warning system in the next step.

TABLE I. TABLE RESULT OF TESTING.

Real Distance (m)	Everage Distance (meters)				Average Distance Error (meters)				Average
	GPS0 & GPS1	*GPS0 & GPS2*	*GPS0 & GPS3*	*GPS0 & GPS4*	*GPS0 & GPS1*	*GPS0 & GPS2*	*GPS0 & GPS3*	*GPS0 & GPS4*	
2.50	5.56	5.18	4.17	5.28	3.08	2.78	1.85	2.78	2.62
5.00	6.23	6.20	6.60	7.01	1.33	1.31	1.85	2.17	1.67
7.50	8.69	8.59	6.93	8.95	1.65	1.33	1.65	1.69	1.58
				Average	2.02	1.81	1.78	2.21	***1.96***
				Min	1.33	1.31	1.65	1.69	
				Max	3.08	2.78	1.85	2.78	

VI. Conclusion

The sensor technology is efficient and suitable for utilizing in unsafe conditions enhancement. In this research, we try our efforts to develop the sensor warning system in order to warn or alert construction workers from dangerous zone. However, this paper focused on the first step of the research study which pilot testing was conducted to get calibration constant. As the result from this testing, we got the constant of 1.96 meters which is necessary for next development of the warning system. Therefore, the sensor warning system can be developed effectively.

Further studies will continue to develop the web service as the system control of the warning system. Then the full-scale system can be developed, and its field experiment can be conducted at construction workplace to ensure its performance.

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