AIR QUALITY MEASUREMENT METHOD OF CLOSED SPACE USING DRONES AND SENSOR TO ENSURE OPERATOR SAFETY

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Abstract- Work in an underground space, a tunnel at a construction site, or in an enclosed space, such as tank, may have hazardous gases. In fact, worker injuries or death caused by hazardous gases or fires in enclosed spaces are quite common. To reduce worker risk for hazards such as smoke/gas inhalation, fire, and explosion in enclosed spaces, technologies are being developed to measure air, pollutants, and hazardous gases in confined spaces in real time. A particular challenge comes from installing measurement equipment at a specific location during maintenance work such as at a construction site, tank or water tank. Moreover, these devices take measurements only while work is being conducted and thus may not adequately measure the safety of the environment prior to commencing such work. As such, this study proposes a method to measure air quality using a drone outfitted with sensors to check conditions in advance in order to determine that an environment is safe for workers.

Index Terms-Air Quality, Drone, Sensor, Closed Space Work

I. INTRODUCTION

Work in an underground space, a tunnel at a construction site and in an enclosed space can pose high risk of having hazardous gases. In fact, accidents that result in injuries or death are quite common in such spaces. Accidents that can occur in enclosed spaces includes oxygen depletion due to the oxidation of substances and respiratory action of microorganisms. Hazardous gases such as carbon dioxide, methane, and hydrogen sulfide can also be generated by various organisms. Nitrogen substitution to prevent oxidation, adsorption, and re-dissolution, as well as nitrogen substitution work for fire and explosion prevention can increase the risk of gas-induced asphyxiation if there is residual methane or carbon dioxide in spaces for tunnel construction or a coal mine (Korea Occupational Safety and Health Agency, 2010).

The Health and Safety Executive (HSE), Occupational Safety and Health Adminstration (OSHA) and Safework Australia provide standards for reducing risks in limited spaces such as in enclosed spaces and suggest monitoring and maintenance of minimum and maximum oxygen levels [2,6,8]. Safework Australia defines a standard were oxygen content should be continuously monitored in enclosed spaces before and during construction. It also defines parameters if the oxygen content in the air decreases from 23.5% to 19.5%, which should preclude work in enclosed spaces [8]. For OSHA standards, the upper limit of oxygen content is set at 22%, and it is defining a situation where increasing oxygen content above the upper limit can cause a fire [6]. In Korea, according to the results of analysis of enclosed spaces and suffocation cases registered in official statistics for industrial disasters in Korea, the average annual number of asphyxiation accidents was 24.4, and the total number of construction projects was 72, which was about 33%, and comprised 40% of the total number of asphyxiation accidents including 14 cases of building management business [4]. Therefore, nearly half of the asphyxiation accidents are related to the construction industry, and indicate the need for measures to deal with this situation.

Due to the nature of enclosed spaces, internal oxygen may be insufficient. In addition, if not sufficiently ventilated, harmful substances remain inside, which may pose a significant risk to the human body. Therefore, sufficient preliminary investigation should be done prior to commencing work in such an area. These measurements can be done by a worker, however, there may be limits in the ability to ascertain problems that may arise in the vicinity of the worker or another space (Korea Occupational Safety and Health Agency, 2010).

To reduce worker risk due to smoke/gas inhalation, fire, and explosion in enclosed spaces, technologies are being developed to measure air, pollutants, and hazardous gases in confined spaces in real time. A particular challenge comes from installing measurement equipment at a specific location during maintenance work such as at a construction site, or in a tank or water tank. Therefore, technology is being developed to provide portable measurement equipment. Developments in IT technology are also facilitating the development of devices that track the position of an operator to ensure safety in an enclosed space and to measure oxygen and noxious gas concentrations in the air using handheld devices that utilize technologies such as sensors and wireless communications. [i]

However, these devices take measurements only while work is being conducted and thus may not have

adequately measured the safety of the environment prior to commencing such work. In this study, the present state and actual situation of safety management technology is reviewed from the existing literature related to safety management of enclosed spaces. Subsequently, this study proposes a method to measure the quality of air using a drone outfitted with sensors to check conditions in advance in order to determine that an environment is safe for workers.

II. LITERATURE REVIEW

There are previous studies investigating various accidents and associated types and factors. Researchers have proposed several methods to gather appropriate safety data. Safety management status has also been looked at by investigating awareness about safety and incidents and compliance with safety rules thru worker awareness surveys [10]. As work in underground spaces increased, researchers also investigated safety management for underground spaces, and included evacuation procedures for incidents such as fire [5, 7]. Several advanced technologies have been introduced in the construction industry, including BIM, IOT, sensors, and drones. Studies have been done to study how best to utilize such technology in terms of safety management in enclosed spaces. In particular, the use of BIM has spurred research to develop techniques to check for safety problems that could occur in a construction environment at the design and planning stage [3]. In addition, technologies such as sensors and wireless communication are being utilized to track worker position and activity while working in an enclosed area. Several techniques are being studied to ensure the safety of workers by measuring oxygen and harmful gas concentrations in the workspace, to operate alarms when appropriate concentrations are exceeded, or in case of an accident to locate workers [1, 11]. Such studies, however, tend to focus on workers and there is not much research on the technology for monitoring oxygen and hazardous gas concentrations in enclosed spaces in advance of work operations

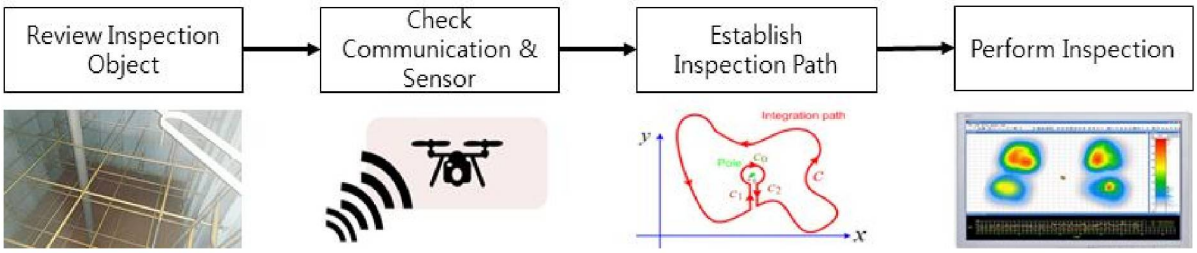
III. PRELIMINARY INSPECTION PLAN TO ENSURE OPERATOR SAFETY IN AN ENCLOSED SPACE

Before working in enclosed spaces, oxygen concentration and noxious gas concentration should be measured and internal conditions should be checked according to the characteristics of a space to cope with any problems that may arise. In a conventional scenario, this is measured with a portable measuring instrument near the entrance and for respiration near the worker. When deep inside an area, such parameters are checked through a pipe gathering collected air. When employing drones, the entire inside area of an enclosed space can be inspected. This approach also provides improved safety for the operator.

Table 1 Literature review

Author	Contents
Kim Jun Su (2015)	After collecting articles on accidents that occurred at a construction site over the last 10 years, a service plan was developed that can provide effective information to workers by determining accident factors for each accident type on the construction site based on the collected data.
Yang Hong Seok and two others (2003)	In order to use data to establish measures to identify conditions that may be hazardous in enclosed spaces, researchers looked at characteristics of enclosed workplaces, personal characteristics, implementation of safety and health education, and compliance with safety regulations by occupational healthcare managers and workers.
Jurgen Melzner et al. (2013)	Since the standards and rules of protective safety equipment vary from country to country, the objective in this research was to develop a tool that allows for ubiquitous understanding and planning about safety, regardless of the country of operation. BIM can be used to identify safety hazards early in the process, including during design and planning.
Zainab Riaz et al. (2014)	A device was developed for safety management of workers in enclosed spaces by using a wireless sensor and BIM. Operator safety was managed by measuring oxygen concentration and temperature around the worker. However, it was not able to recognize when a worker had escaped from the enclosed space.
Chun Dong Jin (200	To prevent suffocation accidents at industrial sites where harmful gases are generated, USN sensors were used to develop noxious gas measurement and monitoring devices, but information on the location of workers could not be obtained.
Sul Moon Hyung (2012)	Real-time three-dimensional positioning technology was developed in a study for the construction of a support system at an underground site to create a ubiquitous environment for efficient management of workers at a construction site with underground spaces and to provide a quick response in case of accident. Experiments on positional accuracy in an enclosed space such as a tunnel yielded a position tracking technique, but the error range was 20 m and the accuracy was low.

Figure 1. An Inspection Process of Closed Space Using Drone



A. Preparation for preliminary inspection

In order to perform a preliminary inspection using a drone, a measurement sensor is necessary to evaluate the workspace. Additionally, wireless communication that is capable of determining the measurement results and the location of the drone is necessary. In particular, since the wireless communication technology propagates signals in the air and is affected by various physical environmental characteristics, the rate of occurrence of various kinds of errors such as interference, attenuation, collision, and disconnection is relatively higher than that of wired communication. In particular, the communication error rate is higher due to high temperature, air pollution, various obstacles and walls inside a building (Song 2008, Jung et al., 2002, Oh et al., 2011). Therefore, it is necessary to apply wireless communication technology suitable for line of sight.

B.Establishment of preliminary inspection plan

The preliminary check path of the enclosed space is set considering the measurement capability of the sensor and the size of the enclosed space. A plan should be made to identify and classify all types of problems that can occur in the work and to check for such problems.

C. Inspection of the enclosed space with drones

The air quality of the enclosed space is measured by sending a drone with air quality measurement sensors along the work path. The measured information is transmitted in real time using wireless communication technology. The operator is thus able to determine the air quality of the enclosed space immediately before the work and can establish an appropriate safety plan according to the air quality.

CONCLUSION

This literature review analyzed the current development status and problems with existing technology aimed at securing the safety of workers in enclosed spaces. Analysis of past studies indicates that further research is needed to investigate advanced inspection technology. In particular, it was identified that a preliminary inspection method for assessing an enclosed space using a drone is needed. In the future, it is necessary to develop the technology to facilitate this approach and to verify utility in actual work environments. Such research and development will allow determination of the safety status of an enclosed area prior to any work commencing and is vital to improving worker safety.

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