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Blockage assessment of buildings during emergency using multiple types of sensors

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ABSTRACT

In case of an emergency in a building, first responders need to know current blockages in the building (e.g., blocked passageways and exits) and safe evacuating paths so that the occupants can be guided to the unblocked exits and safe paths toward those exits. To automatically determine blockage levels at buildings, a system that fuses data from multiple sensors and video camera was proposed. A prototype was developed and tested on an experimental model of a pilot building's hallway. A series of damage tests were conducted on the hallway model and recorded by the sensors and the video camera. Individual performances of sensors and video camera were evaluated, and a decision tree method was used to fuse sensor and video camera data for estimating the level of blockage in the hallway for different damage combinations applied on building components. The results demonstrated the technical feasibility of the proposed system and the findings of the decision tree highlight that by using less number of sensors, a cost-effective configuration can be achieved. The estimated blockage information can be used to create a topological map of the damaged building, indicating safe paths toward available unblocked exits.

1. Introduction

During and after emergency situations in buildings, such as earthquakes and fires, the primary objective is to evacuate the building in a rapid and safe manner. For an effective evacuation, the occupants and first responders need to be informed about the current conditions (e.g., blocked passageways and exits) and safe evacuating paths in a building. Such information would reduce the number of causalities significantly [1]. For example, during two consecutive earthquakes in Van, Turkey, in 2011, 644 people died in over 40,000 heavily damaged/collapsed residences and office buildings [2], while many people tried to figure out a safe exit path from the damaged buildings by themselves. In a documented incident, a news team accompanied hospital personnel, who were trying to rescue newborn babies during the after shocks [3]. It was difficult to evacuate the building since some furnitures and equipment were blocking the hallways and jeopardizing the rescue operation, and the team lost time trying to find a safe exit. In such cases, to evacuate the buildings rapidly, the occupants and the first responders need to know unblocked exits and safe paths toward those exits.

In this paper, a system that fuses data from multiple sensors and video camera was proposed to automatically determine blockage levels at buildings in case of an emergency. The objective of the study is to show that the proposed system is technically feasible. The ultimate goal of the envisioned system is to inform occupants and responders about the unblocked paths inside the building. A prototype was developed and tested on an experimental model of a pilot building's hallway. Two types of sensors that were attached to building components and a video camera were used to determine the level of blockages (e.g., no blockage to complete blockage) occurred at exits and hallways. An experimental model of a pilot building's hallway was constructed, composing of several building components (i.e., infill walls, suspended ceilings, and furniture). Manual damage was applied in various ways (e.g., suspended ceiling connections were detached) to simulate different possible damage conditions. Simultaneously, data from sensors were obtained and fused to determine the level of blockage in the hallway. This blockage information will be used to create a topological map of the damaged building showing the safe paths toward available unblocked exits inside the building for the occupants and the responders.

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2. Background research

There are numerous studies in the construction domain that utilized sensors for various purposes, such as damage detection and material tracking. For example, structural health monitoring studies used sensors (e.g., accelerometers, strain gages) to monitor the structural components of buildings [4–7]. The main objective of these studies was to estimate the behavior of a structural component or a system rather than to estimate possible blockage in a facility, and in most cases, a single type of sensor was utilized. Other studies that focused on damage evaluation approaches were mainly targeting regional damage or loss estimation for building stocks [8,9]. Usually satellite images and aerial photos were utilized in these studies [10,11]. Another way of gathering structural damage information was by monitoring the changes in the dynamic properties of buildings [12,13]. In those studies, accelerometers that were placed at several locations in a building measure the accelerations, which were analyzed to determine the change in building's natural frequency. This method can detect the change in the overall stiffness of the building, and thus the damage in structural components. Neither of these studies, however, focused on determining the amount of blockage at a certain region or estimating local damages in both structural and non-structural components. Moreover, data from multiple types of sensors were not fused in any of these studies.

The prior research studies performed sensor fusion (1) to detect occupancy in offices and (2) to locate and track materials and components at a construction site or to monitor labor productivity. In the former group of studies, magnetic loop counters, optical tripwires, optical motion detectors, high-dynamic range cameras, lighting control, and CO_2 sensors were used [14–20]. To fuse data from multiple sensors, usually model-based methods were used, such as Bayesian probability theory, Markov chain, Monte Carlo sampling, and multivariate Gaussian model [14]. However, such methods were reported to be costly and complex [21]. Another method that is used for sensor fusion is decision trees for integrating sensor data to compare the accuracies of different sensor combinations for occupancy detection [20].

In the latter group of studies, various types of technologies were used. In some studies, the data obtained from radio frequency identification (RFID) and global positioning system (GPS) technologies were integrated [22–25]. In another study, data from real-time location sensing (RTLS) technologies and physiological status monitors (PSMs) were fused for analyzing ergonomic and safe work conditions of workers [26]. Teizer et al. [27] used 3D range camera to obtain the position data of construction equipment and personnel, and these two sets of data were merged to improve personnel safety at a site. Pradhan and Akinci [28] developed a framework to automatically identify and execute a sequence of data fusion steps on the basis of a given data fusion query [28].

The previous sensor fusion studies in the construction domain utilized sensors for collecting different types of data. However, to the best of the authors' knowledge, no previous studies have focused on determining blockage level at a certain region due to damage on building components. Moreover, in the previous studies data fusion was performed by combining two or more types of data, such as ID from RFID units and location coordinates from GPS. However, the same type of data (e.g., status of a component) from two or more sensors was not fused to improve the accuracy. This study proposed a system that fuses data from multiple sensors and video camera for blockage assessment of hallways in buildings during an emergency. The data fusion included integration of two or three different status information that are obtained from different types of sensors attached to the same building component or from a video camera that monitors that building component.

3. Methodology

Blockage of passageways in a building can occur by the change in the position of building components due to the impact of a disaster (e.g., earthquake) or by an emergency, such as fire. While the affects of an earthquake can be simulated to a certain extent, it is difficult to simulate a fire or such an emergency case on the experimental setup. Therefore, the focus of the study is the blockage caused by the damaged building components following an earthquake. The buildings that have light to moderate damage were considered, and heavily damaged buildings were excluded. To develop and test the proposed system, a one-third scaled experimental model of a pilot building's hallway was constructed.

A series of experiments were conducted on the experimental model. Sensors were placed on critical building components that can block a hallway (i.e., suspended ceilings, walls, bulky furniture). Data obtained from sensors were recorded as these building components were manually damaged to simulate an earthquake while a video camera located at one end of the model recorded the experiments. The experiments were performed multiple times for different damage combinations. Every item that had been damaged was fixed before starting the next set of experiments. To determine what type of data collection technologies will be used, a list of potential sensing technologies (i.e., gyroscope, accelerometer, ultrasonic range finder, compass sensor, closed cable circuit system) were identified. The capabilities of these technologies were investigated to determine which sensors can be used during manual damage. Among these technologies two types of sensors, closed cable circuit (CCC) and ultrasonic range finder (URF)), and a high-resolution video camera were selected for use in the experiments. The reasons for selecting these technologies are that they are (1) cost-effective, (2) durable, and (3) relatively easier to deploy and utilize in an experimental setup that involves continuous damage on the building components that they are attached to. Some of the other identified sensing technologies were included in the vision of the study. For example, the accelerometers were envisioned to be attached on slabs to detect the movement of the building. However, these sensors were not used in the experimental setup as utilization of these sensors necessitated dynamic loading tests, which are hard to simulate.

Fig. 1 explains the steps of the methodology used for developing the proposed system. In the first step, possible damage scenarios at a typical hallway of a pilot public building were simulated on the test bed by manually damaging the building components (e.g., by pushing some building components down) while the sensors and the video camera recorded data (Fig. 1, Step 1). In the next step, data from two types of sensors were retrieved and processed individually to determine the success of each sensor in identifying component-level blockage. During this step, it was determined whether each component was damaged in a way to block the hallway or not, based on each sensor output (Fig. 1, Step 2). The video camera was used to estimate the level of blockage in the entire hallway; therefore, video camera recordings were not used to determine component-level blockage.

For interpreting the sensor data, the real status of the building components after the impact and the resulting level of blockage at the

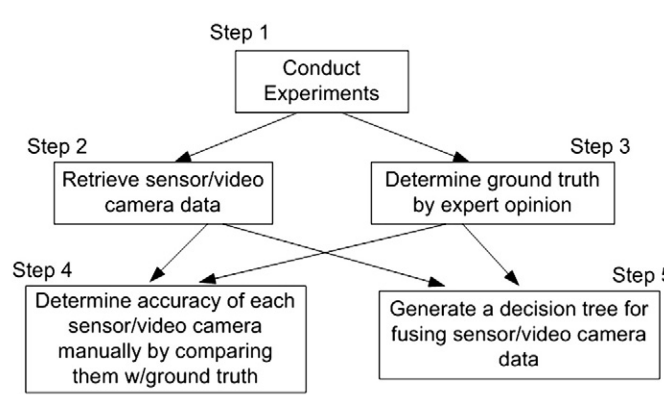

Fig. 1. Methodology for blockage assessment of buildings.