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IMPROVING EFFICIENCY IN EMERGENCY RESPONSE FOR CONSTRUCTION SITE FIRES: AN EXPLORATORY CASE STUDY

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Abstract. This study proposes an approach to assist construction managers with fire management. Since accidental fires at construction sites often go undetected until they begin to spread, they can cause serious damage. Although researchers have applied information technology to construction site safety management, few studies have focused on the relationship between information techniques and construction site fires. After investigating this relationship, the results revealed two problems: difficult fire detection and disorderly emergency response. Therefore, the intent of this study was to build an intelligent construction site fire management platform by integrating image recognition for automatic fire detection and knowledge models for immediate emergency response. Based on several tests on three common types of accidental fires at construction sites, the results demonstrated that the platform can detect fires and alert construction managers quickly. Through mobile information transmission, the construction managers were able to understand the status of on-site fires and respond appropriately. This study offers a useful reference for similar applications in construction site safety management.

Keywords: construction site safety management, construction site fire management, emergency response, image recognition, information technology, knowledge model.

Introduction

In many countries, fatal accidents in the construction industry are more common than in other industries (Helander 1991). Among falls, electrocutions, struck-bys, and fires, construction site fires often carry unpredictable results because these fires are frequently not initially noticed. The U.S. Fire Administration (2002) reported that 4,800 accidental fires occurred at construction sites in the United States between 1996 and 1998, resulting in 10 fatalities, 30 injuries, and a loss of $35.2 million. In Venice, Italy, Zanut (2002) indicated that construction site fires accounted for more than 12% of all accidental fires between 1997 and 2002. Thus, improving the efficiency of emergency response to accidental fires at construction sites is imperative.

Researchers have proposed various means of fire management at construction sites (e.g. maintaining fire protective measures by assessing needs and capabilities). These approaches assist construction managers in establishing management policies. Through periodic training, construction workers learn how to comply with these policies. Moreover, the use of information technology has become pervasive. For example, project management techniques are coordinated with safety plans before, during, and after construction site fires; site monitoring techniques allow recording of the on-site status of construction activities; and object tracking techniques enable observation of on-site objects (e.g. construction workers and equipment) during construction processes.

However, two problems interfere with fire management at construction sites: difficult fire detection and disorderly emergency response. A number of causes (e.g. arson, open flame, smoking) can be responsible for construction site fires (U.S. Fire Administration 2002). Project management techniques may not offer emergency strategies to cope with accidental fires, and site monitoring techniques may not provide sufficient detail regarding fires. In addition, object tracking techniques may not automatically detect fires. As a result, construction managers cannot respond to accidental fires appropriately. Therefore, this study proposes an approach that integrates image recognition and knowledge models. With this approach, construction managers not only can comprehend construction site fires in real time, but also obtain expert assistance for emergency response.

The rest of this study is organized as follows. Section 1 contains a review of information techniques currently used in fire management at construction sites. Section 2 explains the study problems. Section 3 describes the research approach. Section 4 presents an intelligent construction site fire management platform.

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Section 5 provides results of testing the platform in a case study. Section 6 discusses three directions for future research. The final section concludes. This study will serve as a useful reference for similar applications in construction site safety management.

1. Literature review

Fire management at construction sites includes several programs: evaluating and reducing the likelihood of fires, inspecting construction activities and sites, executing emergency response and service, and educating and training construction workers (Chow 2001). Common information techniques used to operate these programs include:

- Project management techniques. Connecting construction activities and project management is the foundation of construction site safety management (Bansal 2011). Since hundreds, even thousands, of activities occur simultaneously at a construction site, many construction processes and practices (e.g. relating to construction materials and waste products) are potential sources of fires. In addition, construction managers have difficulty manually investigating these processes and practices. In contrast, project management techniques detail construction activities, which can help construction managers save time in evaluating strategies for fire prevention. For example, when project information systems show duration and location of a scheduled welding activity, construction managers can determine whether fire extinguishers are near the welding site.
  Several researchers have studied project management techniques in construction site fires. Liu *et al.* (2006) integrated an ANT algorithm and geographic information system (GIS) to locate additional fire stations so as to shorten response time to accidental fires. For fire protection planning in civil engineering, Rueppel and Lange (2006) applied distributed technical models (e.g. software agents) to enable high-quality and efficient cooperative project work. Based on multi-criteria decision analysis and intensive use of GIS data, Stipanicev *et al.* (2007) designed a fire monitoring network for the early detection of forest fires.
- Site monitoring techniques. When a construction site is large, in addition to conducting regular on-site inspections, construction managers can equip numerous surveillance facilities at construction sites as a cost-effective means of rapid data collection. Images and videos acquired from surveillance facilities are factual and context-rich. Since many operation devices can access these images and videos, construction managers can audit fire management on construction sites anytime and anywhere (Vlasic *et al.* 2007). More importantly, construction managers can simultaneously observe several vulnerable areas (e.g. warehouses and smoking areas) using multiple surveillance facilities.
  Many researchers have demonstrated the advantages of using surveillance facilities at fire sites. For instance, Tseng *et al.* (2007) integrated a mobile surveillance and wireless sensor system that can move to fire sites and report. By integrating video monitors and GIS, Fang *et al.* (2008) were able to locate a forest fire and enable synchronous tracking of monitored areas. Bergstrand and Landgren (2009) indicated that on-site videos positively contributed to work practice because these videos provide a rich description of an incident site without the necessity of using words.
- Object tracking techniques. In construction site fires, construction managers must understand the status of on-site objects. To achieve this objective, various object tracking techniques are available, including radio frequency identification (RFID), global positioning systems (GPS), wireless local area networks (WLAN), and ultra-wide band (UWB) (Jiang *et al.* 2011). If these tracking techniques are combined with software modules to automatically provide alerts in the event of a safety hazard, construction managers can identify construction workers, control construction equipment, inventory construction materials, and generate progress reports (Carbonari *et al.* 2011).
  Several studies have emphasized the importance of object tracking techniques for fire management at construction sites. For example, Huang *et al.* (2007) applied RFID to manage water resources for accidental fires so that fire rescue vehicles and personnel had the location and basic data about the hydrants near fire sites. Behzadan *et al.* (2008) argued that the integration of outdoor (GPS-based) and indoor (WLAN-based) tracking offered important assistance when firefighters need augmented information to bring victims out of fire zones. Chiu and O'Keefe (2008) used UWB and GPS for fire rescue because UWB augmentation with GPS was a means to increase safety, efficiency, and surveillance at accident sites.

2. Study problems

Although information techniques are beneficial for on-site fire management, in contrast to the above mentioned studies, this study focused on whether these techniques are available in the four stages of a construction site fire: the incipient stage (in which radiant heat warms adjacent fuel and executes the process of pyrolysis), the growth stage (when the fire continues to spread), the fully developed stage (maximized by released energy), and the decay stage (when the consumed fuel or limited oxygen moderates the fire) (Hartin 2008). This study revealed that construction managers still encounter two problems in the incipient and growth stages of accidental fires:

- Difficult fire detection: Due to the characteristics of construction sites (e.g. temporary facilities, inflammable materials, dispersive participants), project management techniques, site monitoring techniques, and object tracking techniques are insufficient to recognize accidental fires. Figure 1 shows that construction managers can prevent certain construction site fires through the scheduling of construction activities using specific project management techniques. However, construction managers cannot schedule unexpected incidents that often cause accidental fires. Site monitoring techniques rely on manual imagery investigation; thus, they are seldom considered true contenders for automated data collection methods in construction operation analysis (Gong, Caldas 2010). Also, since object tracking techniques need specific devices (e.g. tags, readers), compared to known on-site objects, construction site fires are impossible to embed with these devices. Therefore, a construction site fire is easily overlooked until either someone notices the fire or the fire spreads.

Several case studies have demonstrated the importance of construction managers and workers having a mechanism to recognize on-site fires in a timely manner. For example, in Turkey, a short circuit caused a fire at the construction site for a shopping mall (The Telegraph 2012). Since few of the construction workers were aware of the fire in the incipient stage, many were not evacuated from the site. At least 11 construction workers were killed in the fire. In contrast, Sayre (2012) reported that a hospital construction site caught fire, and construction workers performed firefighting in the incipient stage. During the growth stage associated with flames and smoke, construction workers gave up extinguishing the fire and evacuated so no injuries occurred. Based on the comparison of these two case studies, damage from accidental fires can be contained if construction managers and workers receive immediate alerts regarding accidental fires at construction sites.

– Disorderly emergency response. Fire accidents can be classified into four classes: ordinary combustibles (Class A), flammable liquids and gases (Class B), electrical equipment (Class C), and combustible metals (Class D) (OSHA Office of Training and Education 1996). During construction site fires, construction managers experience significant mental pressure (e.g. fear, nervousness) (Papinigis *et al.* 2010). When construction managers do not respond to fires in a time manner, emergency response is delayed. Also, if construction managers neither have experience nor accept training in fire management, the wrong emergency response, such as putting water on an oil fire, may increase risk and obstruct firefighting.

Numerous case studies have highlighted the significance of construction managers and workers needing a way to respond to accidental fires. For example, in China, when an electrical heater caused a water-induction engineering fire, 24 construction workers were injured and 13 died in the fire (Shaanxi Daily 2012). The post-fire report revealed that the construction workers had neither information nor facilities for firefighting in the incipient stage of the fire. Furthermore, the growth stage of the fire collapsed many temporary facilities, which obstructed construction workers trying to leave the fire site. In another case study, Palmer (2012) described a construction site fire in a hotel. Although construction workers attempted to stop the burning in the incipient stage, they delayed notifying fire officials. Because of natural factors (e.g. high winds), the fire had spread into the fully developed stage by the

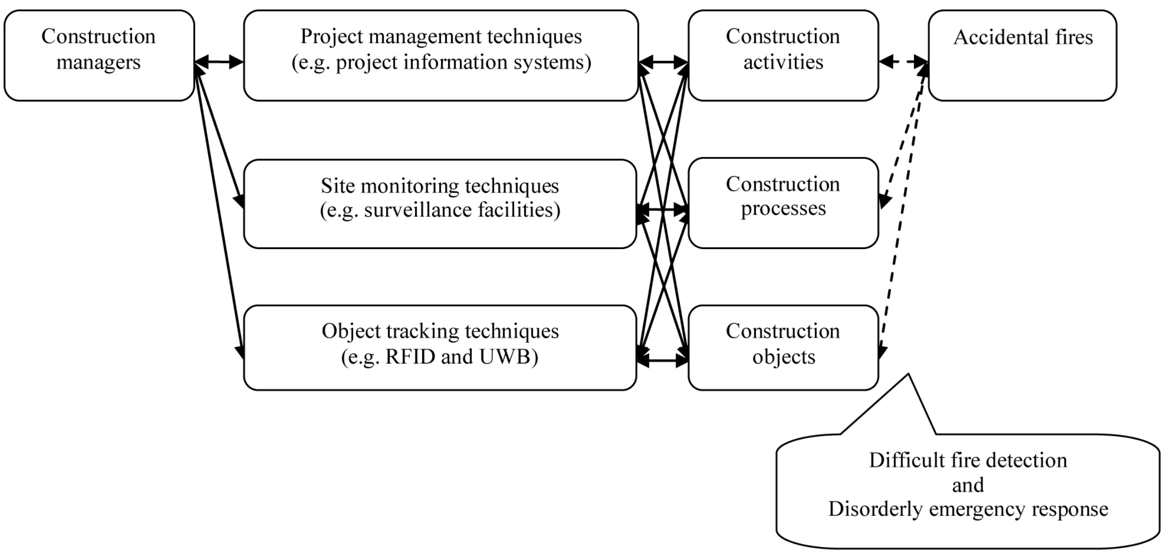

Fig. 1. Using information techniques for construction site safety management

time firefighters arrived. In these two case studies, neither construction managers nor workers understood how to appropriately deal with different emergency scenarios of on-site accidental fires.

3. Approach

The identified problems indicate the interdependent relationship between accidental fires and emergency response. To improve this relationship, this study has proposed an approach that involves two mechanisms:

– An image-recognition-based mechanism for fire detection. Thousands of surveillance facilities are presently deployed at numerous construction sites. These surveillance facilities monitor all types of construction activities day and night (Gong, Caldas 2010). Just-in-time image recognition is a satisfactory means of detecting construction site fires. Since a construction site fire has some critical behavior indicators (e.g. smoke, air track, flames) (Hartin 2008), if surveillance facilities can detect the indicators, the efficiency of fire management at construction sites will increase. Thus, the approach should automatically recognize construction site fires.

  Considering that surveillance facilities can record a sequence of images to form videos (defined as frames), this study compared adjacent frames to achieve incident detection. If the content of the adjacent frames differs, an incident is identified. However, various events might cause this incident (e.g. earthquake). Therefore, based on colour and appearance of the fire behaviour indicators, when the analysis results correspond to specified characteristics, the incident will be identified as a construction site fire accident, enhancing the accuracy of fire detection.

– A knowledge-model-based mechanism for emergency response. During construction site fires, construction managers must make decisions regarding emergency response. The experience of the construction managers will affect these decisions. If construction managers have experience with construction site fires, they can rapidly grasp on-site conditions, and vice versa. Therefore, the approach should offer clear guidelines to assist construction managers in responding to construction site fires.

  A knowledge-model-based mechanism is an alternative solution, as this mechanism involves both theoretical and common-sense knowledge directly from experts. The knowledge is organized into several models based on the identified scenarios. By accessing these models, construction managers can understand the philosophy and purposes of expert recommendations (Hernándeza, Serrano 2001; Tserng *et al.* 2010). For example, for an accidental fire, after construction managers have ascertained the on-site status (e.g. what is happening and what may happen), they will understand the options in various emergency strategies (e.g. what to do).

4. Implementation

Depending on the approach, this study built an intelligent construction site fire management platform consisting of on-site surveillance facilities, remote servers, and mobile phones. From fire detection to emergency response, Figure 2 shows the four steps in the platform: data collection via surveillance facilities (Step 1), image-recognition-based mechanism for fire detection (Step 2), information confirmation via GIS (Step 3), and knowledge-model-based mechanism for emergency response (Step 4). Steps 1 and 2 worked automatically on the remote servers. If the servers identified any on-site fire accident, information from Steps 3 and 4 was delivered to construction managers. To ensure that the four steps formed a seamless information flow, this study configured the platform as described below.

Between Steps 1 and 2, since several surveillance facilities were available at construction sites, these facilities continuously captured and transferred video data to remote servers. Based on the four algorithms proposed by Collins *et al.* (1999) and Töreyin *et al.* (2006), the remote servers analyzed the video data for fire detection. These analyses consisted of moving region analysis to identify moving objects in adjacent frames (Eqn (1)), fire-colored pixels analysis to check whether moving objects matched the defined fire colors (Eqn (2)), temporal wavelet analysis to track the frequency history of pixels in the fire-colored region (Eqn (3)), and spatial wavelet analysis to check color variations in pixel values (Eqn (4)). When construction site fires were identified, the platform calculated the area ratios of the detected fires to the monitored construction sites (Eqn (5)) so that construction managers could assess the status of the fire sites.

Eqns (1)–(5) were as follows:

$$|X_n[i, j] - X_{n-1}[i, j]|; \quad (1)$$

$$[R(X_n[i, j]), G(X_n[i, j]), B(X_n[i, j])]; \quad (2)$$

$$[Y(X_n[i, j]), U(X_n[i, j]), V(X_n[i, j])]; \quad (3)$$

$$A_1 = X_n; \quad (4)$$

$$Area\ Ratio = A_1/A_0, \quad (5)$$

where: $X_n[i, j]$ is the intensity value at pixel position $[i, j]$ in the n^{th} image frame; $X_{n-1}[i, j]$ is the intensity value at pixel position $[i, j]$ in the previous image frame; $[R(X_n[i, j]), G(X_n[i, j]), B(X_n[i, j])]$ is a mixture of Gaussians in the red, green, and black color space for $X_n[i, j]$; $[Y(X_n[i, j]), U(X_n[i, j]), V(X_n[i, j])]$ is a mixture of Gaussians in the luminance and chrominance color space for $X_n[i, j]$; A1 is the summary of the pixels that conform to Eqns (1)–(3); and A0 is the total pixels of the nth image frame. For a specified pixel, if the value of Eqn (1) was

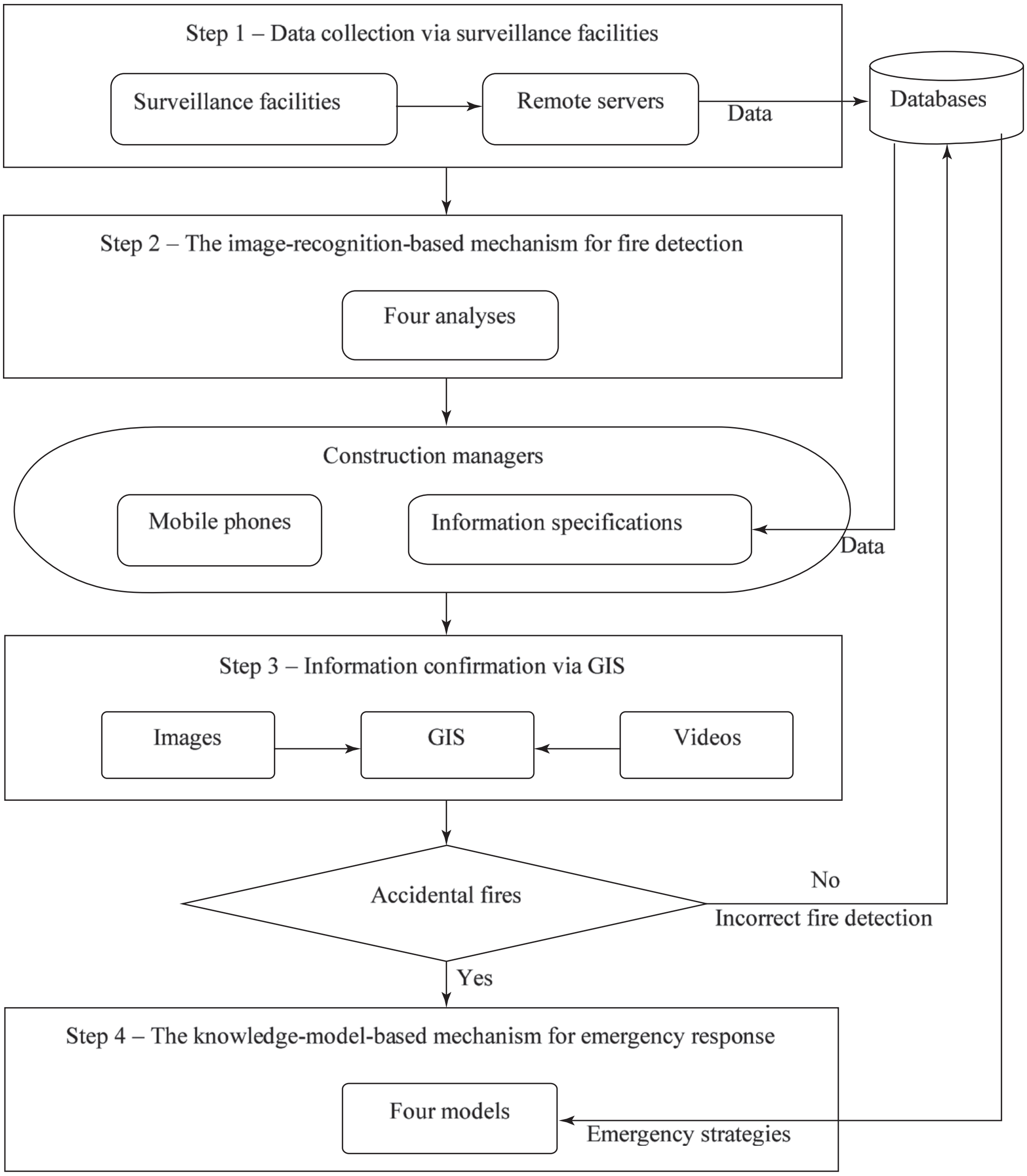

Fig. 2. Information flow from fire detection to emergency response

larger than zero and the values of Eqns (2)–(3) were in the fire-colour cloud (Reynolds, Rose 1995), this pixel was a moving and fire-color pixel.

Moreover, this study not only numbered the established surveillance facilities but also determined their latitudes and longitudes. The surveillance facilities monitored individual zones of the construction sites. Therefore, for the detected construction site fires, the remote servers recorded the analysis results and data (e.g. spatial, numerical, imagery, textual) into the database servers (i.e. Microsoft SQL Server Version 2008). In the meantime, because of the known surveillance facilities, the remote servers acquired the activity name, location, and participants from the project management systems. Construction managers clearly understood the interactive relationship among the fire sites, surveillance facilities, and construction projects.

In Steps 2 and 3, when construction managers accessed the received alerts, the platform connected to the databases and displayed the records regarding construction site fires on satellite-based electronic maps. The construction managers could also control the surveillance facilities to check on-site conditions in advance. As this study applied GIS simultaneously to illustrate a great quantity of data, such information is helpful for confirmation (Tsai, Yau 2012). For example, in a welding activity for a building project, if the remote servers of the platform identify a construction site fire through a surveillance facility, construction managers can identify the name of the project and activity, the geo-data of the fire site, and the imagery of the surveillance facility.

Since carrying heavy devices on construction sites is inconvenient, construction managers performed Step 3 through Google Android-based mobile phones. This study applied several information tools (e.g. Java programming language, Google Android development toolkits, SQLite-based databases) to complete the information components. To facilitate the off-site and on-site information exchange (e.g. indicating the locations of fire sites, explaining the intent of analysis results), the platform supported numerous information specifications, such as GeoAPI, Web Feature Service (WFS), and Keyhole Markup Language (KML) (Open Geospatial Consortium 2012).

For Step 4, after confirming the correct location of a fire accident, construction managers performed emergency responses through the knowledge-model-based mechanism. For development of this mechanism, this study used three elements, as shown in Figure 3. First, in the knowledge base, recommendations obtained from interviews with experts who had 10 years of working experience in either the construction industry or the National Fire Agency, Ministry of the Interior in Taiwan, were stored. Since a construction site fire had four stages, the recommendations were classified into the mapping knowledge models. Then, the researcher adopted if-then logistical rules to program the inference engine. If construction managers identified the current stage of the fire associated with emergency scenarios, the inference engine queried the knowledge base to locate the emergency strategies. Finally, working memory was created to temporarily contain the generated facts as the inference engine operated.

Based on the framework of the knowledge-model-based mechanism (Fig. 3), if a construction site fire is in the incipient stage, construction managers should attempt to fight the fire. In the meantime, construction managers should organize construction workers into rescuing, nursing, and communicating teams and keep them on standby. Adding to the complexity, during the burning stage, all teams go into action. For example,

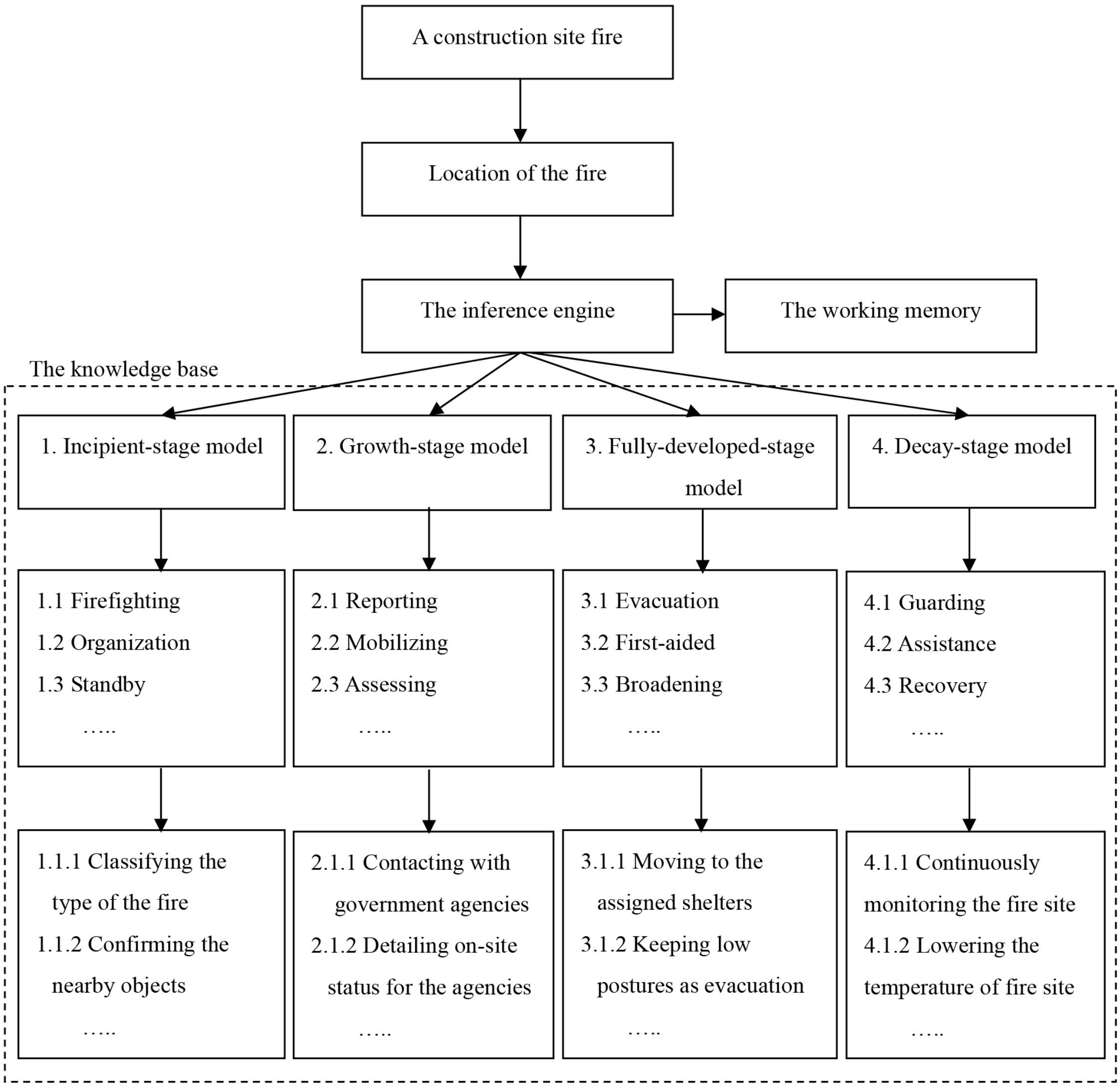

Fig. 3. Framework of knowledge-model-based mechanism

in this case, the rescuing team moved to the construction site fire for firefighting and evacuating victims; the nursing team prepared to offer first aid to victims; and the communicating team kept in touch with fire station houses. Because of the fast development of the on-site fire, construction managers continuously assessed the status.

Unfortunately, when the construction site fire entered the fully developed stage, the potential danger increased. Everyone on the site needed to leave. As soon as they were safe, they needed to be medically checked. The warning regions near the fire site had to be broadened. The construction site fire reached the decay stage with the assistance of professional firefighters. To avoid the recurrence of accidental fires, construction managers had to guard the fire site and lower the on-site temperature. After the construction site fire had been investigated, the site was cleaned and recovered by construction workers.

5. Tests

This study tested an intelligent construction site fire management platform at a construction site. This site had a number of surveillance facilities embedded with colour cameras. Since ordinary combustibles, flammable liquids and gases, and electrical equipment are common sources of accidental fires at construction projects, this study simulated Class A, B, and C fires. Five construction managers, who had three years of experience in the construction industry, participated in the tests; however, they had never encountered a construction site fire.

After every test was executed in different periods and locations, the testers determined the performance of the platform. For example, if the image-recognition-based mechanism identified that Class A, B, and C fires were occurring near the warehouse (Figs 4–6), the remote servers informed the testers. Based on the knowledge-model-based mechanism (Fig. 7), the testers then responded to emergency scenarios. After the tests, the researcher interviewed the testers. Based on the results of tests and interviews, this study determined whether the platform helped the testers in coping with construction site fires.

Table 1 shows the test results:

- Class A fires – Ordinary combustibles. In this scenario associated with five tests, the on-site surveillance facilities worked well for data collection. After construction site fires occurred, since the image-recognition-based mechanism detected four accidental fires, the accuracy rate was 80%. Excluding Tester 2, the other testers correctly performed information confirmation through their mobile phones. After accessing the knowledge-model-based mechanism and obtaining emergency strategies, Testers 1, 3, 4, and 5 alerted on-site construction workers in real time. Then, because of the incipient-stage model, the construction workers, who were near the fire site, were organized to perform firefighting using fire extinguishers. Also, Testers 1, 3, 4, and 5 checked whether their operation was correct (Fig. 7). Before the fires entered the growth stage, Testers 1, 3, 4, and 5 extinguished them.
- Class B fires – Flammable liquids and gases. During the tests, the on-site surveillance facilities were in good condition. Since the flammable fuel accelerated development of the fires, the characteristics of the Class B fires (Fig. 5) were obvious in the tests. All the testers received the alerts and verified

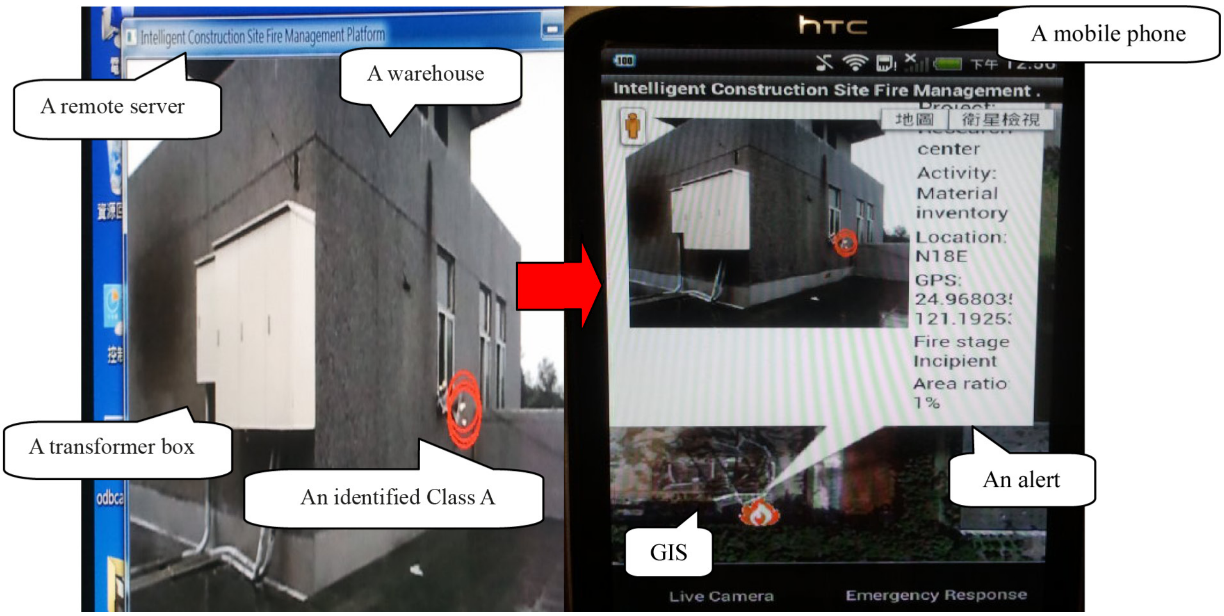

Fig. 4. Image-recognition-based mechanism for a Class A fire

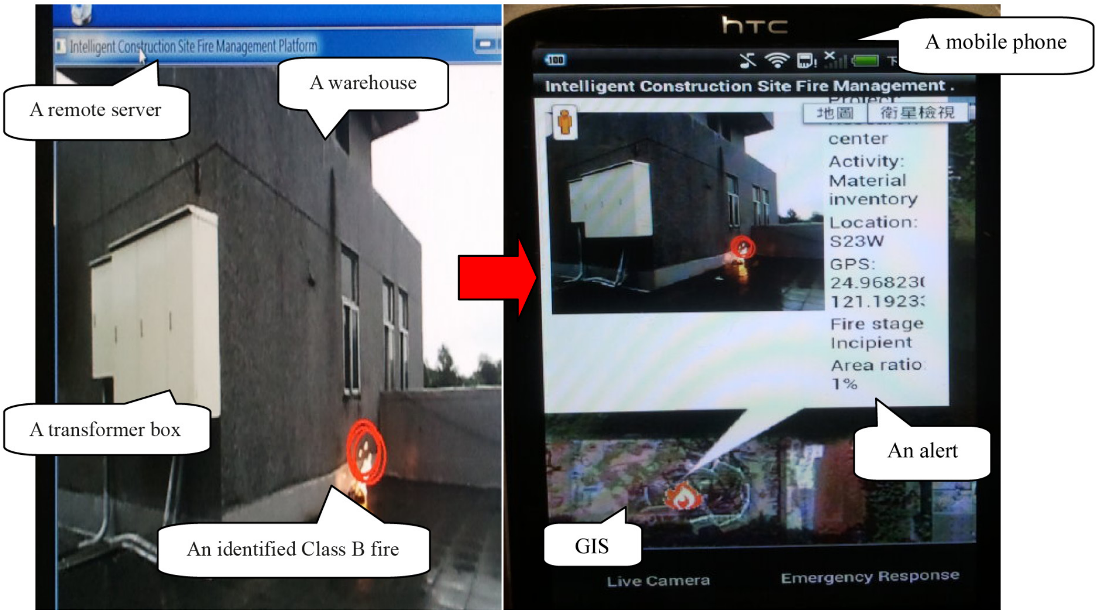

Fig. 5. Image-recognition-based mechanism for a Class B fire

Fig. 6. Image-recognition-based mechanism for a Class C fire

that accidental fires were occurring at the construction site. The accuracy rate of fire detection reached 100% for the image-recognition-based mechanism. According to the knowledge-model-based mechanism, the testers moved to the fire sites and executed necessary emergency processes. To avoid the spread of Class B fires, all the testers verified whether any inflammable material was stored near the fires (the incipient-stage model in Fig. 3). Since the fire site was near the warehouse, the testers organized the construction workers and specified missions for them. With the growth-stage model (Fig. 3), the rescue team fought fires, the support team transported inflammable fuels, and the nursing team prepared first aid.

– Class C fires – Electrical equipment: Unlike Class A fires (Fig. 4) and Class B fires (Fig. 5), the intensity of Class C fires (Fig. 6) was small. In five tests, although all surveillance facilities had no problem in capturing on-site video, the image-recognition-based mechanism merely identified three Class C fires. The accuracy rate of

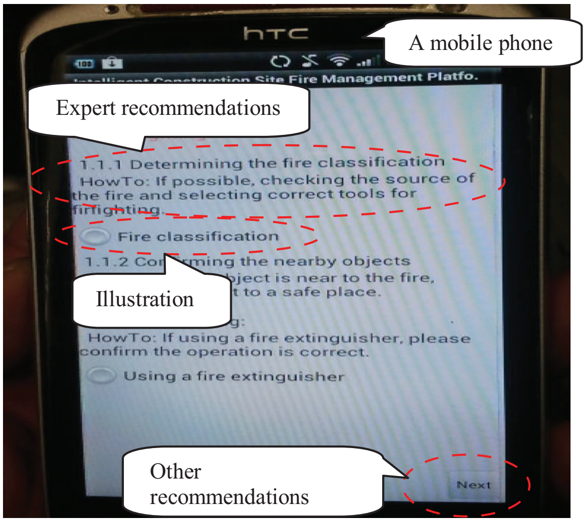

Fig. 7. Using knowledge-model-based mechanism for emergency response

fire detection was 60%. When Testers 2, 3, and 5 addressed the accidental fires, they performed the correct emergency response using the knowledge-model-based mechanism. Since Testers 2, 3, and 5 determined the fire classification, they turned off the power supply and used carbon dioxide fire extinguishers for firefighting (the incipient-stage model in Fig. 3). After Testers 2, 3, and 5 extinguished the fires, they investigated whether the transformer boxes were still in good condition (the decay-stage model in Fig. 3). In the aftermath of Class C fires, when the on-site status corresponded to the descriptions of the knowledge-model-based mechanism, construction workers returned to their construction activities.

Table 2 shows the interview results. All the testers indicated that the platform not only automatically detected construction site fires (Question 1), but also rapidly alerted them (Question 2). However, Tester 2 argued that the image-recognition-based mechanism could not update the stages of accidental fires in real time. When the testers confirmed the received information, the platform enabled them to comprehend the on-site status of fire sites (Question 3). For Tester 3, since the quality of information transmission was unstable, accessing on-site video through surveillance facilities was postponed. To handle various emergency scenarios, the testers obtained useful recommendations (Question 4). Tester 4 thought that some details of emergency strategies were redundant. Finally, Testers 2 and 5 suggested that in the future the tested platform could support compound construction site accidents and offer alternative mechanisms for fire detection (Question 5), respectively.

6. Discussion

To enhance the performance of the intelligent construction site fire management platform, this study discussed three main directions:

– Enhancing image recognition. Because of software- and hardware-created conditions, the accuracy of fire detection is not perfect. Software-created conditions included the characteristics of the video (e.g. the monitoring distance between surveillance facilities and construction activities was difficult in incident determination and the brightness and contrast of the video were inappropriate for imagery analysis). The hardware-created conditions involved failed equipment for data collection and information transmission (e.g. natural disasters interrupted the power supply and human-made events destroyed surveillance facilities). Therefore, either the image-recognition-based mechanism generated incorrect analysis results or the platform suspended service. Applying a self-inspection mechanism to enable the platform to report the quality of software and hard-

Table 1. Test results

Scenario	Class A fires – Ordinary combustibles					Class B fires – Flammable liquids and gases					Class C fires – Electrical equipment				
Tester	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Step 1 – Data collection via surveillance facilities	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Step 2 – The image-recognition-based mechanism for fire detection	OK	NG	OK	OK	OK	OK	OK	OK	OK	OK	NG	OK	OK	NG	OK
Step 3 – Information confirmation via GIS	OK	–	OK	OK	OK	OK	OK	OK	OK	OK	–	OK	OK	–	OK
Step 4 – The knowledge-model-based mechanism for emergency response	OK	–	OK	OK	OK	OK	OK	OK	OK	OK	–	OK	OK	–	OK
Accuracy rate	80%					100%					60%				

Table 2. Interview results

Question \ Tester	1	2	3	4	5
1. Does this platform automatically detect construction site fires?	Yes	Yes	Yes	Yes	Yes
2. Does this platform rapidly alert you to construction site fires?	Yes	Yes Failing in updating the stages of fire accidents in real time.	Yes	Yes	Yes
3. Does this platform enable to confirm on-site status of construction site fires?	Yes	Yes	Yes	Yes Accessing on-site videos through surveillance facilities was postponed.	Yes
4. Does this platform offer useful emergency strategies for construction site fires?	Yes	Yes	Yes	Yes Some details of emergency strategies were redundant.	Yes
5. Do you have any suggestion for this platform?	No	Yes Supporting compound construction site accidents.	No	No	Yes Offering alternative mechanisms for fire detection.

ware can prevent the above mentioned conditions. In the meantime, embedding alternative information techniques (e.g. flame detectors, heat radiation sensors) in the platform may increase the accuracy of fire detection.

– Augmenting knowledge models. Many construction site accidents associated with construction site fires exist in construction projects. However, during development of the platform, this study did not consider compound construction site accidents (e.g. accidental fire and structural collapse synchronously occurring at a construction site). Thus, after various construction managers who had encountered construction site fires tested the platform, their feedback was used to help identify numerous specific scenarios and offer response strategies. Construction managers may effectively perform construction site safety management. To enrich the content of the knowledge-model-based mechanism, the collecting and analysing of additional case studies and the sharing of experience from interdisciplinary experts and numerous countries are necessary.

– Supporting regular training. Although this study focused on automating fire detection and offering response strategies at construction sites, the platform was an assistance tool instead of an omnipotent solution. When a fire breaks out, construction managers have limited time to operate the knowledge-model-based mechanism and access the received content. Consequently, if the platform can offer a number of learning materials regarding fire drills, construction managers may be better prepared for construction site fires.

Conclusions

This study presented an approach for improving emergency response at construction site fires. In previous decades, serious accidents have occurred in the construction industry. To protect the health and safety of construction workers, construction site safety management has become important. While many researchers have applied information technology-based solutions (e.g. project management techniques, site monitoring techniques, object tracking techniques), few studies have focused on the relationship between information techniques and construction site fires. After this investigation of the relationship, two problems associated with accidental fires at construction sites were identified: difficult fire detection and disorderly emergency response.

To solve these two problems, this study has proposed an image-recognition-based mechanism for fire detection integrated with a knowledge-model-based mechanism for emergency response. Also, the researchers constructed an intelligent construction site fire management platform. This study tested this platform with three types of accidental fires at a construction site. The test results showed that three anticipated objectives were achieved. First, since the platform identified on-site accidental fires in real time, construction managers could immediately perform emergency response. Second, the platform enabled mobile information transmission so that construction managers understood the just-in-time status of construction site fires without the limitations of time and location. Third, the platform offered expert knowledge and recommendations to assist construction managers to smoothly cope with various emergency scenarios. Overall, this study contributes to the knowledge of construction site fires for similar applications in construction site safety management.

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