On-site Safety Management Using Image Processing and Fuzzy Inference

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ABSTRACT

Construction is generally conducted in highly changeable site conditions due to operation of machinery, transfer of materials, moving workers, and changing progress status. Such dynamic characteristics can always lend themselves to the potential for safety accidents. However, it is not easy to have a generalized safety management system that can universally apply to every job site. Although there are some guidelines for safety management, their application to a construction site has to be tailored to satisfy the unique nature of the particular project. Based on the good understanding of the particular site, effective and appropriate safety management process should be derived for workers to be protected from potential dangers of the site. This paper presents an on-site safety management methodology based on image processing and fuzzy inference. Image processing is used to extract spatial information of workers; fuzzy inference is then used to provide the workers a proper level of safety warning based on the spatial information. Contextual site information, such as equipment operations and density of workers, also constitute the on-site safety management methodology. The proposed methodology is expected to provide a safer working environment for construction workers, through its capability to easily customize the safety management system for a construction site.

INTRODUCTION

Despite a 37% descent of fatal construction injuries in the United States since 2006, construction industry still accounted for the highest number of fatal injuries of all other industries in 2012 (Bureau of Labor Statistics 2013). This statistics implies that construction sites have one of the harshest working environments than any other job site. Thus, safety management in construction site is consistently being emphasized.

Generally, a construction site contains various activities that have different safety issues (Ismail et al. 2012). Each activity has to be timely assessed based on its unique safety guideline. However, safety monitoring and assessment for a construction site has conventionally relied on manual inspections (Chi and Caldas 2012); manual inspections, owing to their time and labor-consuming nature, do not enable timely monitoring of construction site for safety issues. Highly changeable construction site is another barrier to overcome for developing an effective safety management system. Risk factors that have to be considered for safety are continuously changed, because construction activities are performed by altering geographical features, locations of materials, and structural components.

Safety issues can best be understood when the context of the site is well considered. Here, context refers to the site-specific situations to consider, such as movement of equipment and density of workers; the contextual information determines an overall safety level of the site. However, even though safety context in a construction site has been successfully identified, that has to be expressed in a significant manner. For example, a worker receiving information that an excavator is approaching from a distance of 10 m in 20 km/h may wonder what to do; the information may be precise but not significant enough. The worker would rather have a different type of information like "you are in danger." The latter is more informative, significant, and practical because it allows the worker to promptly understand the problem and take immediate actions, thereby avoiding the danger.

This paper presents an on-site safety management system using image processing and fuzzy inference. Image processing is utilized to detect and track of site objects on a real-time basis for extraction of safety context. This technique can automate a site-monitoring and information retrieving process. Fuzzy inference system is implemented to derive a proper safety level from the contextual information of the construction site.

RESEARCH BACKGROUND

Image Processing. Applicability of image processing for construction management has been constantly expanded to include progress monitoring, equipment efficiency analysis, and construction site safety management. Kim et al. (2013) used image processing for progress monitoring of a cable-stayed bridge construction project. Zou and Kim (2007) used color information in images to extract idle time of excavators. Chi et al. (2012) investigated spatial risk factors of earthmoving and surface mining activities.

Image data of a construction site is generally obtained by optical recording devices such as digital camera and camcorder. The image data is processed for automatically detecting, classifying, and tracking objects by given rules. Image processing can be conducted in various programming languages such as C++, Java, Visual Basic, openCV, Matlab and other languages. Users can select a proper programming language, which has different benefits of processing time, visualization, and matrix calculations.

When workers and equipment on construction site are the objects of interest in images, image processing algorithms for object detection, object classification, and object tracking can be used. Object detection algorithm identifies the objects of interest by their colors, shape or other features. Object classification algorithm categorizes each object into its proper class such as worker, excavator, and others, using intelligent classifiers or discriminant functions. Object tracking algorithm traces the objects in consecutive images, using 3D spatial information, motion segmentation, image matching, and other techniques.

Fuzzy Logic and Inference. In the well-known crisp set theory, a statement is evaluated as true (1) or false (0). Inclusion of an object in a set is represented as either 'in' or 'out' – so called binary membership. However, there exists a range of membership in many linguistic expressions. In case of representing temperature of water, such concepts as 'hot' and 'cold' are used. When a cup of water is said to be hot (or cold), it generally means hot (or cold) to a certain degree. In other words, the membership of the water to the hot (or cold) set is represented and understood in the form of a degree. This concept of partial membership was first introduced by Zadeh (1965). Fuzzy logic is to use the fuzzy set concept for logical reasoning and this logic is similar to human reasoning dealing with fuzzy reality with uncertainty. It is why fuzzy logic can be effective solutions to many real-life problems with fuzzy characteristics.

Fuzzy inference refers to an input-output procedure in a form of membership functions and if-then rules. Membership functions determine a degree of membership and if-then rules show the input-output relationship. For instance, with a rule that "if workers are close to equipment, then they are in danger," the degree of danger can be determined by a membership function that assign the situation to the danger set (60% dangerous). Mamdani's fuzzy inference is one of the most widely used methods to determine how inputs, along with if-then rules, are converted to output values (Mamdani and Assilian 1975).

METHODOLOGY

For an automated on-site safety management, image processing and fuzzy inference system are utilized. Image processing is used for identifying contextual information of the construction site. The contextual information contains risk factors that affect safety of workers. In this study, two risk factors are considered: "distance between equipment and worker (DBEW)" and "crowdedness of workers (COW)." Through image processing, the two risk factors are measured and the values are saved to be transferred to a fuzzy inference system for determining the safety level of the site. The system architecture for assessing safety level is shown in Fig. 1.

An optical video camera was used for data acquisition. The video camera was set at an elevated location to obtain construction site images using a bird's eye view. Images were taken at 24 fps (frames per second) and 1980x1080 (width x height) frame size. Image data were processed in the Matlab environment.

Image Preprocessing. The video footage, which is originally saved in a proprietary file format, is converted to the mp4 format, which can easily be processed in the Matlab environment. For efficient handling of the images, the size of each image can be reduced either by reducing the number of pixels or using some data compression techniques such as Fourier or Wavelet transforms. It is also possible to extract a portion (window) of each image to focus only on the region of interest. This type of preprocessing can significantly reduce the amount of data to deal with, making the following image processing faster and less-dependent on expensive hardware devices.

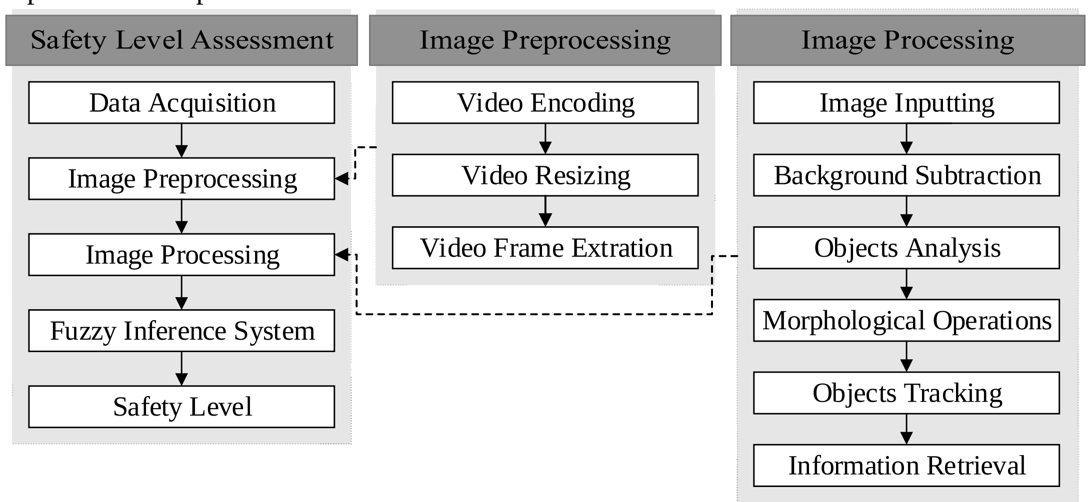

Figure 1. System architecture for safety level assessment

Image Processing. Image processing is composed of six steps as shown in Fig 1. Image file is inputted at the beginning. Second, background is deleted by image subtraction for detecting and tracking objects of interest (foreground). Foreground is detected by their motions based on the assumption of that objects of interest are moving and background is static. When moving objects are segmented from the background, each object is analyzed to understand its geometrical properties such as area and centroid. Object identification, whether the object is a worker or equipment, is performed based on the area of the object. Morphological operations are then conducted for noise removal and hole filling. Finally, objects are tracked in consecutive images. The authors utilized the open source code of Matlab R2013b for the background subtraction and object tracking (Mathworks. 2013). Through the image processing steps, risk factors of interest, such as distance between equipment and worker (DBEW) and crowdedness of workers (COW), can be measured. DBEW is measured by the centroid distance between equipment and worker. COW is defined as the number of workers from a worker within 4m distance. When workers are detected in images, a virtual circle with a 4m radius is created from the center of a worker to count the number of workers. Thus, COW is measured based on the particular worker of interest.

Fuzzy Inference system. This study, as previously mentioned, relies on the Mamdani's fuzzy inference method to extract the safety level of a worker on site. As in the case of the image processing part, the proposed fuzzy inference system is also implemented in the Matlab environment. Figure 2 shows the information flow of the fuzzy inference system. First the system is given two input values – DBEW and COW – from the image processing part. The two input values are fuzzified; they are represented in the fuzzy sets through their membership functions. A total of nine if-then rules are then used to produce output fuzzy sets. The results are aggregated and defuzzified to produce a crisp value – the safety level for the worker of interest.

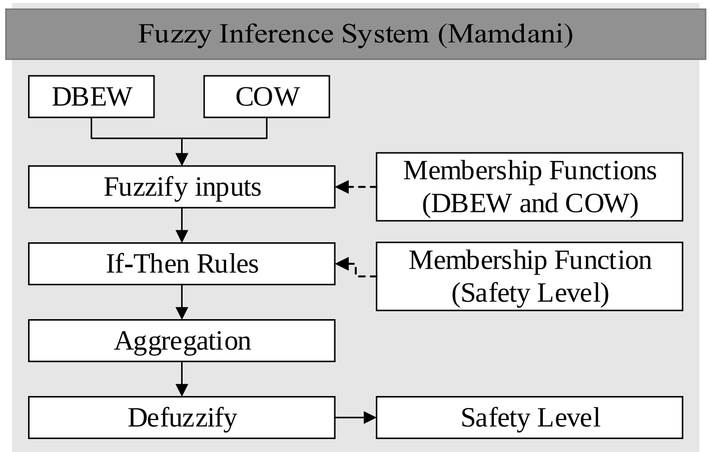

Figure 2. Fuzzy inference system

Membership Functions and If-Then Rules. Membership functions and if-then rules can be developed based on expert opinions of construction sites. Different rules and membership functions can be used for the specific nature of the particular site. Figure 3 shows triangular membership functions (close, medium, and far) used for DBEW. Figure 4 shows triangular membership functions (scattered, normal, and dense) used for COW. Finally, Fig. 5 shows five triangular membership functions (very high, high, medium, low, and very low) used for safety level. For efficiency and simplicity of the fuzzy inference system, the triangular shape is used for all the membership functions. The nine if- then rules are as follows:

IF (DBEW is Close) and (COW is Dense) THEN (Danger is Very High)
IF (DBEW is Close) and (COW is Normal) THEN (Danger is High)
IF (DBEW is Close) and (COW is Scattered) THEN (Danger is Medium)
IF (DBEW is Medium) and (COW is Dense) THEN (Danger is High)
IF (DBEW is Medium) and (COW is Normal) THEN (Danger is Medium)
IF (DBEW is Medium) and (COW is Scattered) THEN (Danger is Low)
IF (DBEW is Far) and (COW is Dense) THEN (Danger is Medium)
IF (DBEW is Far) and (COW is Normal) THEN (Danger is Low)
IF (DBEW is Far) and (COW is Scattered) THEN (Danger is Very Low)

Figure 6 shows the surface of safety level determined by the two input values – DBEW and COW.

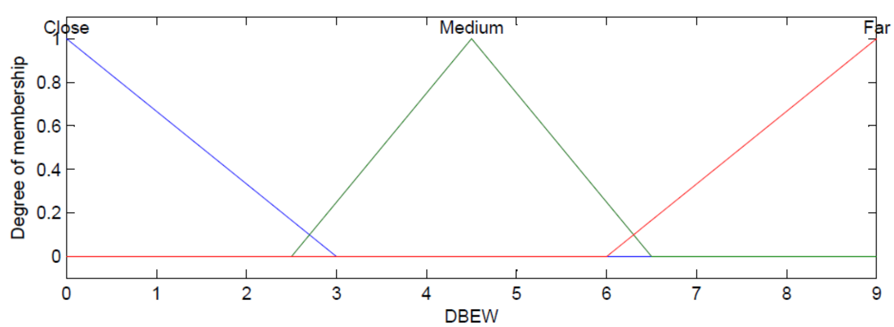

Figure 3. Membership function of DBEW

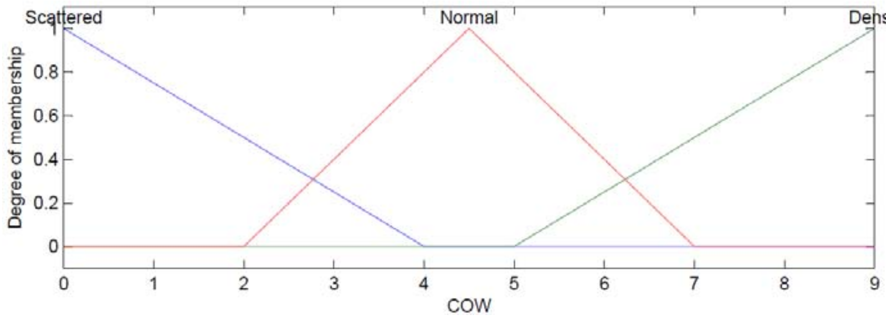

Figure 4. Membership function of COW

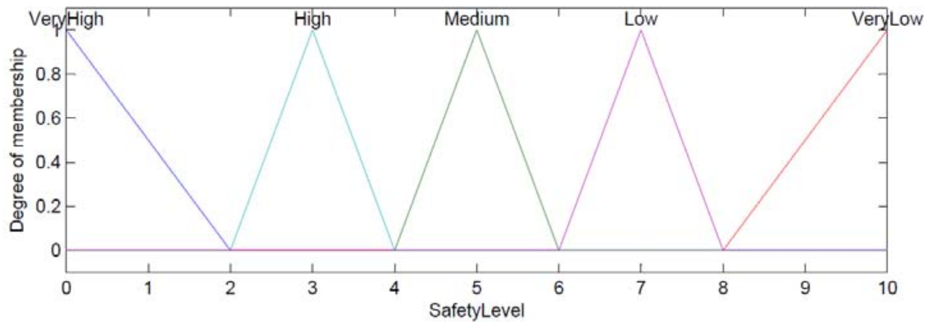

Figure 5. Membership function of safety level

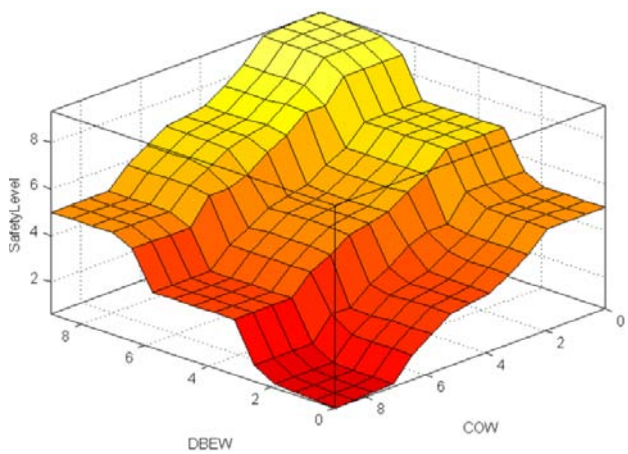

Figure 6. Safety level surface

EXPERIMENTAL RESULTS

Figure 7 shows the result of image processing. Figure 7(a) is an original image with the identified objects – two workers and one excavator – marked by the bounding boxes. Figure 7(b) shows a binary image where the image background was deleted and only the foreground remained, by image subtraction. In Fig. 7, the values for DBEW and COW were 10m and 2/the unit area, respectively. When the input values were applied to the fuzzy inference system, the safety level turned out to be 9.25. Safety level is represented on a scale of 0 to 10, and the higher the value, the safer the site is. Thus, the site for the workers was considered to be very safe.

(a) Result of object tracking (original image) (b) Result of object tracking (processed image)

Figure 7. Results of image processing

CONCLUSIONS

The main purpose of this paper was to develop an effective and efficient on-site safety management system using image processing and fuzzy inference. Image processing automated a construction site monitoring process while fuzzy inference assessed the safety context of a construction site reflecting expert's knowledge and safety guidelines. The measure of safety level was also introduced for workers in order to provide significant safety information for them.

Future studies are required for the idea of the proposed system to be fully implemented. As for now, the transfer of input values between image processing and fuzzy inference is not automated. Minimizing errors in image processing for object identification is another issue to be resolved. With improvement in those areas, the proposed system is expected to successfully reduce the potential for safety incidents on site.

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