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Framework Development for Construction Safety Visualization

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FRAMEWORK DEVELOPMENT FOR CONSTRUCTION SAFETY VISUALIZATION

By

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of the requirements for the

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May 2012

ABSTRACT

Framework Development for Construction Safety Visualization

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Throughout the history of the construction industry, many fatalities and injuries have occurred in construction sites. One of the major causes of accidents is unsafe site conditions; basically, this is due to inadequate supervision. To improve upon the traditional supervision approach, this study proposes a ‘Framework Development for Construction Safety Visualization’ approach. In addition to this, a computer vision Edge Detection Algorithm was developed and tested to convert construction site still images into edges of the objects in the images. The framework development of this study uses computer vision, robot vision, image compression, pattern recognition, internet transmission, network communication, and image processing.

ACKNOWLEDGMENTS

I do heartily thank to my supervisor, Dr. Pramen P. Shrestha, who has not only taught me how to conduct a scientific research but also encouraged, guided, and supported me since my first day at the University of Nevada, Las Vegas. The first vision to produce this thesis work was created by Dr. Shrestha, and now I am offering gratitude on the completion of the thesis. I am lucky that I had gotten a friendly supervisor, who helped me successfully on complete my Master's Degree in Construction Management.

I gratefully acknowledge my mentor and thesis committee graduate college representative, Dr. Evangelos A. Yfantis, who had taught me at every step of the thesis about coding and framework development for hard hat detection. Formally, he is my graduate college representative; however, he also guided me as a co-chair of my thesis committee. This thesis would not have been completed without him.

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CHAPTER 1

INTRODUCTION

There has been a strong myth that accidents are inevitable during construction projects. Nowadays, this notion is beginning to fade out. An innovative idea is emerging that zero injuries at construction sites are possible. As injuries and accidents are quite costly as well as hurt the morale of the workers, contractors have been trying to create a zero-injury culture in the construction industry. However, much effort still is necessary to avoid construction accidents. Basically there are three types of accidents in the construction sites: i) struck by objects and equipment; ii) fall accidents; and iii) electrical and other types of accidents.

In 2010, 4547 people died while working at construction sites. Of these, 742 people (16%) died due to being struck by and against the objects and equipment and 635 people (14%) died by fall accidents (BLS- 2011). If we could assure the proper use of the hard hats in the construction sites, at least we could prevent or reduce the number of fatalities due to fall accidents as well as accidents from being struck by and against the objects and equipment; these encompass 30% of all construction site fatalities. Therefore, it is necessary that construction workers use hard hats at construction sites for head protection; which could save workers' lives.

Construction safety training teaches construction workers to use hard hats at their job sites. Also, contractors do not allow anyone at the construction site without wearing hard hats. However, even though the use of hard hats by workers is mandatory, there are numerous occasions where workers have had fatal accidents due to not wearing hard hats. Therefore, the enforcement of hard hat use in the construction sites is becoming stricter. For example, the safety engineer or construction supervisor has to monitor whether their workers are using hard hats or not. However, due to the pressure of completing the project on time, and also due to complex work schedules, it is becoming difficult for supervisors — and quite expensive to the contractor — to monitor every worker manually to check whether they are using safety equipment at the sites. To overcome this deficiency, if a visualization algorithm can be developed so that the real time image received from the sites can be analyzed to check whether the workers are using hard hats, it will assist supervisors to save the lives of their workers. Thus, the major focus of this research is to explore a visualization method that could determine whether workers are wearing hard hats at the construction sites.

The Occupational Safety and Health Administration (OSHA) has been providing safety training to construction workers, and also prepares construction safety standards to improve construction safety. Due to the OSHA involvement, fatalities at construction sites are decreasing. However, safety personnel still are looking for other innovative approaches because construction fatalities and injuries have not reduced significantly enough.

OSHA has been educating construction workers to use personal protective equipment (PPE), such as hard hats, safety shoes, harnesses, goggles, face shields, reflective clothing, filter masks, and ear plugs. The training/education to use these devices is very important to protect constructions workers from injury and fatality; nevertheless, many times, the construction workers fail to obey safety rules and regulations at the construction site due to stress caused by work progress, extreme environmental conditions, and their own carelessness. In order to implement workers' training at the construction sites, it is necessary to monitor the construction site in real time in order to make sure that the workers are using PPEs.

Nowadays, the visualization technique, which is used in many fields as a pro-active method, is a useful tool to observe the construction workers and give warning messages to the safety personnel if the workers are not using hard hats. In this technique, cameras are installed at the construction sites and real time images are transferred to the office computer by means of wireless technology. The images of the construction site are continuously displayed on an office computer. From the real time images, the computer program will detect whether the construction workers are using hard hats. Once the program identifies a worker working without a hard hat, it automatically dispatches a warning message to the safety personnel in real time. Ultimately, the site supervisor who is responsible for a particular area will be informed so that the safety problem is corrected prior to an accident occurring.

Computer vision uses various methods for image processing, analyzing, and understanding images. It can be used broadly, such as for construction management, productivity access, automation, and transportation. More specifically, the use of computer vision could help improve construction safety at the construction sites. In this research, our main concern is to develop a framework development for construction safety visualization and testing the Edge Detection Algorithm—the first, big step of framework development for hard hat detection. The framework development for construction safety visualization is a subset of computer vision.

The framework that was developed in this study consists of cameras using charged-couple devices (CCD) to capture high-quality, uncompressed analog video at National Television System Committee (NTSC) resolution. The camera set consists of a hardware electronic card at the back of each camera. That card captures and converts the video into digital data. The card also processes the video by applying a detection algorithm and compresses the video, all in real time.

Adding a camera with proper overlap gave birth to stereo vision. Stereo vision is useful for short- and middle-distance objects, (Cristobal et al. 2000). Stereo vision can provide full details of a safety violation, for example, the exact location of the workers at the construction site, the name of the person(s) causing the violation, the time and duration of the violation, and the history of each person relating to safety violations. Stereo vision also can be used in other applications to find loss of property, control graffiti in roads, detect fraudulent accidents, and avoid accidents; this can be done by analyzing activities in real time and issuing alarm events regarding activities that have the potential to cause accidents and illegal works.

To detect the hard hats, two algorithms were used in sequence; the first was an Edge Detection Algorithm and the second, a Segmentation Algorithm. The real time images transferred from the site cameras were a mixture of red, green, and blue (RGB). The Edge Detection Algorithm erased unnecessary data in terms of pixels or points in the image, and preserved the structural properties for further processing; this was done before matching (Marr and Poggio 1979).

A part of this thesis research was published in a peer-review conference publication, the Proceedings for the *International Multi-Conference on Engineering and Technological Innovation* (IMETI-2011), held from July 19 to 22, 2011, in Orlando, Florida, in a paper entitled titled “Construction Safety Visualization.” In that paper, the two algorithms, Edge Detection and Segmentation, were developed. In this research, a framework for construction safety visualization was developed, and the Edge Detection Algorithm was tested and implemented for still images of a construction site. The framework development of this study used computer vision, robot vision, image compression, pattern recognition, internet transmission, network communication, and image processing (Ritchie et al. 2010; Yfantis et al. 1992; Yfantis 1993; and Yfantis 2003). An application file of the Edge Detection Algorithm was compared with two famous algorithms in terms of time efficiency and clarity of the output. The details of the application of these algorithms are described in Chapters 5 and 6 of this thesis.

1.1 Objectives and Scope of the study

The major objectives of this study are:

1. To develop a framework to detect hard hats from the real time images transferred from construction sites, using an image processing technique.
2. To develop an algorithm to convert the images of the construction sites into grayscale images.
3. To develop an algorithm to convert the images of the construction sites into edges (either line diagram or outline) of objects by using the Edge Detection program.

The scope of this study is limited to determine the edges of the objects from still images received from construction sites. In this study, the Edge Detection Algorithm is developed and its application implemented. This converts images of the construction sites into line diagrams of the objects.

CHAPTER 2

LITERATURE REVIEW

A number of studies have been conducted in the area of object recognition. Although many of the reviewed works are not directly pertinent to this research topic, they are very closely related. The summary of the literature reviewed is given in the following paragraphs.

2.1 Summary of Literature

Various papers were studied as a background study for this thesis research. Among those papers, different types of algorithms for object recognition, matching, and image compression as well as other types of pro-active, real time warning approaches, were studied carefully. The relevant research papers in the area of construction safety visualization were considered as the foundation for this research.

Curio et al.(2000) used image processing approach to detect walking pedestrian on the road. A human outline and its walking characteristics were taken as the main parameters to recognize a road-crossing pedestrian. A similar study that analyzed traffic-sign-posts applied the image processing approach to identify defective sign boards along a highway (Tsai et al. 2009). There also are many Edge Detection Algorithms that have been used in different areas. Canny (2009) developed an algorithm that gave a clear boundary of an object.

For a hard hat detection program, first, a set of efficient Edge Detection and Segmentation Algorithms is necessary. Shrestha et al. (2011) gave two sets of important algorithms to detect hard hats of workers. Next, image compression is an important step to reduce time for image processing, because numerous images need to be analyzed in a short time while working in real time. Yfantis et al. (1992) developed a lossless algorithm for efficient image compression for computer animated images. A technology using radio-frequency identification (RFID) created a region, and gave warning when a worker and heavy equipment approach each other nearer than the preset distance fixed between them (CII 2009).

2.2 Details of Literature Review

Visualization techniques have been used in construction planning and operations. One study demonstrated the uses of applying visualization techniques in different areas of the construction industry (Kamat et al. 2010). Basically, this study defined the scope of using visualization techniques for planning, monitoring, and controlling at two distinct levels: 1) the activity, or schedule, level; and 2) the operation, or process, level. This research focused on visualization that could be used for both the activity level and the operation level to communicate what components are built where and when during projects.

Specifically, the authors used visualization techniques that employed dynamic operations to depict a continuously evolving multi-storied structural steel facility. Four-Dimensional Computer-Aided Design (CAD) visualizations, which only showed the evaluation of the construction product, could be linked to project schedules. However, dynamic operation visualization could show the interactions between various resources, including machines, materials, and temporary structures. The authors showed how this process could help the contractors build the project more efficiently and effectively.

In 2009, the Construction Industry Institute (CII) conducted a study to use pro-active, real time safety technology in construction sites. They implanted into heavy equipment and workers' hats a very-high-frequency active radio frequency (RF) technology, consisting of an in-cab device and a personal device. The personal protection unit (PPU) used by construction workers consisted of a chip, a battery, and an alarm. When the workers were in the proximity of the heavy equipment; the alarm was set off in the equipment as well as on the workers' PPU. The field tests demonstrated that by implementing this technology, various benefits were achieved; for instance, it provided real time proactive alerts to workers and operators and also monitored the locations of workers, equipment, and material. Moreover, this study included a cost-benefit analysis to show that it was economically viable to use real time proactive technology at construction sites.

A study was conducted by Irani M. and Anandan P. (1998), in which the detection of moving objects was carried out. Prior to this study, many of these types of studies were done by using 2D algorithms for relatively flat (planar) objects and 3D algorithms when the object had significant depth. 2D algorithms cannot be used for 3D objects and vice versa, so a constant switching from 2D algorithms to 3D was impractical. Therefore, this study used a unified approach for both 2D and 3D scenes. This approach was based on a stratification of the moving-object detection problem into scenarios that gradually increased in their complexity.

A study called ‘Walking Pedestrian Recognition’ was carried out by Curio et al. (2000). The image processing approach was used to detect, track, and recognize pedestrians crossing a road. Using two cameras, stereo vision could be produced, which was useful for short-range and middle-range distances from the camera to the pedestrian. A typical characteristic of a human while crossing a road by walking was taken into consideration in order to recognize a road-crossing pedestrian. Specifically, the outline of lower part of the walker — the movement of legs — was used for matching. Therefore, for final recognition of a walking pedestrian, two conditions were fulfilled. The first one was an outline of a human, detected by shape matching, and the next one was periodic motion of legs, which also should be matched.

Another study, “Generalized Traffic Sign Detection Model for Developing a Sign Inventory,” was conducted by Tsai et al. (2009). This research studied the detection of defective traffic signals by using an image-processing model. The goal of this study was to determine whether imperfect traffic signs could be identified using computer programs. Traffic sign detection included the recognition of the type of sign and the exact location of the sign for inventory purposes; it also included identifying sign conditions, for example, retro-reflectivity; faded sign colors; tilted signs; and sign boards blocked by objects, such as tree branches.

In the detection process, first, traffic sign detection was completed; after that, traffic sign recognition – analyzing the image – was done. Tsai et al. (2009) dealt only with traffic sign detection. Previously, many studies dealt with the detection of only specific types of signs, for example, speed limit signs. This paper covered all the signs, in fact, more than 670 types of signs. Traffic signs were identified in terms of their shape, color, background, and legend. A crucial step for the image processing algorithms was to separate the images that contained traffic signs from those that did not have traffic signs.

In a 1986 paper, “Edge Detection of an Image,” Canny John (2009) developed an algorithm that ran in the following five distinct steps:

1. Smoothing. This is a blurring of an image. Every image has some amount of noise in it, and a Gaussian filter is used to smooth it.
2. Finding gradients. Edges in a grayscale image are where the grayscale intensity changes the most; this is identified by determining gradients.
3. Non-maximum suppression. In this step, the maxima in the gradient image are preserved, and the remaining is erased.
4. Double thresholding. The pixels that remain after Step 3 are marked with their strength, pixel by pixel.
5. Edge tracking by hysteresis. Strong edges and weak edges connected with strong edges are considered as ‘certain edges’.

Ritchie et al. (2010) did a study entitled “Robot Vision and Video Transmission”. The authors studied the problem of distance resolution by using four cameras and a non-invasive laser light for robot vision. A physician used this application to compare health improvements during a patient’s visits. With the help of a nurse, an image was taken at the time of patient’s hospital visit; this image was transferred to the server, then wirelessly to the physician’s computer for real time examination. The images were compared with the previous visit.

Yfantis et al. (1992) conducted a study entitled the “Efficient Image Compression Algorithm for Computer Animated Images”. In this study, they used a Bitmap RLE Algorithm, which uses two passes to compress the image and one pass to decompress the compressed image. The researchers compared their algorithm with other popular compression algorithms. In this study, it was concluded that sometimes this algorithm gave the best output in terms of saving memory space; however, it was time consuming to do the compression. This algorithm is lossless, and especially suitable for computer graphics of animated images.

Shrestha et al. (2011) conducted a research on Construction Safety Visualization. In this study, two important algorithms were developed for hard hat recognition in real time for a construction site. The first algorithm is an Edge Detection Algorithm and the second is a Segmentation Algorithm. The Edge Detection Algorithm was used to change an image into a line diagram of the objects of the image.

2.3 Gaps in the Literature Review

Image processing algorithms have been used in several applications ranging from identifying a pedestrian crossing a road, recognizing changes in a patient’s health in a hospital, and many other areas that need to identify images of people and objects for a particular application. A new application of these algorithms is to identify hard hats of construction site workers in order to reinforce safety rules and possibly saving the lives of the workers. Prior to this study, there has been no literature regarding the use of this image processing technique involving real time images for a construction site safety application. This study is a giant step towards the goal of using an automation system to identify people without hard hats at construction sites.

CHAPTER 3

METHODOLOGY

In this thesis research, a framework was prepared to use a computer-adapted visualization method to detect the hard hats. Specifically, the Edge Detection Algorithm was used in order to change a still image of a construction site into edges of the objects. A detailed description of this application is described in Chapter 6.

Fig. 1 at the end of this chapter shows an overview of the Research Methodology adopted in this research. The steps that were involved in the methodology are described as follows.

3.1 Objectives and Scopes

The primary objectives and scopes of this research were to develop a framework for construction safety visualization, using the Edge Detection Algorithm to convert still images taken at construction sites into line diagrams. This framework is explained in Chapter 1, Introduction.

3.2 Literature Review

The previous works related to this research are discussed in Chapter 2, Literature Review. Journals, peer-reviewed conference papers, reports, and web pages were reviewed in the fields of visualization techniques, image processing, computer vision, pattern recognition, robot vision, image compression, internet transmission, network communication, and radio frequency (RF) technology.

3.3 Framework Development

The important achievement of this thesis was to develop the framework for construction safety visualization using image processing techniques to identify hard hats at the construction sites in real time. This is described in Chapter 4.

3.4 Algorithm Development — Edge Detection

Another achievement was developing the Edge Detection Algorithm to convert still images taken at a construction site into line diagrams. This is explained in Chapter 5.

3.5 Algorithm Application

The Edge Detection Algorithm developed in this study was tested to convert construction site images into line diagrams of the objects of the images. This application is described in Chapter 6.

3.6 Conclusions and Recommendations

The central outcome of the research and the conclusion are presented in Chapter 7. Recommendations for future research regarding detecting hard hat also are described in Chapter 7.

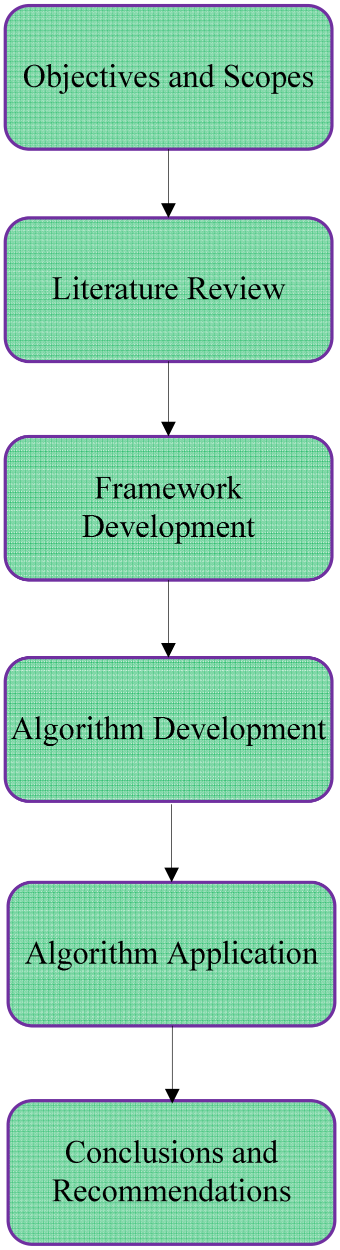


Fig.1. Flowchart of the research methodology.

CHAPTER 4

FRAMEWORK DEVELOPMENT FOR HARD HAT DETECTION

In this research, one of the main concerns was framework development for hard hat detection. This dealt with real time, automatic detection to determine whether or not people were wearing their hard hats. In this framework, if one or more people were not wearing their hard hats, that constituted a safety violation. Such a safety violation was recorded in a safety violation database, along with the time and duration of the violation. Furthermore, this violation issued an alarm event, shown on the alarm events monitor for the on-site manager to see and take corrective action. Alarm events also could be transmitted to cell phones of specified people or else to their office computers in order to make them aware of the violation.

A big concern to some may be to know how the framework detects a hard hat at a construction site in real time. In other words, how does a framework, which is a computer-adapted program, identify that one or more workers are not wearing hard hats on their heads and dispatches a message? Fig. 2 shows a flowchart that describes the steps involved to detect a hard hat on a worker’s head at the construction site.

First, a camera or a set of cameras at a construction site took real time video of the workers working at the site and wirelessly transferred the images to the office computer server. As a video is the collection of images, can be ‘one-second video’ is split into certain number of frames or images. Second, in the office computer, an Edge Detection Algorithm is applied to each of the frames in order to create the edges, or sets of line diagrams, of each object or worker at the site. A set of line diagrams of an object is called a Video Object Plane (VOP). Next, the Segmentation Algorithm identifies whether or not the VOP can be identified as a worker. If the VOP is of a worker, then the Segmentation Algorithm will create Sub-Video Object Planes (SVOP) of the worker's VOP. If the algorithm program could not identify a hard hat as a SVOP after getting a VOP of a worker, it dispatches a warning message to the appropriate safety personnel. This is how the program detects hard hats.

All the algorithms are mathematical modules; the majority of the work involves developing efficient algorithms and transforming the algorithms into computer coding. In this study, only the Edge Detection Algorithm was written using C# (C-Sharp) programming. C# programming is also known as object-oriented or class-based programming.

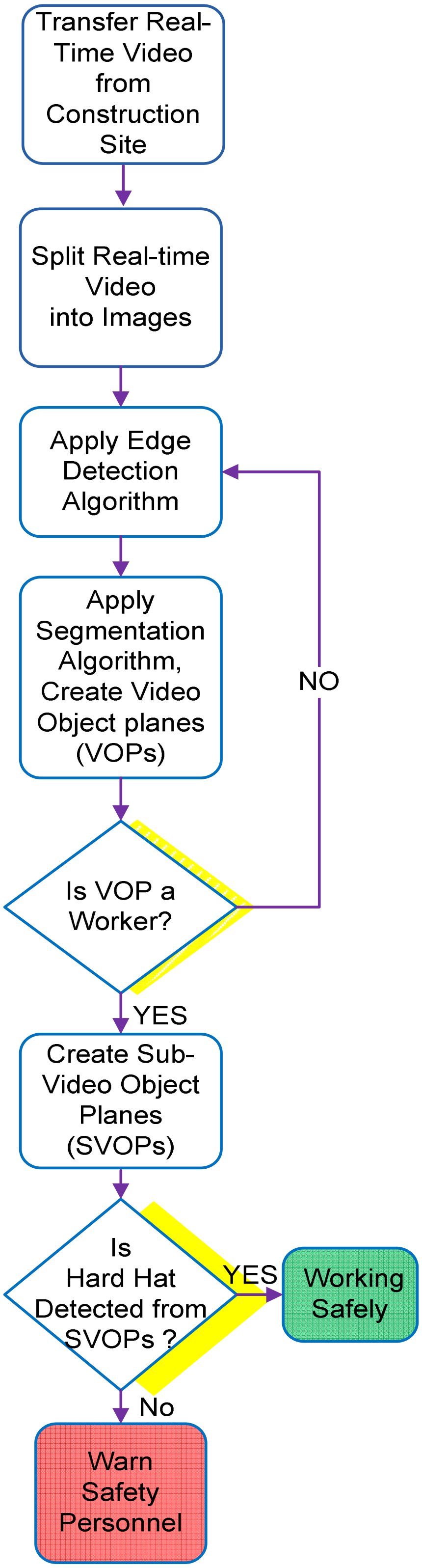


Fig. 2. Framework for identifying hard hats of construction workers.

The framework development consists of a number of camera batteries that are powered by an arrangement of both solar and lithium batteries. Real time video images are captured and processed by a card attached to each camera at the site. The purpose of the card is to compress the video, check for productivity, and transmit the video wirelessly to a local file server. The file server is powered by a both solar panels and other power sources.

This framework development for hard hats can detect one or more people at the construction site who are not wearing their hard hats. In such cases, the time of the event, along with event itself, is transmitted to a special safety event data base in the server. Safety event violations are programmed to create an alarm event, which alerts the onsite safety personnel or construction manager or site supervisor by sending the event to that person’s cell phone. In the case of multiple cameras, the picture of the person causing the safety violation, along with their name, can be transmitted to the construction manager as well as to all other people that are set up in the system to receive this event violation.

For hard hat detection, initially, the ideal position of the hard hats on the heads of the workers was considered. Indeed, not only the position of the hard hat but also the position of the workers usually will not be in the ideal position for workers and their hard hats. Some probable positions and other conditions of the hard hats are discussed below.

Fig. 3 and 4 show hard hats in different positions. Some are rotated in horizontal while others are in the vertical. Out of six hard hats, five show the logos or initials on the front and side of the hard hats. In this condition, the logos or initials give additional information to the pattern recognition system, making it easier to detect hard hats. Also, using more than one camera calibrated at the site, the hard hats can be seen from any angle and successfully identified in stereo vision.

Fig. 3. Hard hats rotated in different horizontal angles.

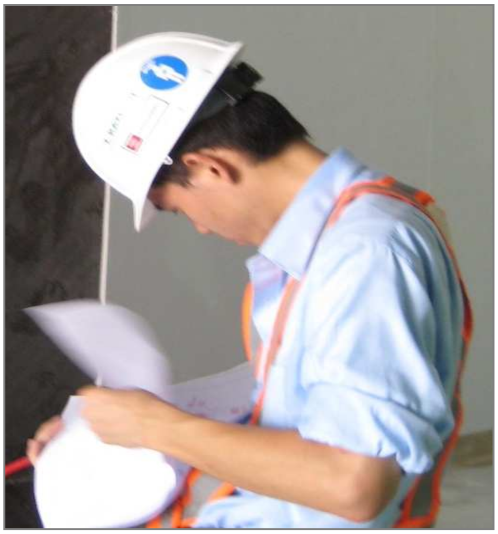


Fig. 4. Hard hat rotated vertically.

Fig. 5 is a photograph taken at the Dubai Metro Project construction site at Jebel Ali Depot, United Arab Emirates, in 2008. The proposed hard hat detection program can detecta hard hat that is being held in the hands rather than being worn on the head. Technically, the program would detect theVOP of the worker and a SVOP of the hard hat; however, detection would fail in relation to each other, and this is against safety site protocol. Thus, the program would give a warning message to the construction manager or resposible supervisor for those conditions of working at the site.

Fig. 5. A construction site picture of the author with a hard hat in his hand.

Fig. 6 shows a group of construction engineers in a construction site of the Dubai Metro Project in 2008. It is clear that two of the workers were wearing their hard hats on their heads . However, the person wearing the red t-shirt was holding his hard hat in his left arm; the leftmost person also is not wearing his hard hat. Under this condition, the program would issue an immediate alarm to concerned safety personnel.

Fig. 6. A construction site picture of the author and his colleagues, in which two have their hard hats on and two do not.

The ideal light condition is not always available at a construction site during all time periods. The photo in Fig.7 was taken at anti-light, and so the faces of the workers are not clear enough to recognize them easily. However, the algorithm can recognize the VOPs of the workers and the SVOPs of the hard hats in order to assure that the working condition is safe, as described in the Safe Site protocol.

Fig. 7. A construction site photo taken in an anti-light view.

CHAPTER 5

DEVELOPMENT OF EDGE DETECTION ALGORITHM

In this thesis, the Edge Detection Algorithm was developed and tested to convert still images into line diagram. The metric used in to encode this algorithm is a non-Euclidian metric. The mathematical space that was operated on was a Banach space. In this Banach space, a probability metric was defined later on.

Let I(*x,y*) be the intensity of the image at position (*x,y*); then, an estimate of the second partial derivative with respect to x is:

$$\frac{\partial^2 I(x,y)}{\partial x^2} = \frac{I(x-1,y)-2I(x,y)+I(x+1,y)}{2} \qquad (1)$$

and an estimate with respect to y is:

$$\frac{\partial^2 I(x,y)}{\partial y^2} = \frac{I(x,y-1)-2I(x,y)+I(x,y+1)}{2} \qquad (2)$$

The Laplacian, or divergence, of the gradient at the point (*x,y*) of the gray scale image is:

$$\Delta I(x,y) = \nabla^2 I(x,y) = \frac{\partial^2 I(X,y)}{\partial x^2} + \frac{\partial^2 I(x,y)}{\partial y^2} \qquad (3)$$

From Equations 1 and 2, an estimate of the Laplacian of the gray scale image at pixel position (x,y) is obtained:

$$\Delta I(x,y) = \nabla^2\ I(x,y) = \frac{I(x-1,y)+I(x+1,y)+I(x,y-1)+I(x,y+1)-4I(x,y)}{2} \qquad (4)$$

The values of the intensity all are integers ranging from 0 to 255. Multiplication by 4 can be obtained by shifting the integer two times to the left.

Division by 2 is obtained by first adding 1 to the numerator if the numerator is positive or subtracting 1 from the numerator if negative, and then shifting the numerator to the right by one. The estimated Laplacian for any image could be negative or positive, with the majority of the values being equal to zero and is symmetric about zero. The probability density function of the Laplacian is:

$$f(x) = \frac{1}{\sqrt{2}\sigma} e^{-\frac{\sqrt{2}|x|}{\sigma}} \qquad -\infty < x < \infty \tag{5}$$

The standard deviation σ depends on the quality of the camera, the light intensity of the scene, and the number of edges as well as the type of edges. For example, edges both of metallic objects and steel objects reflect light differently than edges of non-steel material. The edges of an image represent a relatively small percentage of the pixels of the image; those points are part of the tails of the probability density function of Equation 5. The Segmentation Algorithm consisted of finding the edges by first using the above theory.

5.1 Edge Detection Algorithm Development

The edges describe boundaries of something in an image. Specifically, edges show a drastic change in the value of intensity from one pixel to the next. Edge Detection is the first step in order to segment an object or subject of interest. First, Edge Detection is used to outline the object, and then the necessary rules are provided in order to separate the outline of the object from other outlines. In this case, the outline of a hard hat depends on the angle of the camera with respect to the hard hat. There are many kinds of Edge Detection Algorithms that are used under suitable conditions. In this study, because innumerable numbers of real time images were processed, a comparatively faster Edge Detection Algorithm was needed. The steps for an Edge Detection Algorithm developed by Shrestha et al. (2011) are as follows:

1. Compute the luma component of the image.
2. For every luma component pixel, compute the second-order partial derivative with respect to *x,* using Equation 1.
3. For every luma component pixel, compute the second-order partial derivative with respect to *y*, using Equation 2.
4. For every luma component pixel, compute the Laplacian at position *(x,y*), using Equation 3.
5. Compute the histogram of the values obtained in Equation 4.
6. All the values for which the area of the histogram to the right is less than 2.5% are edges.
7. All the values for which the area of the histogram to the right is less than 10% are possible edges.
8. If any of the neighbors of a possible edge is an edge, then the possible edge is an edge.

5.2 Proposed Segmentation Algorithm Development

Programming for the Segmentation Algorithm was not completed in this study. However, the process of developing the Segmentation Algorithm was researched, and is described below. The word ‘segmentation’ refers to the partitioning process of a digital image into either multiple planes, or segments, or else sets of pixels. An image is split into different segments in order to simplify analysis for specific purposes.

Segmentation was the second application that was necessary for the framework developed for construction safety visualization in this study. This application differentiates the objects in an image. For example, as shown in Fig. 9 in Chapter 6, a worker is one object, or one VOP. Similarly, construction equipment at the construction site can be distinguished. After this step, the VOP needed to be further split into several SVOPs to detect the hard hat and other parts of a human body. The sets developed to do this by Shrestha et al. (2011) are as follows:

1. Use the Edge Detection Algorithm described above.
2. Divide the scene into VOPs.
3. Separate the VOPs according to the people in the scene.
4. Focus on the part of the VOP of a person between the base of the neck and the upper end.
5. The SVOP of the hard hat consists of two orthogonal semicircles.
6. The chord line joining the ends of the top semicircle forms an angle with the *x*-axis of the screen. This angle θ can be determined by taking the dot product of the chord line row vector with the row vector (1, 0).
7. If the above-normalized dot product is 1, then the chord is parallel to the screen coordinate *x*-axis, and the person is standing straight up. In this case, there is a possibility of the head tilting towards the left or right

shoulder. Notice that with more than one camera, this possibility can be resolved.

8. If the dot product is a number other than 0 and between -1 and 1, then the hard hat can be rotated by -arccosθ about the *x* axis into a normalized position.
9. Logos or initials painted on the hard hats are segmented, and are recognizable during the segmentation.
10. If more than one camera has the same object in view, then stereo vision of the hard hat is possible. In this case, straps, logos, the pitch, role, and yaw (turning about the vertical axis) of the hard hat are computable in real time.
11. If the cameras are properly calibrated and the distance between cameras is known, then the distance of the various objects with respect to an origin can be computed in real time.

CHAPTER 6

APPLICATIONS OF EDGE DETECTION ALGORITHM

The Edge Detection Algorithm is the first step of the framework development for construction safety visualization. It converts the objects of construction sites in still images into line diagrams or edges of the objects. This chapter explains the application of the Edge Detection Algorithm.

Fig. 8 was taken by the author while working at the Rashidiya Main Depot construction site of the Dubai Metro Project in 2008. That image shows part of a construction scene that was taken by one digital camera. As a first step to detecting the edges of an object, the RGB color photo was converted into a grayscale photo, as shown in Fig.9. The VOP of the person, as shown in Fig. 10, was obtained was obtained by applying the Edge Detection Algorithm. Part of this image is the VOP detection for a person, and part is the SVOP detection of the hard hat.

The two characteristic semicircles of the hard hat can be seen, the upper semicircle whose chord forms an angle with the x-axis and the slightly deformed horizontal semicircle. The relative clarity of the safety jacket with the characteristic stripes — as well as the clear definition of the right ear, mouth, nose, right eye, right arm, and right hand — all can be noticed in the picture. All of these are part of the features included in the automatic, or computerized, hard-hat recognition algorithm.

One camera was connected to a file server, which applied the pattern recognition algorithm to detect each person in the camera’s view; the program subsequently decides, in real time, if each person in the view of the camera has a hard hat on or not. If two or more cameras are used to view a person simultaneously from two different angles, and if the distance between any two cameras is known and fixed, then camera calibration can be applied prior to using the cameras for detecting whether or not people are wearing their hard hats. If an arbitrary coordinate system with its origin is assigned, then distances can be resolved of people from a specified origin of the coordinate system. Stereo VOPs of people also can be produced.

Fig. 8. A color picture of a worker with a hard hat.

Fig. 9. The grayscale version of Fig.8.

Fig. 10. The VOP of a person and the SVOP of a hard hat (Shreshta et al., 2011**).**

Fig. 11 is a cropped, actual picture of a construction scene that included several workers, all wearing their hard hats except one. Fig. 12 was produced from Fig. 11. First, the Edge Detection Algorithm was applied. Next, the VOP separated each person in the camera view. Finally, the Segmentation Algorithm detected no hard hat for the person. Notice that the upper semicircle is similar to that of the hard hat, but is different from the hard hat semicircle. Those differences are that it is larger than a semicircle, it is not as smooth as a hard hat semicircle, it does not provide the discontinuity with the rest of the head and neck that the hard hat has, and it does not have the lower profile of a hard hat.

Fig. 11. A cropped, color, real picture of a worker with no hard hat.

Fig. 12. The VOP of a worker with no hard hat (Shrestha et al., 2011).

For purposes of this research study, a photo was taken of a hard hat with the University of Nevada, Las Vegas (UNLV) logo, as shown in Fig. 13. Fig.14

was produced from Fig.13; it shows the upper semicircle, the base, and also the initials (UNLV) of the hard hat.

Edge Detection and image Segmentation Algorithms proposed in this study work with all hard hats. Preliminary results show that the hard hats with safety stripes in the back, certain indentations in their design, and logos are easier to recognize because they provide additional information to the pattern recognition system. Camera systems are relatively inexpensive; they could be self-powered and are easy to install. They could be connected on site and from there, transmit wirelessly to offsite computers. Thus, they can automatically monitor if everybody is wearing their hard hats and other Personal Protective Equipment (PPE). In the case where there is a violation; the computer can issue a violation alarm or any other kind of information, making the supervisors aware of the violation so that they can take corrective action prior to accidents occurring.

Fig. 13. A picture of a hard hat on the floor.

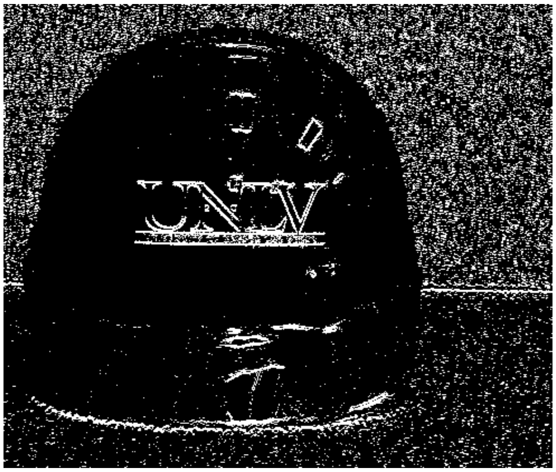


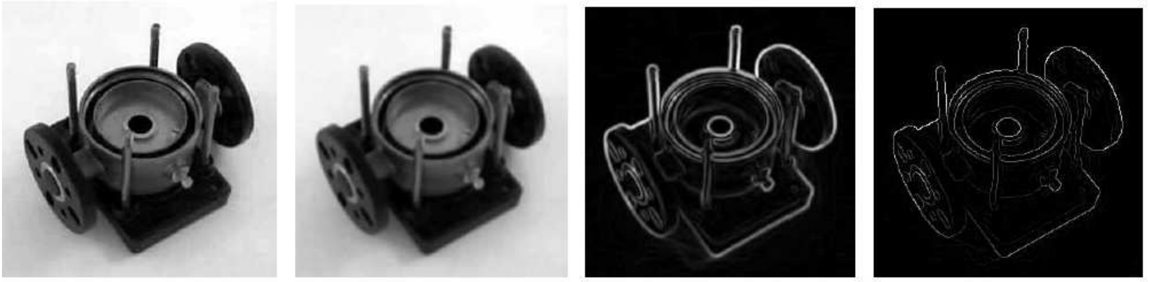
Fig. 14. A picture of a hard hat after applying algorithm (Shrestha et al., 2011).

There are many Edge Detection and Segmentation Algorithms used to detect an object in an image. This discussion will focus on a comparison between the Edge Detection Algorithms developed by Shrestha et al. (2011) and the well-known Edge Detection Algorithm of John Canny, a professor at the University of California, Berkeley.

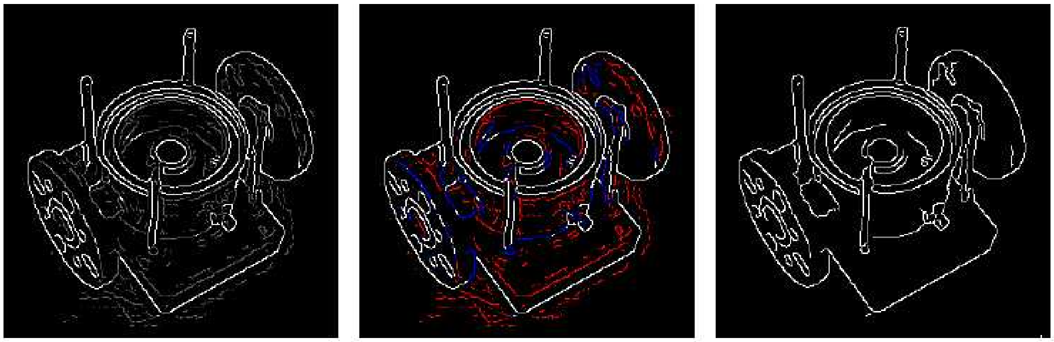
For hard hat detection in an image, there are several steps that need to be executed, as described in Chapter 3, Methodology. Among those steps, image processing is the vital work in this study. Different algorithms take different processing times; therefore, an efficient algorithm is very important for the actual execution of a program. Furthermore, there are several other factors that also play a role in making a program efficient, image compression, for example. Therefore, it is clear that we needed time efficient algorithms for the purpose of this study.

Algorithm developed by Shrestha et al. (2011), as described in Chapter 5, has eight steps involved in detecting edges of objects of an image. In the first step, the luma component of every pixel — that is, the intensity values of the pixels — are determined. In second and third steps, the second-order partial derivatives of the luma components are determined with respect to *x* and *y*. After this, the Laplacian for every luma component is computed. In the sixth step, a histogram is plotted for all the values calculated from Step 4. Basically, the histogram is normally distributed, and the pixels that are 2.5% to the right or tail are considered as edges. Moreover, all the values that fall under 10% to the right of the histogram are probable edges. The probable edges will be edges if their neighbors are edges; otherwise, false. As the steps are simple and there are not any complex loops in the coding, this algorithm seems to be much faster in comparison to other algorithms. The images generated by using Dr. Yfantis's algorithms are shown in Figures 3, 4, and 5.

Another famous Edge Detection Algorithm is that of Dr. John Canny, a professor at the University of California, Berkeley. His Edge Detection Algorithm is described in detail in Chapter 2. The first step of Canny's Edge Detection involves smoothing. The purpose of smoothing is to remove noise in an image, which are unnecessary points in an image. Blurring is done during this step by using a Gaussian filter. The second step involves finding gradients. Edges are assumed to be where the intensity changes the most in a grayscale image, and are determined by determining the gradients. Canny's third step is non-maximum suppression. In this step, the maxima in the gradient image are preserved, and the remaining is deleted. The fourth step involves double thresholding, in which the potential edges of an object are found by thresholding. The last step of this algorithm is edge tracking by hysteresis. In this step, the final edges are determined by suppressing action. Canny's Edge Detection Algorithm shows clear edges and a low signal-to-noise ratio; nevertheless, it takes more time to process the images (Maini and Aggarwal 2009). The original and its derivative images after using Canny's algorithm are shown in Fig.15.



(a) Original (b) Smoothed (c) Gradient magnitudes (d) Edges after non-maximum suppression



(e) Double thresholding (f) Edge tracking by hysteresis (g) Final output

Fig.15. Different steps involved during Canny's Edge Detection process on the test image (Canny J. 2009)

For purposes of this thesis, a code was written for Edge Detection based on the algorithm of Dr. Yfantis. During the initial phase of coding, this program worked well; however, the signal-to-noise ratio was pretty high. 'Noise' is the unnecessary pixels in an image. Also, the program ran slower because of time complexity O (n^4) for 4 loops in the program. It was necessary to make this program efficient to use in the processing of real time video. For comparison, this program was used to create edges, as shown in Fig. 16, 17, and 18. The actual image was taken at the Dubai Metro Project, Jebel Ali Depot in 2008.

Fig. 16. A real RGB image of an author

Fig. 17. A grayscale image of Fig. 16.

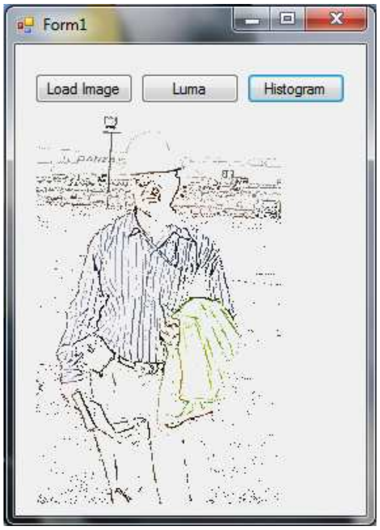


Fig. 18. An output of Edge Detection Algorithm of Fig. 16.

In conclusion, different algorithms have different characteristics used for particular needs. The program file for coding of the algorithm that was developed for this thesis needs to be improved in both time efficiency and clarity of the output. It took approximately 6 seconds to analyze a 640 x 640 pixel image. Canny's algorithm produced much clear edges of the objects but was much slower (Maini and Aggarwal 2009). Algorithm developed by Shrestha et al. (2011) produced clear edges; it also was time efficient in comparison to the algorithm developed by the author.

To analyze real time images, a one-second-long video can be split into a maximum of 16 frames of images. The images should be compressed before analyzing. Therefore, the theoretical efficiency of the algorithm should not be slower than 30 frames per second.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This study developed a framework to detect hard hats from real time images that were transferred from construction sites. This framework is prepared to alert or warn safety personnel if the workers are not wearing hard hats. One of the major steps of this framework is the Edge Detection Algorithm. For this study, this algorithm was developed using C-Sharp programming language; and was tested against still images of construction workers. The application of this algorithm showed that the images of the workers can be converted into line diagrams. The algorithm still needs to be refined, because this program took a longer time than wanted in order to convert the images into line diagrams.

This study completed the development of the Edge Detection Algorithm only. However, there are two main steps to be completed before validating this framework. They are to i) split video images into several frames and ii) test the proposed Segmentation Algorithm. Once these algorithms are developed and tested, then the whole framework can be used to detect hard hats of construction workers from live images from the sites. To make an efficient program, an image compression technique is necessary in order to analyze the images in a shorter time period. In addition to this, electronic design, electronic drivers, embedded systems, file servers, internet software, network software, internet security, and data base management need to be implemented. Further recommendations include extending this hard hat detection algorithm to other personal protective equipment (PPE) as well as to heavy equipment at the construction sites.

In conclusion, this novel approach will reduce fatalities and injuries at construction sites. If implemented properly, this technique can help to achieve zero-fatality records at construction sites.

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