Construction Safety Visualization

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ABSTRACT

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, which basically is due to inadequate supervision. To improve upon the traditional supervision approach, this study proposes a construction safety visualization approach. In this research paper, we provide a computer vision algorithm to detect in real time if any safety violations occur caused by one or more people in the site not wearing their hard hats. Our algorithm is an extension of our previous work in computer vision, and consists of a detection algorithm that is relatively fast and yet has an accurate edge. This is followed by a video object plane algorithm for each person, which is followed by an algorithm for detecting if a person does or does not wear a hard hat.

Keywords: Image processing, Hard Hats, Edge Detection Algorithm, Wireless Digital Camera, Local Area Network.

1. INTRODUCTION

There has been a strong myth that accidents are inevitable during construction projects. Nowadays, this notion is fading 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 is still necessary to avoid construction accidents. There are several categories of injuries at a construction site: falling injury, electrical injury, and injuries due to being struck by falling objects or flying objects, to name a few. In 2009, 4551 people died while working in construction sites. Of these, about 728 people (16%) died due to being struck by the objects and equipment [4]. Therefore, it is necessary that construction workers use hard hats on construction sites for head protection. Construction safety training teaches construction workers to use hard hats in their job sites. Also, the contractor does not allow anybody on 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 had fatal accidents due to not wearing hard hats. Therefore, the enforcement of hard hat use in the construction sites is getting stricter. For example, the safety engineer or construction supervisor has to monitor whether their workers are using hard hats or not. Due to pressure in completing the project on time, and also due to complex work schedules, it is becoming difficult for supervisors to monitor every worker 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.

To improve construction safety, Occupational Safety and Health Administration (OSHA) provides safety training to construction workers and also prepares construction safety standards. Due to the intervention by OSHA, fatalities at construction sites are decreasing. However, construction managers still are worried 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 use of these devices is very important to protect constructions workers from injury and fatality. It is necessary to monitor in real time the construction site in order to make sure that the workers are using PPEs.

The visualization technique, which uses real-time images coupled with computer algorithms, is a useful tool to monitor the construction workers and warn supervisors if they are not using hard hats. In this technique, cameras are installed in the construction sites and the real-time images are transferred to the computers by means of wireless technology. The images of the construction site are continuously displayed on an office computer. From the real-time images, the algorithm will detect whether the construction workers are using hard hats. Once the algorithm identifies a worker working without hard hat, it automatically dispatches a warning message to the safety officer. Ultimately, the site supervisor that is responsible will be informed so that the safety problem is corrected prior to an accident occurring.

Computer vision is a large area that applies to many areas, such as medicine, military, automation, transportation and construction management. The use of computer vision could help increase the productivity, decrease loss of property, and improve safety at the construction site. In this research, our main concern is real-time automatic detection on whether or not people are wearing their hard hats. If one or more people are not wearing their hard hats, that will constitute a safety violation. Such a safety violation will be recorded in a safety violation data base, along with the time and duration of the violation. Furthermore, this violation will issue an alarm event, which will be shown on the alarm events monitor for the onsite manager to see and take corrective action. Alarm events such as this one could also be transmitted to cell phones of specified people or else their office computers to make them aware of violation. The system that was developed in this study consists of cameras using charge couple devices to capture high-quality, uncompressed analog video at NTSC resolution. In the back of each camera is a hardware electronic card specifically designed to capture the camera video and convert it to digital; the card also processes the video by applying a detection algorithm and compresses the video, all in real time. The electronic board that was developed in this study detects hard hat violations and transmits them to the file server; a special flag indicates the type of violation detected, in this case, a hard hat violation. This violation, which is stored on a special data base in the file server, also triggers a software event alarm. The images associated with this alarm event are automatically shown in the special event monitor. If a network of cameras is used with proper overlap, a stereo vision can provide the exact location in the construction site, the name of the person(s) causing the violation, the duration of the violation, and the history of each person relating to safety violations. This camera network system also can be used in other applications to deter loss of property, detect fraudulent accidents, and avoid accidents; this can be done by analyzing activities real time and issuing alarm events on activities that have the potential to cause accident.

This current study is an extension of previous, related work in the areas of computer vision, robot vision, image compression, pattern recognition, internet transmission, network communication, and image processing [1, 3, 6, 7].

2. BACKGROUND

Visualization techniques have been used in construction planning and operations. A study was conducted to demonstrate use of a simulation-driven, dynamic 3D visualization process in a multi-storey structural steel erection operation [8]. The authors used visualization techniques that employed dynamic operations to depict the continuously evolving multi-storey structural steel facility. Four-dimensional computer-aided design (CAD) visualizations only show the evaluation of the construction product and can be linked to project schedules. However, dynamic operation visualization can show the interactions between various resources, including machines, materials, and temporary structures. The authors showed how this process can 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 on the equipment and worker to warn them about possible accidents [2]. They implanted in heavy equipment 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 are in the proximity of the heavy equipment, the alarm is set off in the equipment as well as on the workers' PPU. The field tests demonstrated that by implementing this technology, various benefits can be achieved, for instance, providing real-time pro-active alerts to workers and operators and also monitoring the locations of workers, equipment, and materials. Moreover, this study included a cost-benefit analysis to show that it is economically viability to use real-time pro-active technology in the construction sites.

A study was conducted by Michal Irani and P. Anandan [5], in which the detection of moving objects was carried out. In the past, many studies of this kind were done by using 2D algorithms; this study used a unified approach to handle moving object detection in both 2D and 3D scenes, with a strategy that gracefully bridged the gap between those two extremes. According to the author, 3D algorithms work better when significant depth variations are present in the scene and the camera is translating. This approach is based on a stratification of the moving object-detection problem into scenarios that gradually increase in their complexity.

3. SEGEMENTATION AND REGION OF INTEREST DETECTION

The metric used in this research is a non-Euclidian metric. The mathematical space we operate on is a Banach space. In this Banach space, we define a probability metric 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:

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

and an estimate of the

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

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

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

From equations (1) an (2) we obtain an estimate of the Laplacian of the gray scale image at pixel position (x,y):

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

The values of the intensity all are integers in between 0 to 256. 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 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:

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

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). Our segmentation algorithm consists of finding the edges by first using the above theory.

Edge Detection Algorithm

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.

In order to segment an object or subject of interest, first the 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.

Segmentation Algorithm

1. Use the Edge Detection Algorithm described above.
2. Divide the scene into Video Object Planes (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 sub-video object plane of the hard hat consists of two orthogonal semicircles.
6. The cord 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 cord line row vector with the row vector (1, 0).
7. If the above normalized dot product is one, then the cord 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 different than zero 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 in the hard hats are segmented and recognizable during the segmentation.
10. If more than one camera have the same object in view, then stereo vision of the hard hat is possible. In this case, straps, logos, the pitch, role, and yaw 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.

4. APPLICATIONS

Figure 1 shows the part of a construction scene that was obtained by one camera. The video object plane of the person depicted in the scene was obtained by first applying the edge detection algorithm, then applying the segmentation algorithm, part of which is the video object plane detection for a person and the sub video object segmentation for the hard hat. The two characteristic semicircles of the hard hat can be seen, namely the upper semicircle whose cord 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. Although one camera connected to a file server, which applies the pattern recognition algorithm to detect each person in the view of the camera and subsequently decides in real time if each person in the view of the camera has the 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 by applying camera calibration prior to using the cameras for detecting if the people in the construction scene wear their hard hats or not, and if we assign an arbitrary coordinate system with an arbitrary coordinate system origin, then distances can be resolved of people from the origin of the coordinate system. Stereo video object planes of people also can be produced.

Figure 2 was produced from a colored picture of a construction scene that included several workers, all wearing their hard hat except one. First, edge detection algorithm was applied and then the video object plane was applied to separate each person in the camera view; finally, the hard hat algorithm detected no hard hat for the person shown in Figure 2. Notice that the upper semicircle is similar to that of the hard hat. It 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. 1. The video object plane of person and the sub-video object plane of the hard hat.

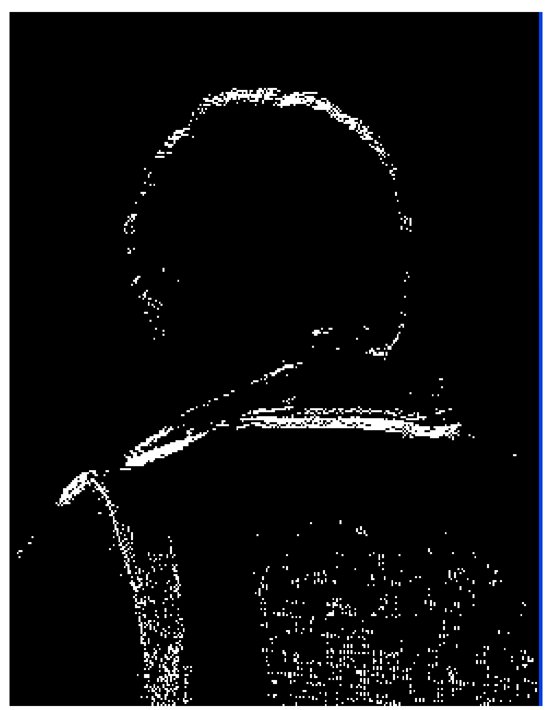

Fig. 2. A worker with no hard hat.

Figure 3 shows the upper semicircle, the base, and also the initials (UNLV) in the hard hat. Edge detection and image segmentation algorithms work which we are proposing 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 as they provide additional information to our pattern recognition system. Camera systems are relatively inexpensive, they could be self powered, and easy to install. They could be connected to our on site and from there transmit wireless to offsite computers for automatic monitoring of productivity, and safety by automatically monitoring if everybody wears their hard hats and other protective gear. In case there is a violation it can issue a violation alarm at the computer screen and make the supervisors aware of the violation so that they can take corrective action.

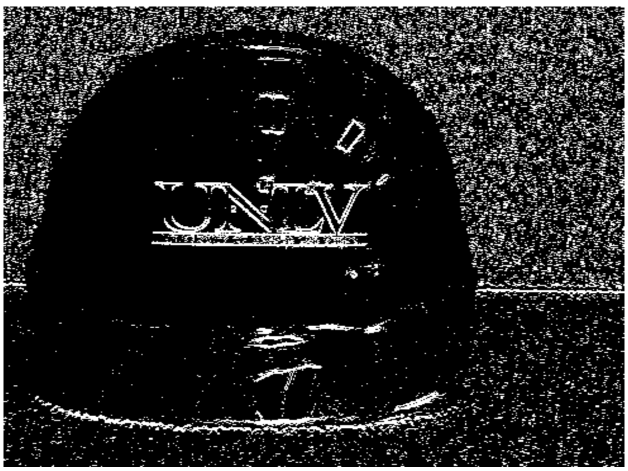

Fig. 3. Hard hat on the ground of the construction site

The system consists of a number of camera batteries that are powered by a combination of solar and other battery sources. Each camera is attached to card for video capture and video processing. The purpose of the card is to capture the video, analyze it for safety, compress the video, check for productivity, and transmit the video and the events wirelessly to a local file server. The file server is also powered by a combination of solar panels and lithium batteries. There are a number of safety events generated by the camera. The one pertaining to this research is the detection of one or more people in 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 database in the server. Safety event violations are programmed to create an alarm event, which alerts the onsite construction manager by sending the event to that person's mobile phone. In the case of multiple cameras, the picture of the person causing the safety violation, along with their name, is transmitted to the construction manager as well as all other people that are set up in the system to receive this event violation.

This system easily can be set up to record productivity of people by recording automatically the total time per day that they actually work compared to the time engaging in non-work activities. Furthermore, the system could also monitor accidents and their causes, which might prevent compensation abuse due to fraudulent accidents.

5. CONCLUSIONS AND RECOMMENDATIONS

An algorithm for detecting hard hat safety violations was described in this research paper. This algorithm involves digital image processing, artificial intelligence, and stochastic pattern recognition. The implementation of the algorithm involves electronic design, electronic drivers, embedded systems, file servers, internet software, network software, and data base management. The purpose of the system is to make construction managers, and others who need to know any safety violations that are a result of one or more people on the site not wearing their hard hats. This system can be used for other safety violations as well as for productivity detection.

A computer system and algorithm developed through this research analyzes real-time images of the construction site in order to detect workers working without hard hats. A demonstration will be done at UNLV's Construction Management Laboratory for the validation of the system before using in the real sites. This technique was developed for the detection of workers wearing hard hats with an aim of significantly reducing injuries at construction sites.

In the future, the authors would like to expand this research for detection of all personal protective equipment (PPEs) as well as heavy equipment used at construction sites so that workers can be safer and more productive.

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