TRUCK HEIGHT DETERMINATION USING DIGITAL VIDEO

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Matthew Jay Sandidge

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TRUCK HEIGHT DETERMINATION USING DIGITAL VIDEO

Approved by:

Dr. Ioannis Brilakis, Advisor
School of Civil Engineering
Georgia Institute of Technology

Dr. Michael Hunter
School of Civil Engineering
Georgia Institute of Technology

Dr. Jorge Laval
School of Civil Engineering
Georgia Institute of Technology

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[To the students of the Georgia Institute of Technology]

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LIST OF SYMBOLS AND ABBREVIATIONS

ITS	Intelligent Transpiration System
GPS	Global Positioning System
OVDS	Over-height Detection System
EWDS	Early Warning Detection System
DOT	Department of Transportation
AADT/mile	Average Annual Daily Traffic / Lane Mile

SUMMARY

Over-height trucks are not only a hazard to the over-height trucks themselves, but they pose a threat to the bridges they come into contact with, and most importantly the other drivers on the road way when a collision takes place with a low clearance structure. Therefore, there is a need for an over-height detection system that is affordable yet also reliable. At this time there exist over-height detection systems using laser and infrared beam devices however, they are expensive. This high cost makes it impossible for Department of Transportations across the nation to implement these systems at all low-clearance headroom roadways. In this research a machine vision based system is proposed to detect the height of trucks and provide a warning for over-height vehicles. The height determination will be completed using line detection and blob tracking; these two methods will be overlapped where an upper point of the truck can be compared to a lower point on the ground. These 2D coordinates will then be translated into 3D world coordinates that will provide an approximation of the truck height. If the truck is over the set height then a warning will sound. The accuracy of the test proves that the method is a reliable method of height determination, achieving a 96.59% accuracy rate for measured trucks. The method does have an error rate of 3.3%. The merit of this work is the creation of an automatic image based method which can provide height determination of trucks and is a low cost alternative to the current expensive laser and infrared detection systems.

CHAPTER 1

INTRODUCTION

The world in which we live is one that is full of constant change and upgrade. We are part of a technological society in which more and more of our lives are consumed by technology. The field of transportation is also part of this technological change, which has formed an entirely new division of transportation known as Intelligent Transportation Systems (ITS). These systems use technology to allow people to be better informed and make more intelligent decisions with regards to the transportation network. These systems can provide information and prevent accidents through the use of GPS, satellite imagery, video detection of traffic flows, etc.

Over-height vehicle detection systems are an example of an ITS. The purpose of over-height vehicle detection systems is to detect the existence of an over-height vehicle on the roadway and be able to warn the driver of the vehicle of the pending danger before a collision with a structure occurs. The definition of an "over-height" vehicle is a vehicle that is too tall to successfully fit under a structure on the route that the driver is taking. Legally a height limit of 13'-6" is placed on all trucks, and a truck over the height of 13'-6" must obtain a permit for travel. In many locations the vertical clearance is less than this measurement and therefore, many vehicles could be considered over-height at those locations. The purpose of these systems is to protect against collisions. The origins of these systems date back to the late 1970's and early 1980's therefore the concept is not a new idea. There exist many different types of over-height detection systems from the simple inexpensive method of chains hanging from a suspended cable, to the expensive of laser or infrared systems that can cost in the tens of thousands of dollars per system.

The most prevalent systems that are in use today, work by installing a pole on either side of the traffic flow; a laser and a receiving device are mounted on the opposite sides respectively, and a beam is projected across the traffic lanes at the predetermined height. If there is an occlusion of the beams passage a warning system will be triggered in order to alert the driver. These expensive systems have proved to be reliable; however, they are expensive which hinders mass implementation. The use of less expensive systems like chains has proved to be relatively ineffective because it is hard for the driver to hear the sound over the noise of the engine. There is another way to determine the presence of over-height vehicles which is through video detection. Although some preliminary work has been done on this topic it is still a relatively new concept and based on research has limited mainstream implementation if any at all in the industry.

The method of digital video for over-height detection can provide a lower cost reliable alternative to laser or infrared detection. These systems also have added benefits such as video evidence of accidents, speed detection of vehicles, traffic surveillance, lower maintenance cost, etc. In this study the primary focus is trucks as they are the primary culprit of over-height vehicles. A process is developed using preexisting vehicle tracking techniques which are trained to only detect truck images. Once this detection exists and certain conditions are defined including a boundary of the truck, then line segmentation and blob tracking can be applied and overlaid into order to determine points on both the ground plane and the plane at the top of the truck. Through these points on parallel planes the height of the truck can be determined in 2D coordinate which can then be translated into 3D world dimensions by use of a fixed reference object height also in the frame.

CHAPTER 2

BACKGROUND

Nearly 70 percent of all freight transported annually in the U.S is transported by truck (ATA 2006). Since trucks transport much of the nation's freight, which contains everything from food to health care supplies, the unhindered flow of trucks across the nation is a requirement. One of the areas where this evolves into a problem is during the transportation of freight on routes with low clearances. Low-clearance roadways are any road way that does not allow safe passage of the legal 13'-6" height restriction placed on trucks. In a study conducted by the University of Maryland where all states were polled and 29 states responded, 18 of those 29 or 62 percent stated they consider over-height collisions to be a serious problem (Fu 2004). Out of those 11 that did not consider over-height collisions to be a serious problem, most, beside the Carolinas and Connecticut are located in the Midwest and Northwest. Also found was that the Annual Average Daily Traffic per lane Mile (AADT/mi) was 40 percent greater for the 18 states that consider over-height collisions a problem (*Highway Statistics* 1999). This information shows that the states that have the highest volume of traffic passing through them feel that over-height collisions are a serious problem. The over-height trucks are not just a hazard to the over-height trucks themselves, they pose a threat to the bridges they come into contact with, and most importantly all the other drivers on the road when the collision takes place. Therefore it should be easy to see that some type of warning system should be mandatory at all low clearance bridges.

There are a number of warning systems that exist and in an article by Hanchey and Exley (1990) three basic bridge protection schemes were investigated: Rigid passive, non-rigid passive, and active detection and warning system. The first scheme for a rigid system poses extreme liability if the system is struck by an over-height vehicle and causes an accident, for this reason it is not a good alternative. The second scheme of non-rigid passive systems such as chains suspended at the height of the clearance was found to not be able to adequately warn the driver of a loud truck of the over-height load. The third scheme investigated was using an active detection and warning system, specifically infrared beam devices. This scheme "utilizing infrared beam devices located in advance of the bridge, which would detect the over-height vehicle and warn the driver through means of audible bells and/or warning signs with flashing beacons" (Hanchey 1990).

The Alaska Department of Transportation conducted an Evaluation of Overheight Vehicle Warning Devices in July of 2003 and found through vendor survey that these systems range in price from $15,000 to $75,000, including labor per system. As one can imagine the State DOTs cannot afford to implement two of these systems (one for each direction) at every low clearance bridge. However, the Alaska DOT study does state that 73 percent of the states using Early Warning Detection Systems (EWDS) believe their systems reduce over-height loads striking infrastructure; 27 percent believe there was a slight reduction in over-height impact. While these systems do help to provide a greater detection against over-height collisions in many cases the capital investment needed to implement these state wide is too high.

This project intends to fill that gap by developing a low cost Early Warning Detection System (EWDS) that would be cheap enough for the state wide implementation without compromising functionality. Ultimately the development and implementation of this type of system would lead to less over-height collisions, which would also lead to more freight getting to consumers and less dangerous roadways. The developed system will be able to recognize and determine the height of the vehicles approaching the overpass. If a vehicle is too tall to pass underneath the bridge or tunnel then the software would alert an EWDS to signal a warning device. Research was conducted specifically to find the number of low clearance locations in the state of Georgia. Based on information obtained from AllStays (2012) there are 87 low clearance locations in the state of Georgia. On the AllStays website there is a section for truck drivers and a page there for low clearance locations for all 50 states. The locations were found on the provided map and referenced while looking them up in Google Street View. Out of the 87 low clearance locations 80.46% were one lane per direction or less, 17.24% were two lanes per direction, and 2.3% were two lanes with one side also possessing a turning lane. Based on these findings the study will be focused on providing an EWDS for the single lane and double lane approaches, which encompasses 97.70% of all low-clearance locations in the state of Georgia.

There has been some preliminary work done in this category (Khorramshahi et al. 2008; Shao et al. 2010). In (Khorramshahi et al. 2008), the authors used digital video processing to capture images and a KLT algorithm to select and track features. They are able to detect objects over a certain pre-chosen height but they are not able to determine the exact height of the vehicles, and there are other drawbacks of their process. The drawbacks of this method are the fact that for the calibration matrix you must have a roadway of known dimensions and a vehicle pass through the video frame with known dimensions; based off of these known dimensions then a manual marking procedure must be done to draw a cube on the frame for future determination. At the time of this paper four years has passed and there are no other published research articles or implementations of this type of work for over-height detection that could be found. There is a need for an implementation process of over-height detection with digital video, and one of the goals is to expand the knowledge base and contribute to the pre-existing research, making this a viable option for state DOTs implementation. Another research effort that took place was led by Shao et al. (2010). In this work the authors present a method for automatically determining the height of moving objects from uncalibrated videos. The authors present a thorough method for the determination of height with advancements made in automatic vanishing line detection as well as height estimation. The process that is developed can be used for the estimation of different object including trucks; however, the work is not suitable to be applied in highway scenarios as is the focus of this study. The main concept of the work is that in order to determine the minimum calibration "two sets of parallel lines (nonparallel to each other) on the ground plane and one set of vertical lines are the minimum requirements". The authors achieve these two sets of parallel lines by using the tracking of two moving objects in different directions. As this work is being done to track the height of over-height vehicles on roadways the movement in the frame will only be in one direction which renders this method unusable.

In order to identify the movement of the trucks in the video frame 2D vision tracking will be utilized for this process. There are a large number of vision tracking methods and algorithms that could be used to perform this task. In a research paper published by Park et al. (2011) a comparative study of vision tracking methods for tracking of construction site resources was completed. In this paper the authors investigated and identified the most effective existing 2D vision tracking methods looking at contour-based, kernel based and point-based methods and compared based on their performance. Of these three after a brief description and advantages and disadvantages were looked at only the kernel and point based methods were looked at in further detail. In the conclusion, the kernel –based method turned out to be the more stable and insensitive to illumination condition, illumination variations, and scale variations than the point-based method (Park et al. 2011). Based on this comparison, this research will use the kernel-based method of 2D tracking. Even though the cited paper specifically looked at the tracking for construction site resources the comparative study can still be used and the object of semi-trucks are also similar in size to much of the construction site resources that were looked at. More specifically, the kernel-based algorithm that will be used was developed by Ross et al. (2008). The general tracking algorithm that is developed by Ross et al. (2008) was used since it is a kernel-based method and provided an open source which only had to be slightly modified. The modifications done to this method were carried out by Man-Woo Park, a Ph.D. candidate at Georgia Institute of Technology, the vanishing points of the recorded scene can be determined manually by marking the line segments on the roadway surface.

Upon having a 2D image from the video it will ultimately have to be translated into 3D coordinates, for this 3D reconstruction is needed. Work has been completed on this very topic by Single View Metrology (Criminisi et al. 2000). In (Criminisi et al. 2000) the authors “describe how 3D affine measurements may be computed from a single perspective view of a scene given only minimal geometric information determined from the image" and how to use a scale factor from the image to determine the real world heights. This paper was referenced in the coding and was ultimately followed as a guide in the 3D reconstruction part of this method.

CHAPTER 3

PROBLEM STATEMENT AND OBJECTIVE

There are multiple types of over-height vehicle detection systems such as rigid which presents a liability issue if struck by an over-height vehicle, non-rigid i.e. chain systems which have been proven to be hard to hear from inside the vehicle, and active warning systems like infrared and laser. However, while they have proven effective these systems have high initial cost and are not feasible for state or nationwide implementation. There also exist image-based technologies which fall into the active warning systems category; although, there are limitations of these which should be improved.

In earlier research efforts on the height determination of vehicles using image-based technologies, progress was made however drawbacks from these efforts have hindered the wide use implementation at the State DOT level of this technology. In the previous work by Khorramshahi et al. (2008) the drawbacks included the manual calibration process of having to have known roadway and vehicle dimensions in order to perform the manual marking process for future height determination; and even with this information the end result does not provide a real world estimation of truck height. While the research efforts of Shao et al. (2010) on this topic were well structured it was determined that their method was un-implementable in a transportation EWDS application due to the parallel flow of traffic and the need for multiple directional flow for frame calibration. Based on the existing research there are areas of improvement in order to make over-height vehicle detection a viable option for state DOTs.

The objective of this research is to propose a method for determining the height of trucks in digital video captured by a fixed video camera for the purpose of over-height truck collision prevention in low clearance headroom roadways. The area of focus will be flat, single and double lane per direction roadways, daytime lighting, and one-directional flow for video processing. The merit of this research is the creation of an automatic image based method which can provide height determination of trucks and is a low cost alternative to the current expensive laser and infrared detection systems.

CHAPTER 4

METHODOLGY

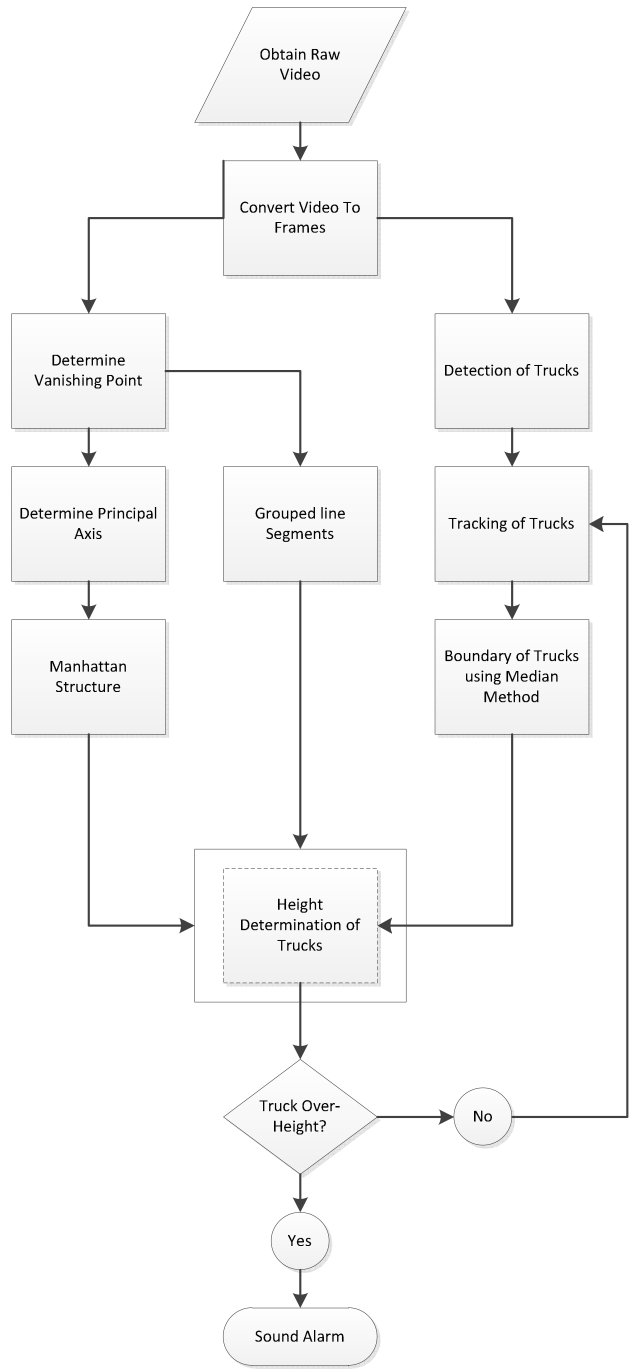


Figure 1: Overview of Process

This chapter presents an innovative process for estimating the height of trucks using digital video.

4.1 - Methodology Overview

The overview of the process is shown in (Figure 1). Video is obtained from a single camera mounted on a fixed position facing the road way traffic (Figure 2), which is then converted into image frames. The method then takes two parallel paths: 1) determining vanishing point, line segments, principal axis and the Manhattan structure, which can be called the scene extraction phase. This phase is done in order to provide axis determination, line convergence, and flow direction which will be used as inputs for the 3D height determination process. 2) The other path is the detection and tracking of trucks, which provide a boundary region of the advancing trucks, this phase can be referred to as the 2D truck detection and track phase. This phase will be used as inputs in the height determination to give a boundary region where to perform the process. When both of these stages are complete then the contributable section of this research, determining the height of the trucks can take place. There are existing processes for height detection however there are none that are applicable to the highway setting and can provide a height estimation of trucks. This paper builds off some of the pre-existing height detection methods in order to produce a novel idea for height estimation for the purpose of an Early Warning Detection System. The contribution of this paper can be seen in (Figure 1) by the dashed box around the Height Determination of Trucks which is further developed in (Figure 5) and will be the main focus of this chapter.

Figure 2- Camera positions used to capture video.

4.2 - Scene Properties Extraction

The first step in the scene properties extraction phase is to extract all of the details out of the scene where the over-height detection is going to take place. The frames from the recorded video are the input in the vanishing points determination. The vanishing points are important feature for both the height determination and 3D scene reconstruction. The vanishing points of the scene along the flow of traffic are determined by marking multiple of the painted lines on the roadway from the image. This is done manually; however, through the development of this process it was determined that it could then be done automatically using the Manhattan structure. The Manhattan Structure is the idea that "all surfaces in the world are aligned with three dominant directions, typically corresponding to the X, Y, and Z axes" (Furukawa 2009) and these directions can be determined from an image. In order to determine the Manhattan structure, first the line segments of the scene are determined and then they are grouped based on different vanishing points. Out of these, the set that contains most line segments with the same vanishing point is used as the principal axis. In (Figure 3) the described can be easily seen, the blue lines are the majority which will make up the principal axis of the frame. Based on this principal axis, a set of line segments that are orthogonal to that axis can be found. These can be found by looking for a triplet of line segment sets by examining their vanishing points orthogonally. This triplet of lines segments is the group that makes up the Manhattan structure (Figure 4). This determination of the Manhattan structure is very important because not only will this allow the automatic determination of the vanishing points in future, but it is an innovative approach in the height determination process. The line segment detection will also be used later in section 4.4 to determine the upper truck boundary for the height estimation section of the process.

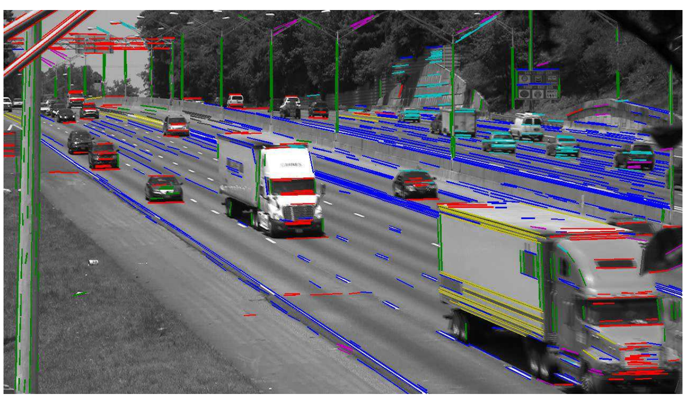


Figure 3: LSD Line Detection Original Frame

Figure 4: Manhattan Structure Original Frame

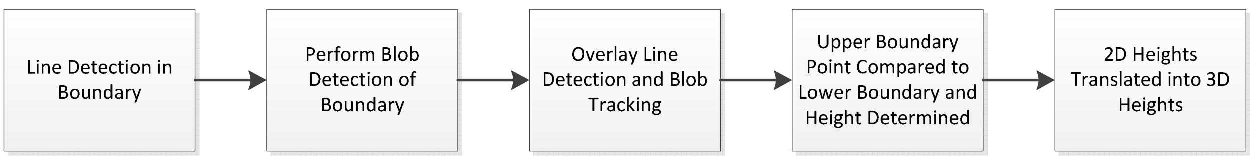


Figure 5: Height Determination

4.3 - 2D Truck Detection and Tracking

Concurrently, while the scene property extraction was on-going, other processes of vehicle detection and tracking were also being worked on. Truck detection and tracking process was completed by the aforementioned modified version of Ross et al. (2006) kernel based algorithm. This method was previously discussed in the background section of this paper. The tracking of the trucks is necessary in order to identify on which vehicles to perform the height detection process. Images of the trucks were cropped from the frames of the collected videos in order to gain a wide number of truck types, and trained through the use of Haar Cascade image training. This process was done so that when the streaming video is playing, the computer will be able to detect the trucks from the cars. Once a database of images exists and training has been complete this algorithm can be implemented and will track and detect trucks present in the frame. The boundary box around the truck is an important concept for the height determination because this boundary area is the location where the processes for determining the height will be carried out. Upon having the boundary of the truck specified, the processes to determine the height can be carried out only in this region, which saves computing time. As previously stated, the boundary area of each truck is provided through the vehicle detection process. Once the truck is detected an area box is generated around the truck, with each frame from the video a text output file is generated and giving the image coordinates for the detected boundary location of the box. The image coordinates are displayed in the format of the upper left boundary corner x and y coordinates and then the width and height of the boundary, so there are four number values associated with each boundary. The output of this side of the parallel process is that trucks can be detected, tracked, and coordinates given of the location of the truck in each frame (Figure 12(b)). The steps of the truck detection and tracking process are important in order to identity which vehicles to determine the height estimation on. With these elements present the process is developed enough that the height estimation process can begin.

4.4 - Truck Height Determination

In the height estimation of the truck the first input that is needed is a boundary around the truck where the height is to be determined; this is given as an input from the detection and tracking (section 4.3). Having a boundary location of the truck, a line detection process can then be run for this region of the frame (see Figure 6). The line detection picks up a large amount of the straight line segments in the boundary location. The reason that the line detection was chosen was to perform an analysis on the boundary area. This analysis main goal is to discover the top line segments of the truck (Figure 7). Since the objective is to provide height determination and early warning detection, this top segment of the truck is needed in order to fulfill these requirements. The method that is implemented for the line detection is the LSD line detection which is "a linear-time Line Segment Detector giving subpixel accurate results. It is designed to work on any digital image without parameter tuning. It controls its own number of false detections: On average, one false alarm is allowed per image (Gioi et al. 2012)." This makes for an extremely reliable method and gives very limited number of false positive and false negative detections. (Gioi et al. 2008)

The next step in the height determination process after the truck boundary is obtained and line segments are detected in the boundary region is to preform blob detection in the same region. Blob detection cannot be used for the top of truck detection because it does not distinguish planar shapes like the sides or top of the truck; however it does work well in determining the lower boundary regions. While line detection works well in determining the upper boundary, this type of method is unable to properly detect lines where the truck meets the surface of the roadway which is why blob detection which focuses on moving objects rather than objects throughout the entire scene is used. Blob detection looks to find certain regions of the image that differ in properties of light or color and highlight these "blobs". The background image fades away into black while the foreground image is highlighted in white blobs of regions that were detected. The median method of blob detection was used in the detection of these lower regions. The justification of using the median method was based on a comparison of three methods which is discussed in the implementation chapter of this paper. The blob detection of the video frames provides a white “blob” outline of the truck in the boundary region (Figure 8). These white marks are actually small detected regions, and together, show the outline of the truck. This blob detection image over a series of frames provides a type of optical flow of the truck which will then be used in height estimation. With this blob detection the “blob” can be converted into a pixel line by the canny method; as seen in (Figure 9), the lower boundary regions indicated by the yellow arrows, show the lowest regions of the truck detected. The Canny Method was developed by John Canny in 1986 but is still considered one of the premier edge detection methods in computer vision. This method works by maximizing the probability of detecting real edge points and minimizing the probability of falsely detecting non-edge points; while trying to obtain that detected edges should match as closely as possible to the real edges (09gr820 2009). Once both of the components of line and blob detection have been detected from the image frame, these images can then be combined or overlaid on each other. This process yields an image that has the upper line segment that was detected from the LSD method (Figure 7.) overlaid on top of the blob of the truck (Figure 9). This is an innovative approach and a main contribution of this paper, based on the research conducted, this combination of processes has never before been implemented for over-height detection. This approach yields a way of creating an upper boundary line on the top of the highest point of the vehicle, while the blob detection has highlighted the lowest regions.

Figure 6: Line Detection

Figure 7: Line Detection Upper Boundary

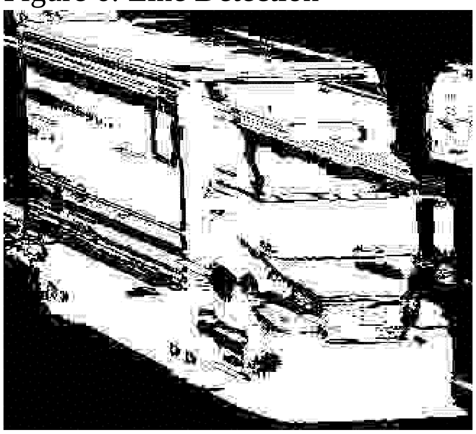


Figure 8: Blob Detection

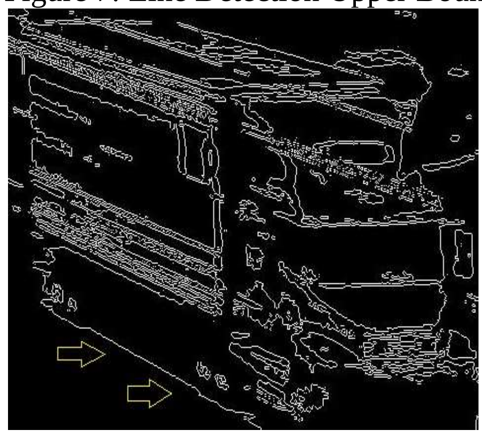


Figure 9: Blob Detection with Lower Boundary

At this point the process begins to take form on determination of the truck height in the image. There are two parallel planes that must be identified which are: the plane of the roadway surface and the plane that lies on top of the highest point of the truck. The "Z distance" or vertical distance is the difference in height from the roadway plane to the top of the truck plane. The roadway elevation can be set at the height of "0". Determination of the Z distance can be calculated by scanning the boundary region and finding the upper line segment that is farthest in the vertical direction but also farthest in the left image direction. This provides the beginning point for the line that runs along the top truck boundary. Once this line is determined it can be compared to the pixel line generated by the canny method. A bottom up scan of the frame is done based on the length of line segment of the top. This length is broken up into 20 intervals and the scan searches for the intersection with the lowest canny line point. Each end point of the interval is the beginning point of the next interval, thereby, creating 20 line segments. The line segments are then compared to the top boundary line of the truck. The goal is to find the segment whose inclination most closely matches the inclination of the top line so that these lines are parallel, thereby creating a way of finding the Z distance (Figure 10). The comparison by inclination of the line segments protects against falsely detected blob regions or "noise" in the picture. A falsely detected blob would create a line that would not have the same corresponding line inclination as the top line segment. This is another innovative approach presented by this paper which is original in the height detection process.

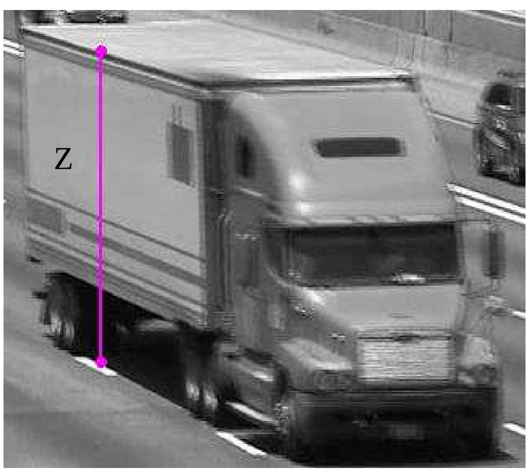


Figure 10: Vertical Z distance found between upper line segment and lower blob detected boundary regions

However, there is one main problem with the Z value that is found, it is still in 2D image coordinates. This value must be translated into 3D real world height so that we can determine if the object is too tall to pass under the bridge structure; and this process is done by 3D reconstruction and the use of a reference height. Using a reference height is incorporating the use of a known height of a stationary object in the video background. The importance of using a reference height is to use it to translate the heights from 2D image coordinates into 3D world coordinates. The reference height used in this process is a roadway sign displayed in the background, since these signs are standardized, size measurements were taken, and determined that the sign was 10 feet tall by 15 feet wide. These measurements can then be implemented by taking the pixel locations of the sign in the image and how the real world dimensions transfer into image coordinates. From this a comparison algorithm can then be used to transfer the Z values into actual dimensions. The output is world dimensions of the truck height which can then be used for the EWDS. If the height of the truck that is being processed is greater than the preset allowable height clearance of the bridge then the computer will recognize this fault and sound an alarm to alert the driver of the truck before a collision occurs. The next chapter of this paper will discuss the implementation of this work.

CHAPTER 5

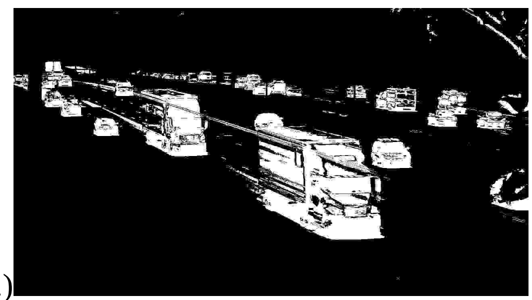
IMPLEMENTATION AND RESULTS

5.1 - Implementation

Raw video footage was taped using a Canon VIXIA HF S100 camera. The footage was recorded on Interstate 75 in Atlanta, Georgia at mile marker 254, Moores Mill road. The primary focus for implementation is: one and two lane per direction, low clearance roadways however, the reason that this location was chosen was because it provided a straight approach, a safe and ideal place to film, and there was a large amount of tall vehicles that travel on I-75. The camera was fixed and was offset from the traffic travelling in the southbound direction at approximately the same height as the bridge clearance. The recorded video file format was "*.mts" format however it was converted from an "*.mts" file into an "*.avi" file so that it could be transferred into individual "*.jpg" frames. The reason for this is because the software that was used preferred "*.avi" files. The algorithms, LSD line detection, and blob detection codes were implemented in MATLAB 2010a and C#. The LSD line detection and the blob detection were open source code files that were slightly modified from the original version. The original videos were recorded in 1440x1080p resolution in color at the rate of 30 frames per second, however during the format conversion they were reduced to 1280x720p resolution for file size. Also, during the process of implementing the videos they were converted to gray scale images as the algorithm's used required.

LSD line detection was implemented for the line detection section of the process. LSD line detection is a commonly used line detection method that provides reliable and accurate results. The method was developed by Gioi et al. (2008) and is provided as open source code which made the implementation achievable, and provides superior results to the built-in line detection methods that MATLAB possesses.

Three options of blob detection were implemented to find the best option for this specific case of detecting the bottom region of trucks. The three methods that were looked at for blob detection were the median method, mod method, and FGD method. The median method is one of the most commonly used background modeling techniques. The way the median method works is by replacing pixels by the median of all pixels in the neighborhood (Cheung and Kamath, 2004). The Mod method is based on a mixture of Gaussians. The method was developed by Stauffer and Grimson (2000), and they "determine which Gaussians may correspond to background colors. Pixel values that do not fit the background distributions are considered foreground until there is a Gaussian that includes them with sufficient, consistent evidence supporting it to convert it to a new background mixture" (Stauffer and Grimson, 2000). The FGD (Foreground Object Detection) method was created by Li et al. (2003). FGD uses "a Bayer decision rule for classification of background and foreground from selected feature vectors is formulated. Foreground objects are extracted by fusing the classification results from both stationary and moving pixels" (Li 2003). Each of these methods were implemented on the same segment of video in order to determine which method would work best to portray the feature points at the bottom of each truck. It should be added that the computation time for all of the methods was the same, and since there is no difference in the computation time, the main factor of which method works the best is based on a visual result. For the purposes of determining the height of the truck the most clear and dense blob is the best for our calculations. The results of this experiment are shown in (Figure 11). The best method for the use of determining the truck height was the median method, which was followed by the MOD method and then the foreground object detection. The median method provides an excellent quality blob which has the most dense region detection out of all the methods. The blob density was measured by the image program called "Gimp". The findings were for the boundary area of the truck: the median method possessed 37.4% white pixels, the MOD possessed 32.6% white pixels, and the FGD possessed 16.5% white pixels. The dense detection area allows the lowest region to be found as discussed in the methodology chapter of this paper.

(a.)  (b.) 

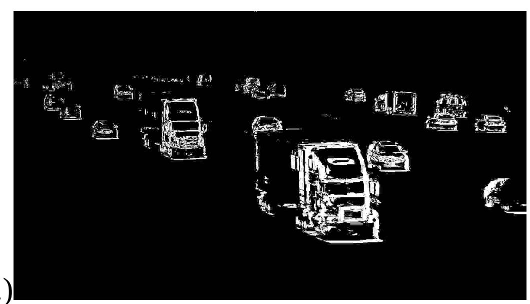
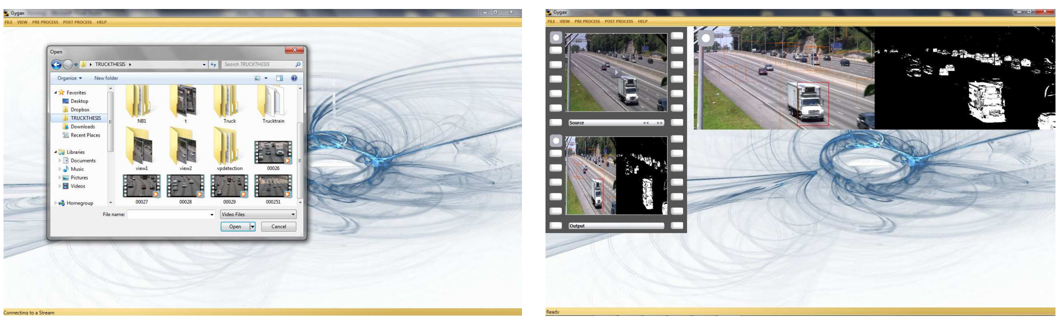
(c.) 

Fig. 11 – Examples of Blob Detection all on the same frame of video. (a.) Median Method shows dense regions at the bottom. (b.) Mod/Gaussian Method show good detection but not as dense as Median. (c.) FGD Method shows least detection of all methods.

The tracking and detection of the trucks was implemented through a group program interface Gygax. The interface is written in Visual Studio C# and allows the user to open the specific file of choosing and then process this video to detect and track trucks in real time (Figure 12). The methods that are used for the detection and tracking are a modified version of Ross et al. (2006) kernel based algorithm. This algorithm and the methods of detection and tracking are discussed in the methodology chapter of this paper.



(a) (b)

Figure 12: Gygax Screenshots

The process of over-height detection was implemented and tested on four acquired videos, which are all 6-8 minutes in length. The length and number of videos was taken because a sample size of at least 200 trucks is needed to properly preform the Haar Cascade image training. All of the videos that were tested were obtained from the same location on I-75 as previously mentioned. The first three videos were taken in the same location relative to the bridge and traffic, while the fourth video was taken at a lower vantage point of the road. The reason for the change of location for the last video was to test a different view point and reference height while seeing if the performance was similar. Certain key metrics were chosen to be recorded during the implementation and testing of the code on the videos. These key metrics were: number of trucks in the sample size, number measured detected 2D height, measured 2D height, 2D accuracy, 3D estimated height, 3D actual height, and 3D accuracy (Table 1). Since the actual height of every truck traveling on interstate I-75 is not known exactly, a sample set of trucks with known heights was taken from the videos and tested separately for this purpose. Two categories of trucks existed, semi-trucks with standard trailers, and certain box trucks. A total of 60 trucks, 30 belonging to each category were tested to determine an average result for the method created. The previously listed metrics were measured in this section of the implementation.

The process described above was implemented in a prototype that was developed by the Construction Information Technology Laboratory at the Georgia Institute of Technology. Figure 12 shows the screenshots of the developed prototype in use. Figure 12(a) shows how a user can browse recorded videos to load and test. Figure 12(b) shows a video being processed; the left side of the enlarged windows shows truck detection and tracking while the right side is showing blob detection.

5.2 – Results

Approximately 60 trucks were selected from the collected data that were used to validate the effectiveness of the method proposed in this paper. Out of those 60 trucks there were two main categories semi-trucks and box trucks. For the test purposes of this study and in order to test the accuracy and validity, the videos collected were converted into images. These images were then tested on the basis of the key metrics that were described in section 5.1 of this paper. The inputs needed for the code to be run on the images were having a raw image file, and an image of the boundary area of the truck both in raw format and in blob format. The output of the test was a height measurement in both 2D coordinates and 3D coordinates. The raw data collected is presented in Table 1. Table 1 shows the 2D and 3D actual height, the detected or estimated height, and the accuracy of both methods. A summary table presented in Table 2 shows the overall effectiveness of the method proposed in this paper. As we can see from the results the accuracy of this method is promising. The measure of the detected 2D image height when compared to the actual 2D image height boasts a 97.52% accuracy rate for the measured trucks. This accuracy rate for estimated 3D truck height when compared to the actual 3D truck height drops to 96.59% which is slightly lower. This lower accuracy rate can be attributed to the inaccuracy of the vanishing line and point detection. However, this coupling of similar results is to be expected since the same line to measure the truck is used, the only difference is the translation from 2D image to 3D by the use of vanishing lines and point detection derived from the image scene. There were two instances in the 60 Trucks where the code failed to recognize the height of the truck. Therefore the detection error rate of 3.3% can be given to this method.

5.3 – Discussions

The results show that the developed method is highly accurate in testing the height of trucks from a streaming video input. During the testing phase there were a couple of problems with two trucks not being measured, and therefore the coding still needs a little bit of fine tuning to make it perfect. However, with an error ratio of 3.3% [7.7% better than the previous method by (Khorramshahi et al. 2008)], and the actual height accuracy of measured trucks at 96.59%, shows that the method does work and is reliable. This method was developed for low-clearance roadways, specifically for low-clearance locations in Georgia. In the background chapter of this paper, research was done on these roadways and found that 80% were one lane per direction, 17% were two lanes per direction, and less than 3% were occurrences of more than two lanes. This method is implementable at 97% of all of the low-clearance locations in the State of Georgia. Since this method uses video that is taken from the side there are potential for occlusions occurring the frame, for this reason it is proposed that on roadways greater than two lanes per direction this method is not a viable option. With roadways of two lanes, two cameras will be needed for each direction with a camera being placed offset on each side of the traffic flow. Being able to provide a low-cost solution for 97% of all low-clearance locations in the State would definitely be a benefit and a savings of money. Preliminary work has already begun for future work of front facing cameras that will be able to detect over-height vehicles straight on. This method will provide an advantage because with it there will be no occlusion and therefore it could be implemented on 100% of all roadways. However, due to time restrictions at this time the work is still in its beginning stages and will be discussed at a later time. One drawback of overhead detection using digital video is the fact that it is unable to detect trucks during night time conditions due to lack of illumination. Therefore, other studies should also be done to determine if how much lighting must be provided in order to detect truck heights.

Table 1- Raw Test Data

Truck	2D Actual Image Height (Pixels)	2D Detected Image Height (Pixels)	2D Accuracy	3D Actual Height (Feet)	3D Estimated Height (Feet)	3D Height Accuracy
1	150	144	96.00%	13.5	12.96	96.00%
2	157	157	100.00%	13.5	13.23	98.00%
3	157	156	99.36%	13.5	13.27	98.32%
4	158	134	84.81%	13.5	11.49	85.12%
5	158	158	100.00%	13.5	13.50	100.00%
6	161	161	100.00%	13.5	13.37	99.00%
7	162	162	100.00%	13.5	13.33	98.77%
8	163	164	99.39%	13.5	13.65	98.89%
9	164	169	97.04%	13.5	13.01	96.34%
10	166	149	89.76%	13.5	11.97	88.64%
11	167	127	76.05%	13.5	11.07	82.00%
12	167	127	76.05%	13.5	10.27	76.08%
13	169	168	99.41%	13.5	13.10	97.00%
14	171	171	100.00%	13.5	13.49	99.90%
15	172	171	99.42%	13.5	13.42	99.42%
16	173	164	94.80%	13.5	12.62	93.46%
17	174	174	100.00%	13.5	13.50	100.00%
18	177	152	85.88%	13.5	11.83	87.60%
19	177	153	86.44%	13.5	11.67	86.44%
20	180	178	98.89%	13.5	12.99	96.23%
21	179	179	100.00%	13.5	13.50	100.00%
22	185	185	100.00%	13.5	13.82	97.71%
23	184	182	98.91%	13.5	12.62	93.45%
24	185	184	99.46%	13.5	13.67	98.78%
25	187	186	99.47%	13.5	13.16	97.46%
26	/	/	0.00%	13.5	/	0.00%
27	196	196	100.00%	13.5	13.26	98.23%
28	190	188	98.95%	13.5	12.74	94.35%
29	/	/	0.00%	13.5	/	0.00%
30	193	195	98.97%	13.5	13.94	96.87%
31	143	141	98.60%	12.5	12.30	98.43%
32	146	146	100.00%	12.5	12.50	100.00%
33	147	146	99.32%	12.5	12.41	99.32%
34	148	149	99.33%	12.5	12.79	97.72%
35	177	177	100.00%	12.5	12.50	100.00%
36	174	173	99.43%	12.5	12.37	98.93%

Table 1- Continued

37	179	179	100.00%	12.5	12.23	97.87%
38	178	178	100.00%	12.5	12.76	97.93%
39	182	181	99.45%	12.5	12.18	97.43%
40	183	182	99.45%	12.5	12.31	98.44%
41	184	183	99.46%	12.5	12.43	99.46%
42	187	187	100.00%	12.5	12.84	97.33%
43	187	187	100.00%	12.5	12.65	98.81%
44	189	190	99.47%	12.5	12.64	98.90%
45	190	190	100.00%	12.5	12.50	100.00%
46	190	189	99.47%	12.5	12.35	98.77%
47	193	189	97.93%	12.5	12.24	97.93%
48	196	195	99.49%	12.5	12.44	99.49%
49	198	195	98.48%	12.5	12.31	98.48%
50	197	220	89.55%	12.5	13.54	92.30%
51	200	200	100.00%	12.5	12.87	97.14%
52	205	205	100.00%	12.5	11.97	95.73%
53	206	206	100.00%	12.5	12.50	100.00%
54	207	204	98.55%	12.5	12.32	98.55%
55	207	207	100.00%	12.5	12.86	97.23%
56	211	212	99.53%	12.5	12.36	98.88%
57	210	210	100.00%	12.5	12.23	97.84%
58	212	211	99.53%	12.5	12.07	96.56%
59	219	219	100.00%	12.5	12.44	99.53%
60	216	216	100.00%	12.5	12.37	98.92%

Table 2- Summary Table

Truck Category	**# of Trucks**	**# Measured**	**% Accuracy of 2D Measured**	**STDEV. 2D Measured**	**% Accuracy of 3D Measured**	**STDEV. of 3D Measured**	**Total % Error**
1 & 2	60	58	97.52%	5.45%	96.59%	4.75%	3.33%

CHAPTER 6

CONCLUSION

In conclusion, this paper has presented a method for determining the height of trucks using digital video captured by a fixed video camera for the purpose of over-height truck collision prevention in low clearance headroom roadways. The area of focus was flat, single and double lane per direction roadways, with daytime lighting, and one-directional flow for video processing. The merit of this research was the creation of an automatic image based method which can provide height determination of trucks and is a low cost alternative to the current expensive laser and infrared detection systems. This method that was developed showed through testing and implementation that it can perform to high standards achieving a 96.59% accuracy rate in determining the truck height for measured trucks. While the method does currently have a 3.3% error ratio, with fine tuning, in the future that will hopefully be lowered to less than 1%. This method was achieved through the use of vehicle tracking and detection, and blob and line detection. With these elements combined the proposed method is innovative in several ways: including the overlaying of line and blob detection methods, and line segmentation and inclination matching. The end result is a method that is more reliable than previous methods and provides exact height estimation, something that has not been done before in over-height vehicle detection for an EWDS. Given the typical lower cost of digital video compared to laser and infrared detection systems this approach presents an opportunity of significant cost and maintenance savings. Given the demonstrated system capabilities future efforts will detail cost comparisons and potential savings between the proposed video based approach and other height detection systems, in various operating environments. This proposed method could be the perfect answer to the budget limited DOTs that have a need for early warning detection systems state wide implementation. Since trucks transport much of the nation's freight, which contains everything from food to health care supplies, the unhindered flow of trucks across the nation is a requirement and safe passive of freight across our nation is a must. The proposed method is a step in the right direction to help all the truck drivers across our nation, and to help save costly accidents and repairs at the DOT level.

REFERENCES

09gr820, Canny Edge Detection, March 2009 http://www.cvmt.dk/education/teaching/f09/VGIS8/AIP/canny_09gr820.pdf

AllStays, (2012) "Low Clearance Locations in Georgia." #1 Mobile Source for Real Travel Information. <http://www.allstays.com/c/low-clearance-georgia-locations.htm>. 15 June 2012

American Trucking Associations, (2006) "When Trucks Stop, America Stops." American Trucking Association. <http://www.trucking.org/Newsroom/Trucks%20Are/When%20Trucks%20Stop%20America%20Stops.pdf>. (12 Mar. 2012.)

Criminisi A., Reid I., and Zisserman A., (2000) "Single view metrology," *Int. J. Comput. Vis.*, vol. 40, 123–148

Fu, C.C. Burhouse, J.R. and Chang, G.L., (2004) "Overheight Vehicle Collisions with Highway Bridges, " *Transportation Research Record, Journal of the Transportation Research Board*, No. 1865, TRB, National Research Council, Washington, D.C., 80-88

Furukawa Y., Curless B., Seitz S.M., and Szeliski R., (2009) "Manhattan-world stereo," Conference on Computer Vision and Pattern Recognition, vol. 0, pp. 1422–1429

Gioi R. Grompone von, Jakubowicz J., Morel J.M., and Randall G, (2012) LSD: a Line Segment Detector, Image Processing On Line, http://dx.doi.org/10.5201/ipol.2012.gjmr-lsd (May. 4, 2012)

Gioi R. Grompone von, Jakubowicz J., Morel J.M., and Randall G., (2008) "LSD: A Line Segment Detector," technical report, Centre de Mathématiques et de leurs Applications (CMLA), Ecole Normale Supérieure de Cachan (ENS-CACHAN).

Hanchey, C. M. and S. F. Exley. (1990) "Overheight Vehicle Warning Systems in Mississippi." *ITE Journal*, Vol.60, No. 6, 24-29.

Highway Statistics (1999) Office of Highway Policy Information, FHWA, U.S. Department of Transportation, 2000, Table HM-81.

Khorramshahi, V. Behrad, A. Kamhere, N. K.(2008) "Over-Height Vehicle Detection in Low Headroom Roads Using Digital Video Processing" *International Journal of Computer and Information Engineering* 2:2, 82-86

Li, L.W. Huang, IYH Gu, Q Tian, (2003) Foreground object detection from videos containing complex background. *Proceedings of the eleventh ACM international conference on Multimedia (MULTIMEDIA '03),New York, NY, USA* (ACM), 2–10

Mattingly, S. P., (2003) “Evaluation of Overheight Vehicle Warning Devices” Alaska Department of Transportation & Public Facilities, Report # FHWA-AK-RD-02-12, June

New International Version. Grand Rapids: Zondervan, (1986)

Park, M.-W., Makhmalbaf, A., and Brilakis, I. (2011) “Comparative study of vision tracking methods for tracking of construction site resources.” *Journal of Automation in Construction*, 20(7), 905-915.

Ross, D. A. Lim, J. Lin, R.-S. Yang, M.-H. (2008) Incremental Learning for Robust Visual Tracking. *International Journal of Computer Vision* 77(1-3): 125-141

Shao, J. Zhou, S. K. Chellappa, R. (2010) “Robust height estimation of moving objects from uncalibrated videos” *IEEE Trans Image Process*. Aug;19(8):2221-32.

S.S. Cheung, C. Kamath, (2004) Robust techniques for background subtraction in Urban traffic video, in: Video Communications and Image Processing. *SPIE Electronic Imaging*, vol. 5308, San Jose, California.

Stauffer C., Grimson W., (2000) Learning patterns of activity using real-time tracking, *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22 (8),747–757.