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A vision-based method for on-road truck height measurement in proactive prevention of collision with overpasses and tunnels

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ABSTRACT

Over-height trucks are continuously striking low clearance overpasses and tunnels. This has led to significant damage, fatalities, and inconvenience to the public. Smart systems can automatically detect and warn oversize trucks, and have been introduced to provide the trucks with the opportunity to avoid a collision. However, high cost of implementing these systems remains a bottleneck for their wide adoption. This paper evaluates the feasibility of using computer vision to detect over-height trucks. In the proposed method, video streams are collected from a surveillance camera attached on the overpass/tunnel, and processed to measure truck heights. The height is measured using line detection and blob tracking which locate upper and lower points of a truck in pixel coordinates. The pixel coordinates are then translated into 3D world coordinates. Proof-of-concept experiment results signify the high performance of the proposed method and its potential in achieving cost-effective monitoring of over-height trucks in the transportation system. The limitations and considerations of the method for field implementation are also discussed.

1. Introduction

Semi-trucks are a major form of transportation unit in the United States delivering nearly 70% of all freight tonnage [1]. The large percentage of tonnage signifies the importance of unhindered flows of these trucks across the nation. One of the areas where this evolves into a problem is during the transportation of freight on routes with low clearance overpasses (a bridge, road, or railway that crosses over another road or railway) and tunnels. There are a considerable number of old low clearance overpasses in the U.S. and the world, which cause accidents associated with collisions of trucks with overpasses. In a study conducted by the University of Maryland where all states were polled and 29 states responded, 18 of those 29 or 62% stated they consider over-height collisions a serious problem [2].

Accidental crashes of over-height trucks with overpasses and tunnels have been continuously reported over the years [3–7]. Even though the frequency of these accidents might not be thought significant, the costs they involve are considerably high. The damages involve direct costs related to injuries or fatalities for drivers or pedestrians and clearing/restoring the overpass/tunnels and underway roads, as well as indirect costs charged due to traffic delays. For example, an over-height truck collision with the Melbourne's Burnley tunnel on April 17, 2013 led to a damage loss and traffic jam cost which was up to one million dollars [6]. In terms of the frequency of over-height collisions, 14 (3%) out of 503 bridge failures in 1989–2000 were due to vehicle/structure collisions [8]. Agrawal et al. [9] reported that bridges in New York State have been experiencing approximately 200 strikes annually by over-height trucks. In Beijing, it was reported that approximately 20% of the overpasses are associated with over-height collisions [3]. Based on these statistics, and despite the fact that occurrences of over-height truck collisions are not as frequent as other traffic accidents such as vehicle collisions, the consequence of over-height collisions are usually quite severe [2].

In order to avoid these accidents and to reduce involved costs, it is beneficial to have a warning system that detect an over-height truck and notify its driver ahead of the presence of the low clearance overpass/tunnel. In the United States, many states have started deploying warning systems using laser or infrared light [10]. The systems (except for laser profiling units) generally consist of 1) a transmitter and 2) a receiver mounted on opposite sides of the road, 3) loop detectors under the road, and 4) a visual/aural warning system [11]. However, the high cost of implementing the systems constraints the wide use of those technologies [12]. In addition, the installation of loop detector requires temporary road closure causing another indirect cost. In contrast to the laser- or infrared-based systems, a vision-based system can be a cost-efficient alternative and resistant to false alarms. In the system,

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the aforementioned three components 1)–3) can be replaced with one or more cameras and an embedded processor running computer vision algorithms. This paper introduces an overall framework of the system and evaluates a vision-based method for measuring truck heights as a part of the framework. The method combines line segmentation and blob tracking in order to detect lines on the top and bottom of the truck. Two points are selected as they comprise a vertical line perpendicular to the road plane. The length of the line determines the truck height in 2D coordinates which can then be translated into 3D space. This process also involves unit conversions from pixel to a length unit such as meter or feet by use of a fixed reference object height. The present research signifies the potential of achieving cost-effective solution of preventing possible collision between over-height trucks and low-clearance overpass/tunnels by simply utilizing existing surveillance systems. Furthermore, the low cost will allow the system's broader applications. For instance, it can be applied at the entrance to parking decks where over-height vehicles are prohibited. The proposed system is also applicable to luggage handling systems in airports.

2. Background

2.1. Protective measures for overpass/tunnel crash accidents prevention

To prevent the over-height collisions, a couple of protective measures have been implemented. For example, in the United States, permits are required for the trucks over 13′–6″ (4.12 m) [13]. 13′–6″ is the allowed legal height of trucks. In general, the protective measures can be categorized as: 1) providing a listing of restricted structures on federal/state-maintained roadways for truck drivers to plan their travel routes ahead of time, to avoid where low clearance overpass/tunnels may occur, 2) installing signs along the road or on the overpass/tunnel, informing drivers of the low clearance of the structure, 3) enforcing detour of the over-height trucks and providing get-around directions over the road, and 4) installing a sacrificial system in which an audible alarm is made when over-height vehicles hit a physical obstruction [14] such as chains, metal strips, or sacrificial beams installed at the overpass/tunnel height in advance of the overpass/tunnel. These measures play a positive role in protecting existing structures from over-height truck collisions. However, their effects are limited. The measures 1)–3) highly rely on drivers' attention and do not eradicate the collision problem. It is still drivers' responsibility to confirm clearance heights along their routes. As a result, crash accidents continue to occur in that truck drivers often accidentally ignore the structure clearance [2,6]. In addition, outdated low clearance overpass/tunnels exist that have not been marked on the drivers' maps. As to the measure 4), although sacrificial beams cause damages on trucks, a high detection rate and a low false alarm rate may be achieved. A truck driver would appreciate that a little damage incurred to the truck will prevent catastrophic damages. However, if the driver has noticed a low clearance ahead while still needing to hit the detecting chains and metal strips to let the truck pass through, the inconvenience of being hit or a small damage becomes a disadvantage of this approach. Moreover, chains and metal strips may not provide an alarm loud enough to be heard inside trucks [15]. A more preventive way is having a warning system that can detect an over-height truck and notify its driver ahead of the presence of the low clearance overpass before a collision occurs [16]. The remainder of this section first reviews the implementation of existing over-height warning systems, the context within which this paper lies. The review is then followed by current research in vision-based height measurement, on which this paper is based.

2.2. Over-height vehicle warning systems

Over-height vehicle warning system, also called Early Warning Detection System (EWDS) is an active system. It automatically detects the existence of an over-height vehicle for a particular tunnel or overpass and warns the driver of the vehicle of the pending danger before a collision with the structure occurs. Sinfield [17] provided an overview on existing EWDSs and the state of their implementation in the U.S. According to his review, the majority of existing systems fall into the categories of utilizing the sensing technologies of visible beam, laser (acronym for Light Amplification by Stimulated Emission of Radiation), or infrared, all of which rely on the interruption of a beam or sheet of light to identify a vehicle exceeding a predefined height threshold or to construct the profile of a vehicle that can be translated into accurate vehicle dimensions.

Visible beam systems are the types of optoelectronic sensors. They operate by emitting a beam of visible light from a source unit to a detection unit that either processes the light or reflects it back. In general, the cost of visible beam systems is low, but they are unreliable to ambient light and inclement weather that are particularly common in outdoor conditions. Systems that utilize laser are generally divided into laser sheet systems [18] and laser profiling systems [19]. The former works by generating a plane of one or more laser beams that is interrupted by a passing object. The latter reconstructs the point cloud of a passing object such that the object's height can be easily interpreted. It is worth mentioning that the cost of laser profiling systems is particularly high and the effect of these systems is limited to moving traffic with slow speed. As a result, they tend not to be used solely for overheight vehicle detection. Similar to laser systems, infrared systems work by directing a focused beam of light in the infrared region of the optical spectrum from a transmission unit to a reflective target or detection unit. Both laser and infrared systems present more robust features for outdoor use than visible beam systems. A typical infrared/laser system (except for the laser profiling system) consists of 1) a transmitter and 2) a receiver mounted on opposite sides of the road, 3) loop detectors under the road, and 4) a visual/aural warning system [11]. In this system, the transmitter mounted on a pole at the height of the bridge clearance emits the laser or infrared beam. The interference of the beam due to the appearance of a truck activates a warning system that informs the driver with flashers and/or audible alarms. Loop detectors identify the appearance of a vehicle and their lanes [11]. The identification is used to remove false detections caused by non-vehicles such as birds and flapping tarps. Many states in the U.S. have started deploying warning systems using laser or infrared [10]. It is reported accidents were reduced after the systems began operation [12]. The use of infrared light is more dominant than laser in these systems, being considered safer and more durable in various environments (e.g., better penetration of rain and fog). However, the high cost of implementing the systems restricts the wide use of these technologies [20]. For example, the deployment of the system in both directions of a road in Maryland cost a total of $146,000 [21]. Moreover, the installation of loop detector needs temporary road closure causing another indirect cost.

2.3. Computer vision based height measurement

As an alternative to the laser- or infrared-based system, a vision-based over-height vehicle detection system has the potential of being cost-efficient since it can identify truck heights only with one or more cameras for each direction, equipped with a processor unit. As video is one of the major data types that most DOTs (Department of Transportation) daily collect, continuous research efforts have been made on the application of computer vision algorithms for intelligent transportation systems (ITS). For instance, automated detection [22,23] and tracking [24,25] of vehicles have drawn great interests and been extensively investigated for counting vehicles and extracting their trajectories, which are essential information in monitoring and analyzing traffic conditions.

The vision-based vehicle monitoring generally works as follows. Once the cameras are positioned, their video streams are processed by an embedded processor unit to identify and locate vehicles. This processing involves three steps: camera calibration, vehicle detection, and vehicle tracking. Camera calibration provides a transformation between