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Real-time validation of vision-based over-height vehicle detection system

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ABSTRACT

Over-height vehicle strikes with low bridges and tunnels are an ongoing problem worldwide. While previous methods have used vision-based systems to address the over-height warning problem, such methods are sensitive to wind. In this paper, we perform a full validation of the system using a constraint-based approach to minimize the number of over-height vehicle misclassifications due to windy conditions. The dataset includes a total of 102 over-height vehicles recorded at frame rates of 25 and 30fps. An analysis is performed of wind and vehicle displacements to track over-height features using optical flow paired with SURF feature detectors. Motion captured within the region of interest was treated as a standard two-class binary linear classification problem with 1 indicating over-height vehicle presence and 0 indicating noise. The algorithm performed with 100% recall, 83.3% precision, false positive rate of 0.2% and warning accuracy of 96.6%.

1. Introduction

An over-height (OH) vehicle strike is an incident in which a vehicle, typically a lorry (truck) or double-decker bus, tries to pass under a bridge or tunnel that is lower than its height, subsequently colliding with the structure. Bridge and tunnel strikes are recurrent incidents, often costing thousands of pounds in repairs and causing hours of delays; this disruption that can be felt across various road and rail networks [20]. When a strike occurs, the event can affect five key groups: these include owner/operators of roadways, railways, and bridges/tunnels, as well as both vehicle drivers and the wider public.

Current state of practice in strike prevention can be split into three categories, each with limitations: passive systems (effective only 10–20% of the time) [3], sacrificial systems (costly) [16] and active systems (also costly) [1]. Although expensive, the active laser-beam systems are the most effective. However, due to the high costs associated with pole erection and installation (£60 k+ per pole), adoption has been limited [5]. Particularly in severe wind, active systems are more prone to false positive warnings. To keep costs low, minimum hardware such as typical steel brackets are used and tested. The camera will be subdued to a variation of wind motion when mounted to an outdoor pole therefore, the need for a wind experiment is required to demonstrate its robustness. If we chose to install a heavy-duty steel casing around the system, permanent infrastructure is required therefore providing little incentive for asset owners to adopt the system due to its high upfront installation costs.

In this paper, we perform a real-time validation of a vision-based OH vehicle detection system for the prevention of bridge and tunnel strikes. The paper addresses the wind sensitivity issue by using a constraint-based approach to minimize the number of OH vehicle misclassifications resulting from windy camera conditions. Our approach involves understanding the behaviors of moving vehicles and wind motion in order to prevent misclassifications and resultant erroneous warnings to drivers. This paper is organized as follows: Section 2 explores negative effects of wind in outdoor computer vision applications, and feature detection methods for vehicle detection. Section 3 steps us through the proposed approach to tackle windy camera motion and vehicle displacement checks. Section 4 reveals the results of the experiment and Section 5 concludes with a discussion and conclusions.

2. Background

Computer vision-based OH vehicle detection is a relatively new area of research. It has grown in popularity as infrastructure owners have increasingly sought more affordable methods of strike prevention. One of the earliest computer vision-based solutions to the OH problem includes height estimation of moving objects. This approach uses vanishing lines to estimate vehicle heights [24,5]. Although these methods have yielded favorable results, they rely on the sometimes problematic assumption that vehicles are fully visible in the images. On a multi-lane roadway, this is often untenable, given the number of vehicle occlusions in a typical scene.

Nguyen, Brilakis and Vela [22] expanded on the height estimation concept by introducing a threshold line approach which mimics the

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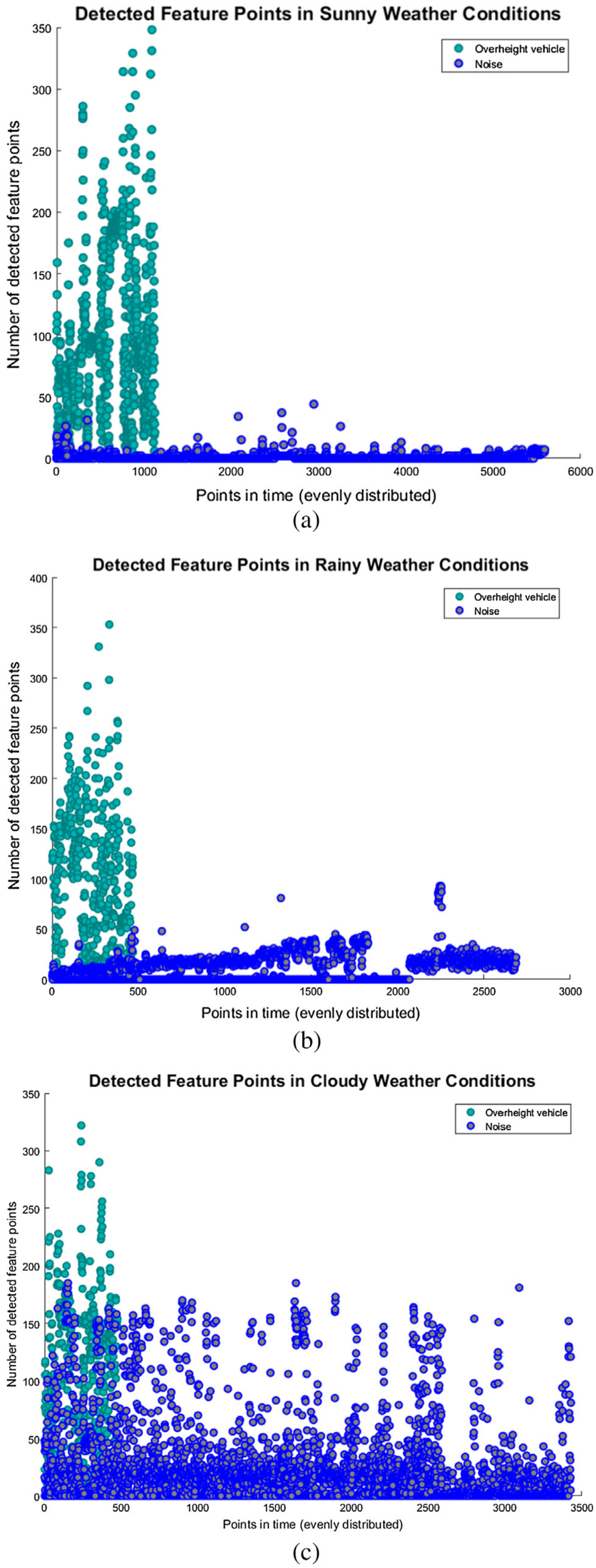

Fig. 1. Plot showing the number of detected features over time in sunny, rainy and cloudy weather conditions.

behavior of the active laser-beam method. In Fig. 1, under ideal sunny yet minor-windy weather conditions, the distinction between OH vehicle and noise (wind, illumination changes) is distinguishable by the average number of feature points detected. When the number of feature points are high, we expect to see motion consistent with a vehicle passing through the frame; otherwise, any detected features points can be classified as non-vehicular movement. While the threshold line approach performs ideally in sunny weather conditions, the performance drops by nearly 31.0% in windy weather (as shown in Fig. 1c). This is problematic and will need to be addressed for system robustness.

A reliable camera-based setup may prove challenging in windy conditions, hence understanding the characteristics of wind motion is crucial in designing an intelligent OH detection system. The National Weather Service UK defines '*windy*' as speeds of 15 to 25 mph. In the UK, average wind speeds are ± 3 mph; therefore, camera installation locations will need to consider the wind levels in specific regions to maintain robustness during wind activity. The following sections describe methods related to increase robustness and stability including video stabilization, feature-based and intensity-based methods for OH vehicle detection.

2.1. Video stabilization methods

Camera stabilization is a device that is used to securely fasten a camera in a manner that prevents or compensates for unwanted camera motion. In an OH context, although the camera is intended to be static and fastened to a secure bracket, severe wind can still cause motion in the system, due to the slenderness of the mounting pole and its height relative to the road plane. This problem can be addressed using feature- or intensity-based methods. Related methods to tackle this problem of windy camera frames can be explored using video stabilization methods.

Computer vision image enhancement techniques for video stabilization is the process of identifying and removing undesired image motion from video data. Shaky and blurry video data due to wind movements suffer from significant amounts of unexpected image motion caused by external weather conditions. The initial step in video stabilization is global motion estimation followed by feature and intensity-based methods.

Global motion estimation is a vital step in the process of video stabilization for OH vehicle detection. Huang et al. [10] describes the process as, '*what is happening in the frames and what motions are evident?*' By understanding what is happening, the motions can be separated into two categories: (1) intentional motion (what we are trying to analyze) and (2) unwanted motion (camera jitteriness, jerkiness, background noise and wind motions). By removing the unwanted motion, we are then left with a stabilized frame. The use of video stabilization techniques as part of a pre-processing stage can be used to bridge this concept to minimize the number of false positive detections invoked by the system. Methods for video stabilization fall under two categories: 2D and 3D methods. Although 3D methods are more accurate, the method is more computationally complex and 2D methods are sufficiently robust to solve the problem of windy camera frames. A general survey of approaches to address this challenge of feature and intensity-based methods are presented.

2.2. Feature-based methods

This section covers the current feature-based extraction methods. Feature based methods has become an increasingly used method for detecting objects in a scene, ideal for OH vehicle detection which include distinctive attributes such as edges and corners. Edge detection is one of the most practical and commonly used algorithms which treats edge detection as a signal processing problem that maximizes the signal to noise ratio to provide good detection [11]. However, corners are mathematically the best features to track due to its difference in intensity values [25].

Corners are common features to track, due to its distinctive edges (a sub-attribute of a corner) and distinguishable changes in intensity