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Automatic vehicle trajectory extraction by aerial remote sensing

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Abstract

Research in road users' behaviour typically depends on detailed observational data availability, particularly if the interest is in driving behaviour modelling. Among this type of data, vehicle trajectories are an important source of information for traffic flow theory, driving behaviour modelling, innovation in traffic management and safety and environmental studies. Recent developments in sensing technologies and image processing algorithms reduced the resources (time and costs) required for detailed traffic data collection, promoting the feasibility of site-based and vehicle-based naturalistic driving observation.

For testing the core models of a traffic microsimulation application for safety assessment, vehicle trajectories were collected by remote sensing on a typical Portuguese suburban motorway. Multiple short flights over a stretch of an urban motorway allowed for the collection of several partial vehicle trajectories. In this paper the technical details of each step of the methodology used is presented: image collection, image processing, vehicle identification and vehicle tracking.

To collect the images, a high-resolution camera was mounted on an aircraft's gyroscopic platform. The camera was connected to a DGPS for extraction of the camera position and allowed the collection of high resolution images at a low frame rate of 2s. After generic image orthorrectification using the flight details and the terrain model, computer vision techniques were used for fine rectification: the scale-invariant feature transform algorithm was used for detection and description of image features, and the random sample consensus algorithm for feature matching. Vehicle detection was carried out by median-based background subtraction. After the computation of the detected foreground and the shadow detection using a spectral ratio technique, region segmentation was used to identify candidates for vehicle positions. Finally, vehicles were tracked using a k-shortest disjoints paths algorithm. This approach allows for the optimization of an entire set of trajectories against all possible position candidates using motion-based optimization.

Besides the importance of a new trajectory dataset that allows the development of new behavioural models and the validation of existing ones, this paper also describes the application of state-of-the-art algorithms and methods that significantly minimize the resources needed for such data collection.

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Keywords: vehicle trajectories extraction; driver behaviour; remote sensing.

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1. Introduction

The study of detailed driving behaviour heavily depends on data availability, as traffic micro-simulation models try to capture sub-second vehicle interactions and drivers' decisions. In the last couple of decades safety and driving behaviour modelling research has devoted efforts to the collection and analysis of such detailed traffic data through vehicle-based, site-based or mixed methods.

Vehicle-based methods make use of probe vehicles equipped with multiple sensors that travel in the traffic stream and collect time series information on the behaviour of a test driver and/or adjacent vehicles (Neale et al., 2005). However, these studies provide limited vehicle trajectory data, including trajectories of a small number of instrumented vehicles and snapshot trajectories of adjacent vehicles. Site-based methods make use of sensoring technologies installed in delimited areas for detailed road traffic trajectories collection. Recent advanced sensor technologies, such as RADAR (Aoude et al, 2011) and infra-red (Bhattacharya et al, 2011) may also be found in the literature, but photo and video cameras have been the main tools used in site-based trajectories extraction (Hoogendoorn et al., 2003, Hranac et al, 2004, Laurenshyn, 2010). The developed methods can be classified depending on the type of observation, either static or dynamic. Sensors may be placed either on poles, cables and high-rise buildings (static) or on airborne vehicles such helicopters, aircrafts drones and satellites (dynamic).

Although the main video-based trajectory extractions are based on static sensoring, airplanes and helicopters have already been used as platforms for dynamic observation and trajectory extraction in driving behaviour research. Despite the apparent (space and time) limitations of all these data sets, they allowed for several important developments on traffic flow theory,driving behaviour analysis and transportation systems impacts modelling (Ossen et al, 2008, Toledo et al, 2009, Knoop et al 2009, Jie et al 2013).

Previous methods struggled with adverse weather effects, image stabilization and orthorrectification, the vehicle tracking efficiency, budget limitations and a considerable manual work burden. In this paper we present a new method for automatic vehicle trajectory extraction from a sequence of aerial images that minimizes all these effects. Gyro stabilizing equipment, terrain modelling and advanced computer vision techniques helped to enhance the image referencing process, while colour algorithms brought several advantages to the shadow and vehicle detection processes. Finally, the use of the powerful *k-shortest path algorithm* efficiently fitted the trajectory reconstruction.

2. Image processing algorithms for vehicle tracking

Typically, the majority of both static and dynamic observations rely on the same main two tasks of image processing algorithms: identification of moving objects and filtering and classification of the road users of interest (Yilmaz et al, 2006). The border line between these tasks is not always explicit, but in this section we present the general aspects of the main algorithms found in the literature for the trajectory extraction process.

2.1. Background Subtraction

Background subtraction technique is one of the most common methods for motion detection in many object tracking applications. Typically, each image frame is compared against a static background image, using a pixel-by-pixel value subtraction. To build the background image, several methods have been developed, including the frame average method, maximum/minimum intensity value method (Cho and Rice, 2004), median (and approximate median) value method (Remagnino et al, 1997), Gaussian and mixture of Gaussian methods (Magee et al, 2004) and Kalman filtering techniques (Cheung et al, 2004). Background subtraction provides the most complete feature information and a high detection-rate, but the disadvantage of all these techniques is that they are extremely sensitive to dynamic scene changes due to lighting and extraneous events and, sometimes, computationally demanding. Knoop et al (2009), for example, when focusing in car-following trajectory