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On accuracy of position estimation from aerial imagery captured by low-flying UAVs

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ABSTRACT

The application of low-flying Unmanned Aerial Vehicles (UAVs) for traffic monitoring and surveillance requires an estimation of position measurement accuracy of monitored objects. In this work we aim to analyse and provide insight into the accuracy of position estimation of objects based on aerial imagery captured by low flying UAV for the purpose of traffic monitoring. The analysis is focused on data gathered by a low-cost action camera mounted on a multicopter UAV flying above a planar scene. We assume a simple, straightforward method of position estimation of object based on homography mapping between two 2D planes derived from the position of images of landmarks – objects with known real world position. We assume errors caused by inaccuracy of the following values: the landmarks' real world position, the landmarks' and target's real world elevation, and the captured image positions of both the landmarks and the target. Additionally, a geometric deformation of captured frame caused by imperfect camera lenses is considered. The paper further analyses the effect of varying magnitude of errors, camera position, incidence angle and both the landmarks' and the target's positions in the scene or captured frame, and compares the results with real world experiments. The results can be used to estimate the feasibility and applicability of certain solutions to object position estimation. The tool for the calculation of the accuracy of position estimation and locating the most suitable camera pose for a given setup is provided.

1. Introduction

Over the past few years the pursue for better and safer transportation systems has resulted in an emerging trend of using more precise and thorough analyses of traffic elements and its participants. The aim of such micro-analyses is to investigate the transportation system by inspecting a detailed behaviour and inter-relationships of each traffic participant. Microanalyses can be conducted in the context of elements of transportation systems, such as road junctions, or in the context of specific behaviours or situations, such as overtaking manoeuvres and dangerous situations. A detailed overview of studies of intersections from various aspects is presented in Shirazi and Morris (2015) and Shirazi and Morris (2017). They examine recent studies focused on behaviour analysis of vehicles, drivers and pedestrians, as well as studies of traffic safety based on inter-vehicle gaps, threats, conflicts and intersection safety systems. They conclude that to improve intersection safety

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necessary infrastructure must be created to collect and share dynamics and profiles of all traffic participants. Another application of microanalyses is to investigate traffic in the context of certain type of behaviours, such as overtaking manoeuvres of motorbikes, which are studied in work of Barmpounakis et al. (2016).

Such analytic and detailed approach to traffic analysis requires a data collection method which can provide sufficiently detailed, accurate, and extensive data concerning the positions, trajectories and dynamics of traffic participants. One of such methods is to deploy unmanned aerial vehicles (UAVs). A survey of application of UAVs for traffic monitoring is presented in the paper by Kanistras et al. (2015). The use of UAVs in traffic analysis, monitoring and control is described in the paper by Mohammed et al. (2014) as one of the main application of UAVs in smart cities, alongside with civil security and geo-spatial and agricultural surveillance and management. Practical matters of traffic analysis using UAVs are discussed by Khan et al. (2016) presenting extensive systematic and practical guidelines on how to conduct a UAV-based traffic study, derived from analysis of multiple past publications.

In our previous work, we developed a system for extraction of traffic spatio-temporal data from video sequences captured by low-flying UAVs (Apeltauer et al., 2015). Such approach opens the opportunity to harvest precise data about members of traffic flow using inexpensive hardware: an action camera mounted on a low-flying radio-controlled UAV, as presented also by Hart and Gharaibeh (2010), Lee et al. (2015), and Salvo et al. (2014), and is currently commercially available via project DataFromSky (RCE Systems, 2016). To assess the feasibility of the approach, an estimation of its accuracy in real world application is necessary. While the accuracy and sensitivity analysis of perspective mapping (Collins, 1992; Waldman et al., 1998) and the comparison of the accuracy of various approaches to object tracking from UAV have been presented (Nuske et al., 2011; Dille et al., 2011), a thorough analysis of effects of commonplace inaccuracies present in practical application of object localisation from aerial imagery has been lacking.

For object position estimation from aerial imagery, the accuracy estimation is non-trivial as it depends on a number of factors that change from experiment to experiment – the pose of the UAV, the camera properties, the position of targets and the position estimation dependencies, such as the landmarks used to derive the spatial mapping between the camera frame and real world.

This paper is concerned with the analysis of effects of errors caused by the use of position estimation from aerial imagery captured by a low-cost action camera mounted on low-flying UAVs. We address geometrical properties of inaccuracy propagation of the object position estimation based on homography estimation between the projection plane and the scene plane. The paper discusses the potential errors caused by imperfect camera calibration, inaccurate object localisation and non-planarity of the scene. The propagation of the errors and their impact on the position estimation of the objects in the captured scene is analysed via Monte Carlo based simulation. To compare the simulation outputs with reality, accuracy analyses of position estimation of three distinct real world scenes were carried out and compared against their simulation-based counterparts.

The paper is divided as follows: Section 2 describes applied position estimation technique and possible errors and introduces terminology used throughout the paper. The simulation tool developed by the authors is described in the third section of the paper. The fourth section is devoted to the synthetic analysis of assumed errors in various configurations with respect to the magnitude of the errors, the camera incidence angle, the spatial distribution and the presence of non-linear geometric deformation. The fifth section provides accuracy analyses of real world captured data and compares them with their respective simulations. The sixth section concludes the paper by discussing the implications of the results.

2. Object position estimation

The algorithm of the object position estimation for the traffic analysis is based on projection mapping between the image frame captured by the camera mounted on a UAV and the traffic scene analysed. The projection mapping is derived from the

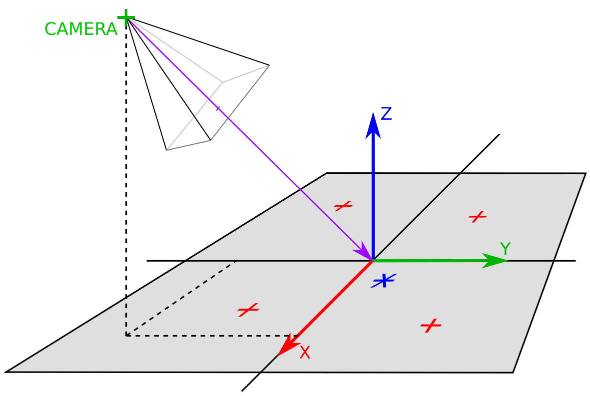

Fig. 1. Illustration of the virtual scene. A camera (green cross) is hovering above the scene plane (grey), which contains points with known world coordinates – landmarks (red crosses), and a point with unknown world coordinates, which we wish to recover – a target (blue asterisk). The thin violet arrow represents the principal ray of the camera.