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Map-Enhanced Visual Taxiway Extraction for Autonomous Taxiing of UAVs ⋆

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Abstract: In this paper, a map-enhanced method is proposed for vision-based taxiway centreline extraction, which is a prerequisite of autonomous visual navigation systems for unmanned aerial vehicles. Comparing with other sensors, cameras are able to provide richer information. Consequently, vision based navigations have been intensively studied in the recent two decades and computer vision techniques are shown to be capable of dealing with various problems in applications. However, there are significant drawbacks associated with these computer vision techniques that the accuracy and robustness may not meet the required standard in some application scenarios. In this paper, a taxiway map is incorporated into the analysis as prior knowledge to improve on the vehicle localisation and vision based centreline extraction. We develop a map updating algorithm so that the traditional map is able to adapt to the dynamic environment via Bayesian learning. The developed method is illustrated using a simulation study.

Keywords: knowledge-based systems, map-prior, taxiway centreline extraction.

1. INTRODUCTION

Unmanned Aerial Vehicle (UAV) was initially investigated for military applications to reduce the risk of losing precious human lives, and the cost of such a UAV was extremely high. Thanks to the rapid technological development in the recent years in a number of areas such as sensor, battery, engine, etc., the capability of a low cost UAV has been substantially increased and consequently UAVs can now be used for many civil applications. While a military UAV deserves to have a dedicated aerodrome due to its particularity, a civil UAV is more likely to share the infrastructure with existing civil aerodromes to reduce additional cost so that the technology is more affordable to public. Manned and unmanned hybrid civil aerodromes are a highly complex and dynamic environment; a UAV operating in it needs to be both efficient and robust without additional infrastructures. Autonomous taxiing in such an environment becomes a new challenging research area.

Taxiway localisation is a fundamental problem of UAV autonomous ground navigation in aerodromes. Based on Differential Global Positioning System (D-GPS), Cho et al. (2007) provide a solution for automatically taxiing, takeoff and landing. However, D-GPS is not available on every aerodrome, which limits the application of this method. In addition, it is unrealistic to assume that a UAV autonomously operates in such a dynamic environment (civil aerodrome) with a single localisation system. In order to increase the system robustness and to deal with unexpected changes in the environment, other sensing approaches should be also considered to deliver an integral system.

Various autonomous navigation solutions have been proposed with integrating different sensors. Sun et al. (2013) use an Inertial Measurement Unit (IMU) to enhance the reliability of a GPS-based navigation system. On the other hand, in a GPS denied area, a multi-sensor fusion technique is developed in Ilyas (2013) for a local navigation. In addition, a continuously rotating 2D laser scanner is used to build an allocentric 3D map of a rough terrain environment in Schadler et al. (2014). For the same environment, a 2.5D egocentric map is built with eight RGB-D sensors in Schwarz and Behnke (2014), and drivable path is assessed based on it. Although different combinations of local sensors can be used for navigation, not all of them are suitable for a flat and open environment, e.g. an aerodrome. Due to the lack of obstacle features in such an environment, range sensors (e.g. laser and RGB-D based) are not appropriate for this application.

For the navigation process on a manned aircraft, most of the local guiding information are obtained visually, including taxiway centreline, signs, pavement markings, etc. Hence a visual based information extraction turns out to be a reasonable choice. From a perspective of image processing, taxiway centreline extraction has no difference from road lane marker detection. A commonly used approach of which is to extract bright (yellow or white painted) regions from a dark background (asphalt pavement). Many research results have been reported in this area; we summarise some of the most recent/relevant

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studies below. Revilloud et al. (2013) proposes a multi-lane detection and estimation approach in which the road markers are obtained by setting a threshold on the pixel intensity. With the same intensity based extraction approach, an adaptive threshold is used in Kheyrollahi and Breckon (2010), where the extracted pixels are grouped into isolated shapes and features of road markers are further recognised. With a set of learned road marker templates, a road marker recognition approach is developed in Wu and Ranganathan (2012). As reported in Sebsadji et al. (2010), stereo images can also be used to improve on the extraction accuracy. The most representative visual navigation for autonomous vehicle is from the VisLab, University of Parma in Italy. As reported in Broggi et al. (2012), their autonomous vehicles successfully drove across the Eurasian continent from Parma, Italy to Shanghai, China.

Although it is feasible that autonomous navigation is purely based on vision, additional information can be used to improve on its reliability. Semantic information from digital map is one of the many choices. Based on the belief that a vehicle is more likely to locate at accessible places (i.e. a road or a car park), various probability zones are assigned to map segments and used to adjust the motion model of vehicle in Oh et al. (2004). Instead of defining probability zones, Jabbour et al. (2008) use a hierarchical Bayesian framework to assess the probability of multiple localisation hypotheses. Specifically, digital map information is used as a geographical measurement (similar to other canonical sensor measurements) to improve on the GPS positioning accuracy. The Oxford mobile robotics group proposes several prior-based approaches for improving on visual localisation for road autonomous navigation. Particularly, Napier et al. (2010) use a coarse-to-fine matching scheme together with an image alignment approach to find the bias between vehicle vision and a birds-eye image. Following the work of Napier et al. (2010), Napier and Newman (2012) employ a mutual information based matching scheme in their study. Instead of using imagery digital map, an obstacle point cloud is collected as prior information and Kullback-Leibler divergence is used to compare between the prior point cloud and real-time laser scan for acquiring better localisation accuracy in Baldwin and Newman (2012).

Comparing with the previous studies mentioned above, this paper aims not only to get a better localisation by matching the visual observation with the map, but also to continuously update the map with visual observation. Specifically, GPS measurements and taxiway map are synthesised to produce a group of prior centreline distribution candidates, and an observed centreline distribution is generated from the image processing techniques. Then an error assessment is carried out with Kullback-Leibler Divergence (KLD) to correct the GPS measurement error, and improve on the centreline extraction accuracy. With the corrected locational information, this enhanced centreline extraction is then used to replace the corresponding area in the taxiway map so that the map is adapted to the environment.

The paper organises as follows. Section 2 highlights various research challenges in this area, and proposes a framework to deal with each of these research issues. Section 3 formulates and investigates the taxiway centreline extraction problem with observation and map. In Section 4 we develop a probability based map-observation matching method, and in Section 5 we discuss how to make the map adapt to a dynamic environment. Finally, this paper concludes in Section 6.

2. CHALLENGES AND FRAMEWORK

2.1 Research challenges

As stated in Section 1, the performance of image processing based taxiway centreline extraction highly depends on the quality of captured images (e.g. noise level, resolution). This section discusses various research challenges of using GPS and taxiway map to enhance the visual extraction.

The research in this paper includes two key elements, i.e. observation and taxiway map. An observation is defined to be a camera-captured image, and a taxiway map is a binary image shows taxiway centrelines. In order to exploit the map to enhance the taxiway centreline extraction, several research issues need to be addressed:

(1) **Representation of map and observation:** In order to pool and combine the information from the map and observation, the information need to be represented in the same format;
(2) **Locational matching:** Because of the noisy GPS measurements, it is not a trivial task to seek a consistent local map that matches to the observation;
(3) **Updating the map:** A map could be out-of-date or incomplete. Therefore, the research framework to be developed in this paper needs to be capable of updating the map on-line to adapt to the dynamic environment.

We will address each of these research issues in Sections 3-5. We first of all outline an overall framework structure in Section 2.2.

2.2 Framework structure

The overall structure of the proposed framework is shown in Fig. 1. At the top of the framework, there are two inputs: measured vehicle state and camera observation. A single output is the enhanced centreline extraction.

With respect to the first research challenge, a Region of Interest (ROI) from the camera observation is projected into an orthographic view from the top, so the observation is now having a consistent view with the 2D taxiway map. Then the vehicle state is used to crop a local region from the map that matches to the ROI in camera observation. A dashed line separates the system into two levels (image level and probability level), and the enhancement of centreline extraction is undertaken at the probability level. Detailed discussion about the probability representations of observation and map, namely observation distribution and map-prior distribution, are given in Section 3.

Then a matching process is done by finding the minimised Kullback-Leibler divergence between them, so the second challenge can be solved (KLD matching). Then the optimal map-prior is used to enhance the observation