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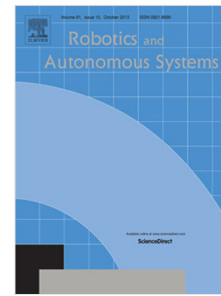
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Assessment of VDM-based Autonomous Navigation of a UAV under Operational Conditions

Mehran Khaghani^{a,*}, Jan Skaloud^b

^aEPFL (mehran.khaghani@epfl.ch)

^bEPFL (jan.skaloud@epfl.ch)

Abstract

This paper presents extensions and practical realization of a previously proposed novel approach to navigation and sensor integration for small unmanned aerial vehicles (UAV). The proposed approach employs vehicle dynamic model (VDM) as process model within navigation system, and treats data from other sensors such as inertial measurement unit (IMU), barometric altimeter, and global navigation satellite system (GNSS) receiver as observations within the system. In comparison to conventional approach that employs inertial navigation system (INS) as process model, employing VDM requires no added hardware, yet significantly improves navigation performance, especially in case of GNSS outages. Experimental results from a real flight on a custom made fixed-wing UAV, as well as Monte Carlo simulation results, reveal improvements of 1 to 2 orders of magnitude in navigation accuracy during GNSS outages of 3 minutes' duration. This is a prerequisite for safer navigation without exteroceptive sensors. Uncertainty levels are predicted consistently within the filter, and a discussion on observability based on covariance matrix analysis is presented. Computation time is also compared to conventional INS-based approach.

Keywords: UAV, autonomous navigation, vehicle dynamic model, GNSS outage, inertial navigation

1. Introduction

Recently, a novel approach to navigation and sensor integration for UAVs was proposed [1]. A shortened version of [1] was also presented in [2]. This paper first provides extensions to modeling by considering global frame realization (Earth rotation and curvature effects) and integrating additional autonomous navigation aids such as barometric altimeters; and second, presents experimental results to assess performance of proposed system under operational conditions in real world. Therefore, more details on introduction and system description are given in [1], while fundamental elements are repeated for the sake of completeness and readers' convenience. One should note that as any dead reckoning navigation method, performance of proposed navigation system is trajectory dependent in general, as is the observability of different states within the navigation system. In this paper, a real flight trajectory of a very common type in aerial mapping is considered to assess the navigation performance. Although the reader needs to mind the trajectory dependence of the results, this sample trajectory can demonstrate the benefits of proposed VDM-based navigation in comparison to conventional INS-based approach.

Similarly to INS-based autonomous navigation, the performance of the proposed method is trajectory dependent in general, as is the observability of different states. In this paper, the aim is to assess the performance for a fixed-wing micro UAV on a real-flight trajectory, shape of which is very common in aerial mapping. Although the general trajectory dependency shall be

kept in mind, such typical trajectory is believed to demonstrate well the benefit of the proposed VDM-based navigation in comparison to INS-based approach.

1.1. Motivation

INS/GNSS (INS-based navigation, in general) is the dominant navigation system for small UAVs today [3, 4]. INS provides autonomous position, velocity, and attitude (PVA) solution with high frequency in a dead reckoning fashion. This PVA solution gets updated in a filter, whenever GNSS observations are available, which normally consists of time, position, and velocity (TPV) solution at a lower frequency. Due to accumulation of errors in INS, the navigation solution drifts when GNSS outage occurs [5, 6, 7]. If this drift, whose rate is directly related to IMU quality, is not controlled by some other means, the UAV gets quickly lost in space [8]. In case of long outages in beyond line of sight (BLOS) flights, large navigation errors may pose dangers to people, animals, or objects on ground. This is one of the reasons why UAV operation of micro aerial vehicle (MAVs) are limited to line of sight (LOS) in most developed countries (e.g., US [9], Canada [10], and a large part of the EU [11]).

1.2. Available solutions

There are mainly two types of attempts to address the problem of rapid drift of navigation solution during GNSS outages; trying to improve INS error modeling using advanced techniques [12, 13, 14], and employing additional sensors to aid the system [15, 16, 17]. Insufficient improvements made by the first approach and added cost and complexity and potential

*Corresponding author

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