A Flight State Estimator that Combines Stereo-Vision, INS, and Satellite Pseudo-Ranges

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Abstract. This paper presents a flight state estimator which couples stereo vision, inertial (INS), and global navigation satellite system (GNSS) data. The navigation filter comes with different operation modes that allow loosely coupled GNSS/INS positioning and, for difficult conditions, improvements using visual odometry and a tighter coupling with GNSS pseudo-range (PSR) data. While camera systems are typically used as an additional relative movement sensor to enable positioning without GNSS for a certain amount of time, the PSR data filtering allows to use satellite navigation also when less than four satellites are available. This makes the filter even more robust against temporary dropouts of the full GNSS solution. The application is the navigation of unmanned aircraft in disaster scenarios which includes flights close to ground in urban or mountainous areas. The filter performance is evaluated with sensor data from unmanned helicopter flight tests where different conditions of the GNSS signal reception are simulated. It is shown that the use of PSR data improves the positioning significantly compared to the dropout when the signals of less than four satellites are available.

1 Introduction

Positioning and navigation with limited satellite reception is one of the current challenges for unmanned vehicles. Global satellite navigation has its known drawbacks such as a varying accuracy due to the satellite constellation, atmospheric errors, or
possible signal interruption and reflection. Unmanned aircraft navigation becomes problematic especially in the proximity of ground objects, for example in flights through urban or natural canyons. Especially such scenarios require abilities to reduce the positioning uncertainty for safe flights without collisions. The combination of satellite navigation (GNSS), such as GPS or the upcoming Galileo system, with inertial systems (INS) is quite common. But the ability to compensate longer satellite signal dropouts depends on the accuracy and drift rates of the INS, and the available technology for small and lightweight unmanned aircraft is presently insufficient [6].

![Fig. 1 DLR’s 13 kg helicopter with a stereo camera, onboard image processing and GNSS/INS navigation filtering](image)

The application context of this paper is low-altitude outdoor exploration flights in disaster scenarios with the unmanned helicopter shown in fig. 1. Since cameras are often on board these vehicles for various applications and their motion can be obtained from image sequences, it is straightforward to use them for improving the navigation solution here as well. The developed solution should be able to be run under difficult conditions and also in unknown areas, this is why the usage of a-priori knowledge from maps as proposed in [11, 14] is not suitable here. With that, only relative movements are determinable from the camera images so that the presented solution will be influenced by accumulating errors as soon as satellite navigation becomes unavailable. Contrary to many other approaches, this paper does not address scaling issues that come with monocular cameras being solved by integrating inertial measurements into the motion estimator [22, 27] which determines the scale with respect to the observed accelerations, or by using additional sensors like a barometer [1] or distance sensors like laser scanners as proposed by [25]. Instead, this approach uses a calibrated stereo camera to determine relative 3D movements and rotations. Similar approaches are used in [10, 13, 16]. However, the developed filter might be further improved by the mentioned related work so that laser scanners, monocular