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Navigation and Guidance System Architectures for Small Unmanned Aircraft Applications

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Abstract : Two multi-sensor system architectures for navigation and guidance of small Unmanned Aircraft (UA) are presented and compared. The main objective of our research is to design a compact, light and relatively inexpensive system capable of providing the required navigation performance in all phases of flight of small UA, with a special focus on precision approach and landing, where Vision Based Navigation (VBN) techniques can be fully exploited in a multisensor integrated architecture. Various existing techniques for VBN are compared and the Appearance-Based Navigation (ABN) approach is selected for implementation. Feature extraction and optical flow techniques are employed to estimate flight parameters such as roll angle, pitch angle, deviation from the runway centreline and body rates. Additionally, we address the possible synergies of VBN, Global Navigation Satellite System (GNSS) and MEMS-IMU (Micro-Electromechanical System Inertial Measurement Unit) sensors, and the use of Aircraft Dynamics Model (ADM) to provide additional information suitable to compensate for the shortcomings of VBN and MEMS-IMU sensors in high-dynamics attitude determination tasks. An Extended Kalman Filter (EKF) is developed to fuse the information provided by the different sensors and to provide estimates of position, velocity and attitude of the UA platform in real-time. The key mathematical models describing the two schemes i.e., VBN-IMU-GNSS (VIG) system and VIG-ADM (VIGA) system are introduced. The first uses VBN at 20 Hz and GNSS at 1 Hz to augment the MEMS-IMU running at 100 Hz. The second mode also includes the ADM (computations performed at 100 Hz) to provide augmentation of the attitude channel. Simulation of these two modes is carried out and the performances of the two schemes are compared in a small UA integration scheme (i.e., AEROSONDE UA platform) exploring a representative cross-section of this UA operational flight envelope, including high dynamics manoeuvres and CAT-I to CAT-III precision approach tasks. Simulation of the first system architecture (i.e., VIG system) shows that the integrated system can reach position, velocity and attitude accuracies compatible with the Required Navigation Performance (RNP) requirements. Simulation of the VIGA system also shows promising results since the achieved attitude accuracy is higher using the VBN-IMU-ADM than using VBN-IMU only. A comparison of VIG and VIGA system is also performed and it shows that the position and attitude accuracy of the proposed VIG and VIGA systems are both compatible with the RNP specified in the various UA flight phases, including precision approach down to CAT-II.

Keywords : Global Navigation Satellite System (GNSS), Low-cost Navigation Sensors, MEMS Inertial Measurement Unit (IMU), Unmanned Aerial Vehicle, Vision Based Navigation
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