Transactions of the Institute of Measurement and Control 33, 6 (2011) pp. 647–649

Editorial: Special issue on Measurement & Estimation for Unmanned Navigation

Measurement and estimation of motion variables is an important feature for autonomous navigation. Since the not-so-distant past, global positioning systems (GPS) and GPS-aided inertial navigation systems (INS) have been the main measurement tools for civil and military unmanned systems. A widely employed technique has been the extended Kalman filter (EKF) for the integration and filtering of GPS and INS data, which serves to remove sensor noises and biases, as well as estimating motion states between GPS updates. While many navigation systems depend almost entirely on the integrity and reliability of GPS data, persistent challenges in this technology are non-linearities and the need to maintain estimation accuracy in the absence of GPS, in order to ensure safe operation of unmanned platforms.

Recent development in unmanned systems has also presented new challenges for measurement and estimation. One of these is that new designs tend toward the use of position- and attitude-only sensors such as gyro-less measurement units, magnetometers for geo-relative attitude measurement, vision-based systems for relative navigation, etc. The underlying reasons may be to overcome reliability problems with gyroscopes, cost reduction, or both. For the purpose of navigation and control, such measurement systems require online estimation of state variables that are unavailable or too costly to measure. For example, estimation of unmeasured velocities and angular rates presents a particularly challenging task, because higher sampling rates are desired but may lead to amplification of measurement noise. Different types of such sensors may also be used together, which calls for efficient and accurate sensor fusion techniques.

In this special issue, three papers are devoted to the problem of filtering for low-cost measurement systems. First, Hong *et al.* present a simple filtering method to suppress short-term broadband noise in low-cost MEMS gyroscopes in mobile robots. At issue is the broadband gyro noise that compromises accuracy in yaw angle determination. Instead of Kalman filtering, Hong proposes a simple two-phase filtering method that consists of a threshold filter and moving-average filter,

 10.1177/0142331209342186

each activated depending on the determined motion type. Interestingly, the method is able to capture fast transient motion. Next, Yun *et al.* study integration of low-cost inertial sensors and GPS to obtain position and navigation signals for a mini unmanned aerial vehicle (UAV). Common problems with these low-cost INS are bias, random noise and scaling errors. To overcome these, through modelling of the non-linear motion and subsequent linearization, the authors present an estimation scheme based on H-infinity filtering. The advantages are that precise knowledge of noise characteristics is not required, and the method is robust against system uncertainties. A third paper by You *et al.* investigates a general problem encountered in low-cost implementations, namely quantization. To minimize estimation error related to quantization, the authors present a multi-level quantized Kalman filter for linear stochastic systems. The paper discusses optimal quantization threshold, robust quantization and shows, in the limiting case of infinite quantization levels, that the quantized Kalman filter in fact approaches the standard Kalman filter.

This special issue also gathers three papers on attitude determination in the absence of a complete GPS/INS sensor suite. Mahony *et al.* propose a simple non-linear observer for attitude estimation based only on inertial measurements with three-axis gyroscopes and accelerometers, and dynamic pressure measurement with a pitot tube. The observer is based on the full non-linear motion model (with attitude in quaternion representation), and additional models of gravity and angle-of-attack dynamics. Closely related to the latter is the paper by Palanthandalam-Madapusi *et al.*, which studies wind field reconstruction in the absence of unknown wind disturbance. For a UAV in planar flight, the authors assume the available of position and airspeed measurements, and consider two cases where the heading angle is known on the one hand, and unknown on the other hand. Particularly, for the second case, which is non-linear in the unknowns, the authors propose an extension of the unscented Kalman filter. A third paper on attitude determination, by Zhang *et al.*, considers a different technology, namely vision-based horizon recognition. Motivated by their observation that the horizon projection using Hough transform is not robust, the authors present three new indicators of projection peaks, based on which they propose an adaptive recognition algorithm that allows real-time computation.

Finally, the paper by Jagadish and Chang presents an interesting approach for computing Euler angles using vectorial measurements of Earth's gravity and magnetic field relative to the body of a vehicle. By a combination of 25 different ways of calculating the same Euler angles, the approach offers what the authors call 'diversified redundancy', which renders the computation tolerant to faults or extraneous perturbations in some sensing axes. The insight provided in this paper is relevant to attitude measurement for UAVs where fault tolerance is an important consideration.

There are other issues related to unmanned navigation not covered in this special issue, eg, tracking of manoeuvring targets, anti-spoofing for GPS, urban navigation, etc. While they are beyond the present scope, these and many other topics are certainly worth continual attention and future discussion.

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