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In-flight Initial Alignment for Small UAV MEMS-based Navigation via Adaptive Unscented Kalman Filtering approach

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Abstract:

In this paper, an adaptive unscented Kalman filter for UAV's MEMS-based navigation is derived to realize in-flight initial alignment aided by GNSS (global navigation satellite system) and fulfil data fusion. In the filter, unscented transformation is used to handle strong INS (Inertial Navigation System) model nonlinearity under large misalignment condition due to large and sudden maneuvers, and the technique of optimal adaptive factor is used to resist the influence of noise uncertainty of MIMU (MEMS-based Inertial Measurement Unit) and kinematic model errors. The flight test results indicate the proposed alignment algorithm can complete the initial alignment more quickly and accurately compared with the conventional EKF/UKF-based in-motion alignment approaches, especially when the initial attitude errors are large. As a unified in-flight alignment, it can guarantee the accurate and reliable alignment in situations of either large or small initial attitude errors without model changes for small UAV applications.

Keywords: Low-cost MIMU; In-flight Alignment; Robust Adaptive Filtering; UKF; Unmanned Aerial Vehicle (UAV)

Nomenclature

$\boldsymbol{r}$	:position vector, $[r_x,r_y,r_z]^T$
$\boldsymbol{v}$	:velocity vector, $[v_x,v_y,v_z]^T$
$\mathbf{q}_b^n$	:unit attitude quaternion from n-frame to b-frame, which corresponds to direction cosine matrix C_b^n or Euler angles, $[q_0,q_1,q_2,q_3]^T$
$\boldsymbol{f}^a$	:specific force referenced in a-frame
$\boldsymbol{\omega}_{ab}^c$	:angular rate between a-frame and b-frame resolved in c-frame
$\boldsymbol{g}^a$	:gravity referenced in a-frame
$\boldsymbol{C}_n^b$	:transformation matrix from n-frame to b-frame of a vector
$\delta\boldsymbol{\omega}_{ib}^b$, $\delta\boldsymbol{f}^b$	:gyroscope and accelerometer output error in body frame, modeled as a Gauss-Markov process with correlation time T_{gb} and T_{ab}, driven by white noise $\boldsymbol{w}_{gb}$ and $\boldsymbol{w}_{ab}$
$\boldsymbol{x}$	:non-augmented system state vector, i.e. $\boldsymbol{x}(t)=[\varphi,\lambda,h,v_N,v_E,v_D,q_1,q_2,q_3,q_4,\delta\omega_X,\delta\omega_Y,\delta\omega_Z,\delta f_X,\delta f_Y,\delta f_Z]^T$
$\boldsymbol{w}$	:system noise with the terms of random walk, white noise and bias instability, i.e. $\boldsymbol{w}(t)=[w_{Vx},w_{Vy},w_{Vz},w_{\Psi x},w_{\Psi y},w_{\Psi z},w_{gbx},w_{gby},w_{gbz},w_{abx},w_{aby},w_{abz}]^T$, with covariance matrix $E\left[\boldsymbol{w}_k\boldsymbol{w}_i^T\right]=\boldsymbol{Q}\delta_{ki}$
$\boldsymbol{x}^a$	:augmented system state vector considering the non-additive noise, i.e. $\boldsymbol{x}^a(t)=[\boldsymbol{x}(t)^T,\boldsymbol{w}(t)^T]^T$
$\boldsymbol{Z}_k$	:system observation at epoch t_k
$\boldsymbol{v}_k$	:observation noise with covariance matrix $E\left[\boldsymbol{v}_k\boldsymbol{v}_j^T\right]=\boldsymbol{R}\delta_{kj}$
ℓ_G^b	:lever-arm vector from MIMU center to GNSS antenna center in body frame
$f(\bullet)$, $h(\bullet)$	:nonlinear system kinematic function and observation function, which can be approximated as $f_{k-1}(\bullet)$ and $h_{k-1}(\bullet)$ during the interval $[t_{k-1},t_k)$
$\boldsymbol{x}^-$, $\boldsymbol{P}^-$	:a priori state estimates and estimation-error covariance (non-augmented)
$\boldsymbol{x}^+$, $\boldsymbol{P}^+$	:a posteriori state estimates and estimation-error covariance (non-augmented)

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