Lightweight Detection of Abrupt Orientation Changes Using a 6-Axis IMU

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Abstract

This work investigates simple yet robust algorithms for long-term monitoring of mast orientation using the ST ISM330DHCX inertial measurement unit. We focus on KISS-principle solutions that (i) track azimuth and altitude, (ii) ignore slow drift, and (iii) reliably detect abrupt orientation changes under outdoor noise.

1 Introduction

Brief context of mast monitoring, device configuration (WDS axis), and problem statement.

2 Related Work

Short survey of complementary filters, Kalman filtering, threshold-based detectors, adaptive drift compensation.

3 Methodology

3.1 Mathematical Model

The raw accelerometer output $\mathbf{a}_m \in \mathbb{R}^3$ and gyroscope output $\boldsymbol{\omega}_m$ are modeled as

$$\mathbf{a}_m = \mathbf{R}^T(\mathbf{g}) + \mathbf{b}_a + \boldsymbol{\eta}_a, \tag{1}$$

$$\boldsymbol{\omega}_m = \boldsymbol{\omega} + \mathbf{b}_g + \boldsymbol{\eta}_g, \tag{2}$$

where $\mathbf{R}$ is the body-to-world rotation, $\mathbf{g} = [0, 0, g]^T$, $\mathbf{b}_a, \mathbf{b}_g$ are constant biases and $\boldsymbol{\eta}_{(\cdot)} \sim \mathcal{N}(0, \sigma^2)$ are white noises.

Pitch (θ) and roll (ϕ) are extracted from the low–pass accelerometer tilt:

$$\theta = \operatorname{atan2}\Big(-a_x, \sqrt{a_y^2 + a_z^2}\Big), \tag{3}$$

$$\phi = \operatorname{atan2}(a_y, a_z). \tag{4}$$

A first–order complementary filter fuses the gyro integration with the accelerometer tilt,

$$\phi_k = \alpha\big(\phi_{k-1} + \omega_x\,\Delta t\big) + (1-\alpha)\,\phi_k^{\mathrm{acc}}, \tag{5}$$

$$\theta_k = \alpha\big(\theta_{k-1} + \omega_y\,\Delta t\big) + (1-\alpha)\,\theta_k^{\mathrm{acc}}, \tag{6}$$

with $\alpha = 0.98$.

Abrupt changes are detected by comparing the current filtered orientation to an adaptive baseline mean $\bar{\phi}, \bar{\theta}$ over a $2\,exts$ sliding window. A detection flag d_k is raised when

$$|\phi_k - \bar{\phi}_k| > \tau \quad \text{or} \quad |\theta_k - \bar{\theta}_k| > \tau, \tag{7}$$

where $\tau = 5^\circ$ (tunable).

3.2 Proposed Algorithm

Algorithm **??** summarises the procedure.

3.3 Evaluation Metrics

Detection latency, false positives, energy cost.

4 Results

Table **??** summarises the prototype performance over 30 Monte–Carlo trials (sensor noise $\sigma_{\mathrm{acc}} = 50\,\mathrm{mg}$, $\sigma_\omega = 20\,\mathrm{dps}$, detection threshold 5°).

Metric	Value
Detection rate	$100\,\%$
Mean latency	$0.03\,\mathrm{s}$
Median false positives	$\mathcal{O}(2.4 \times 10^4)\,/\mathrm{h}$

Table 1: Baseline complementary–filter detector performance. Raising the threshold to 10° lowered false positives below $20\,/\mathrm{h}$ while maintaining a $> 95\,\%$ detection rate.

5 Discussion

Analysis of trade-offs, recommended threshold selection, calibration procedure, long-term stability.

Algorithm 1 Lightweight long-term orientation change detector (matching C++ implementation)

Input: stream $\mathbf{a}_m[k]$, $\boldsymbol{\omega}_m[k]$ at f_s Hz
Parameters: α (filter gain), window $N = f_s T$ samples, threshold τ
State: orientation ϕ, θ, circular buffers Q_ϕ, Q_θ, running sums S_ϕ, S_θ
Initialise $(\phi, \theta) \leftarrow \textsc{TiltFromAcc}(\mathbf{a}_m[0])$ ▷ static calibration
for $k \leftarrow 1, 2, \ldots$ **do** ▷ 1) Complementary filter
    $(\phi^{\mathrm{acc}}, \theta^{\mathrm{acc}}) \leftarrow \textsc{TiltFromAcc}(\mathbf{a}_m[k])$
    $\phi \leftarrow \alpha\big(\phi + \omega_x \Delta t\big) + (1-\alpha)\phi^{\mathrm{acc}}$
    $\theta \leftarrow \alpha\big(\theta + \omega_y \Delta t\big) + (1-\alpha)\theta^{\mathrm{acc}}$ ▷ 2) Update baseline mean for ϕ
    push ϕ to Q_ϕ; $S_\phi \leftarrow S_\phi + \phi$
    if $|Q_\phi| > N$ **then** $S_\phi \leftarrow S_\phi - \mathrm{pop\_front}(Q_\phi)$
    end if
    $\bar{\phi} \leftarrow S_\phi / |Q_\phi|$ ▷ 3) Update baseline mean for θ
    push θ to Q_θ; $S_\theta \leftarrow S_\theta + \theta$
    if $|Q_\theta| > N$ **then** $S_\theta \leftarrow S_\theta - \mathrm{pop\_front}(Q_\theta)$
    end if
    $\bar{\theta} \leftarrow S_\theta / |Q_\theta|$ ▷ 4) Threshold test
    $d_k \leftarrow (|\phi - \bar{\phi}| > \tau) \vee (|\theta - \bar{\theta}| > \tau)$
    if d_k **then**
        start validation timer and alarm if condition persists
    end if
end for

6 Conclusion

Key findings and future work.