SRS Presentation

Attitude Check:
An IMU-based Attitude Estimator

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Introduction

- Many robotics and aerospace applications require knowledge of their attitude (orientation)
- Inertial Measurement Units (IMUs) are popular measurement devices, but can add noise and bias to the signal
- Attitude estimation aims to find the orientation relative to a reference frame

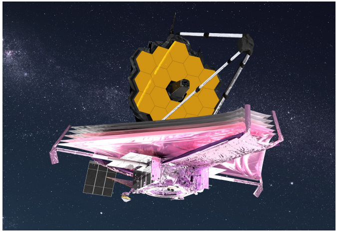

Figure 1: NASA's James Webb Telescope.

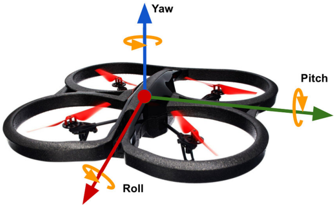

Figure 2: Quadcopter with labelled Euler angles.

Reference Material

Table 1: Table of Units

symbol	unit	SI
m	length	metre
rad	angle	radian
s	time	second
Hz	frequency	hertz
T	magnetic field	tesla

Table 2: Table of Symbols

symbol	unit	description
v	m/s	linear velocity
a	m/s^2	linear acceleration
ω	rad/s	angular velocity
g_0	m/s^2	gravitational constant
b	T	earth's magnetic field

- Current state of the reference tables.
- Must be careful, in the literature, v, represents a vector of $[x, y, z]$, and v is velocity, and $\mathbf{v}$ is the velocity vector.

Introduction - Scope and Reader

Scope of Requirements

- Dynamics models of this project will only consider a flat local earth, and the effect of the Earth's rotation will be ignored.
- MEMS sensor modelling, we will simplify the measurement error characteristics. Additionally, we will assume there are no local magnetometer disturbances.
- The IMU is assumed to be mounted to a rigid body, the IMU orientation will be the orientation of the object it is attached to.
- All measurements are assumed to be in the range of the sensors.

Characteristics of Intended Reader

The reader should have an understanding of university-level math including matrix and vector operations, numerical methods, and state estimation.

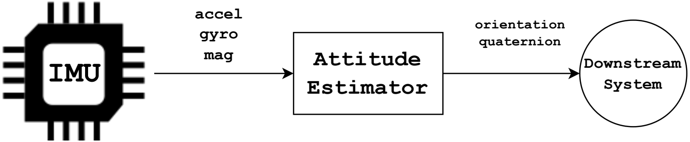

Figure 3: System Context

- User Responsibilities:
  - Provide IMU measurements.
- Attitude Check Responsibilities:
  - Detect data type mismatch, such as a string of characters instead of a floating point number.
  - Return orientation value for each set of measurements.

User Characteristics

- High-school kinematics.
- Understand what attitude estimation is, and has an expectation of the inputs and outputs.
- Designed for users looking to process IMU data.

System Constraints

Attitude Check is often ported to microcontrollers or used in high performance applications. It should be implemented in C or C++ to be integrated into existing projects.

Specific System Description

Problem Description

Attitude Check is intended to estimate the attitude of an IMU sensor, given noisy measurements.

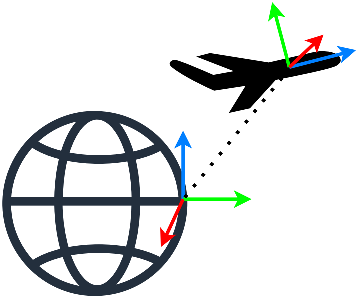

Figure 4: Physical System

Specific System Description

Physical System and Goals

Physical System Description

- PS1: Problem Domain is $\mathbb{R}^n$, where $n = \{2, 3\}$ (Sometimes Yaw angle can be ignored).
- PS2a: Gravitational Acceleration.
- PS2b: Earth's Magnetic Field/Force.
- PS2c: Gyroscopic effect: Rigidity in space and Precession.
- PS3: All rigid body transformations reside in the special Euclidean group, SE(3).
- PS4: Initial conditions: Initial orientation value.

Goal Statements

GS1: Convert sequential IMU measurements into an orientation relative to the Earth.

Specific System Description

Theoretical Models

TM1a: Attitude parameterization (quaternion): $\mathbf{q} = w + xi + yj + zk$.
TM1b: Attitude parameterization (Rotation Matrix): $\mathbf{R} \in \mathbb{R}^{3\times3}$.
TM1b: Attitude parameterization (Euler Angles): Roll, pitch, yaw.

TM2: World Magnetic Model: North East and Down (NED).

TM3a: Magnetometer measurement model: $\mathbf{m} = \mathbf{R}^T\mathbf{h} + \mathbf{B}_m + \mu_m \in \mathbb{R}^3$.
TM3b: Accelerometer measurement model: $\mathbf{a} = \mathbf{R}^T(\dot{\mathbf{v}} - g_0) + \mu_a \in \mathbb{R}^3$.
TM3c: Gyroscope measurement model: $\Omega_y = \Omega + b_g + \mu_g \in \mathbb{R}^3$.

TM4a: Kinematic Model (Rotation matrix): $\dot{\mathbf{R}} = \mathbf{R}\lfloor\Omega\rfloor_\times$.
TM4b: Kinematic Model (quaternion): $\dot{\mathbf{q}} = \frac{1}{2}\mathbf{q}\mathbf{p}(\Omega)$.

TM5: Non-linear filtering - Equations depends on the selected solution:

- Extended Kalman Filter (EKF)
- Nonlinear Complementary Filter (Mahony Filter)
- Madgwick Filter

The End

Questions?