ROCO503 IMU Report

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# Introduction:

This report details solutions to the tasks set out in the “ROCO503 IMU Coursework 2017-18” document.  
Each task is broken down into four sections:

* Problem statement – Outlines the task boundaries and interpretation
* Hypothesis – Provides a theoretical assessment of the problem and the expected results of the task
* Methodology – Details the step-by-step procedures performed to collect the data for analysis
* Results – Assesses the collected data, comparing and contrasting where appropriate

Finally, the report is concluded with a summary of the tasks performed by each team member, and a brief overview of what has been accomplished.

# Task 1: Noise Analysis

## Problem Statement:

* Quantification of noise present within the Phidget 21 Spatial 1044 along all 3 axes for the accelerometer and gyroscope sensors.
* Identification of dominant frequency bands causing aforementioned noise.
* Demonstrate the effects of filtering with respect to dead-reckoned positional data, contrasting against the stationary ground truth.

## Hypothesis:

### Theoretical Assessment:

MEMS accelerometers and MEMS gyroscopes are subject to various sources of error. A non-exhaustive list of such errors being:

* Manufacturing quality, manifesting as systematic errors such as a DC bias; non-uniform scaling between sensors; non-linearity in measurements and susceptibility to other error sources
* Flicker noise, or bias random walk, acting as a low frequency component
* Thermo-mechanical white noise, providing high frequency components
* Temperature & pressure, causing numerous mechanical, geometrical and fluid dynamic properties to change; can be represented as a DC or low frequency offset, and modelled as a polynomial function
* Power supply noise can cause artefacts in the signal across the frequency spectrum; depending on the severity, such as electro-static discharges or power surges, it may also cause damage to the sensor
* The Earth, causing effects such as a DC offset within gyroscope as the Earth’s rotation is measured; scaling issues across large distances due to the non-uniform gravitational pull; additional noise depending on how much cosmic radiation is absorbed by the atmosphere or focussed by the Earth’s magnetic field

The IMU used for these experiments also happens to be a digital IMU, meaning the data has been discretised. This results in two more sources of error, specifically the quantisation error of the signal and the quantisation error of the timestamp for that signal.

### Null Hypotheses:

* Dead-reckoned position and orientation will closely match the ground truth over a period of 2 minutes
* The frequency response for a stationary system will comprise solely of low frequency or DC components within all three axes for both the accelerometer and gyroscope sensors
* Filtering the raw data will provide no significant improvement in system performance

## Methodology:

## Results:

# Task 2: Filtering Effects

## Problem Statement:

* Observe differences in dead-reckoned positional data with respect to known motion patterns, specifically:
  + Pendulum motion with known mass and length
  + Vertical motion up and down, aided with a pulley system
  + Z-based motion along a horizontal plane, aided with a smooth table
* Compare and contrast aforementioned positional data for filtered and unfiltered datasets

## Hypothesis:

### Theoretical Assessment:

Task 1 provided insight into how noise filtering affects system reliability for a stationary setup. However, IMU’s are often used for mobile systems, such as within smartphones and other such tracking devices. To begin assessing the efficacy of the filters it is necessary to analyse the system for constrained motions.

Each of the three motions provides a test bed for approximating the direction of gravity. When averaged over a large enough timeframe, all three setups can be modelled as a stationary point. As such, when compared the frequency responses to task one, any additional frequency components will be related to desirable motion to be detected.

### Null Hypotheses:

* For a time period of 2 minutes, averaged gyroscope and accelerometer data will not be similar to the stationary setup
* Dead-reckoned data with filtering will show no significant difference when compared to dead-reckoned data without filtering

## Methodology:

## Results:

# Task 3: Comparison with Ground Truth Data

## Problem Statement:

* Perform Task 2 measurements again whilst capturing ground truth data
* Compare and contrast dead-reckoned positional data for filtered and ground-truth datasets

## Hypothesis:

### Theoretical Assessment:

Task 2 provided an assessment of the noise characteristics within a moving system, and a comparison of the effects filtering has on the dead-reckoned data. However, it is difficult to properly assess that data without also having a ground-truth to compare against. From this it is possible to determine the rate of change of system error over time.

### Null Hypotheses:

* The system error for the dead reckoned data is negligible
* The system error will either stay the same or decrease over time

## Methodology:

## Results:

# Task 4: Complementary Filter

## Problem Statement:

* Implement a complimentary filter as set out in the coursework specification document
* Perform Task 3 measurements again with application of the complementary filter
* Compare and contrast dead-reckoned positional data for filtered; complementary filtered and ground-truth datasets

## Hypothesis:

### Theoretical Assessment:

It is well known that gyroscopes suffer from significant bias drift, or angle random walk, over time. These artefacts are typically low frequency, however. Accelerometers on the other hand are very sensitive to sudden movements, whilst being under the constant influence of gravity. Both sensor sets can also provide a measure of the IMU’s orientation, with the notable exception of rotations about the z-axis (yaw) for the accelerometer datum.

Thus, a sensor fusion between the low-frequency components of the accelerometers measure, and high frequency components of the gyroscopes measure, can provide an overall more accurate representation of the IMU’s orientation. This allows for an improved separation of the gravity component and, hence, improved system performance.

### Null Hypothesis:

* The complementary filter will show no significant improvement in the system error or its rate of change

## Methodology:

## Results:

# Task 5: Extended Assessments

## Problem Statement:

* Assess the performance of the system for dead-reckoning the position of the IMU in real time:
  + In 3D space, aka not limited to axial or planar movements
  + Over larger distances
  + Under variable IMU orientation
* Assess efficacy of alternative complementary filter setups

## Hypothesis:

### Theoretical Assessment:

The previous tasks have honed in towards an optimal system setup for dead reckoning with the IMU. However, previous experiments have been limited to point, axial or planar motion, over a limited range of translations and orientations. To more fully test the capabilities of the system experiments over larger distances, varying orientations and compounded motions in 3D space.

### Null Hypotheses:

* The system will not be able to reliably dead-reckon under varying orientations for any extended period of time
* The system will not be able to reliably dead-reckon over large distances for any extended period of time
* The system will not be able to reliably dead-reckon in a volumetric, 3D space for any extended period of time

## Methodology:

## Results:

# Conclusion: