HIGH FIVE: A First Step Towards Getting Robotic Manipulators Into the Air

(Hybrid Intrinsic Extrinsic Calibration of Multiple IMUs and Joint Encoders on a Robotic Manipulator)

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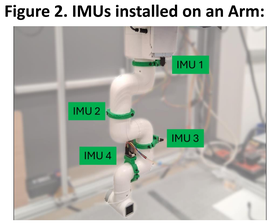
Introduction

- **Robotic Manipulators** are actively being used to create a **flying vehicle** that can **interact** with its environment **(UAM)**:

Figure 1. Robotic Arm on a UAM (Concept):

Figure 2. IMUs installed on an Arm:



- **IMUs** can used to find the **position** of the arm while it is in the air**,** however **current calibration methods** are **tedious** and **expensive**

A new method is needed for calibration!

Problem

- IMUs can be used on an arm to accurately capture its motion, however **IMUs must always be calibrated…**

- **Calibration of the IMUs** is usually a solved problem, however the method that currently exists has **3 main problems**:

1. It requires expensive equipment (**inaccessible**)
2. It necessitates each IMU be taken off (**cannot be done in-place**)
3. It must be done before each use (**tedious and repetitive**)

- As such, this **research focused on** creating an intuitive method to **calibrating the IMUs** both **intrinsically and extrinsically** such that it is:

Accessible, Done in-place and Easy to Preform!

Method

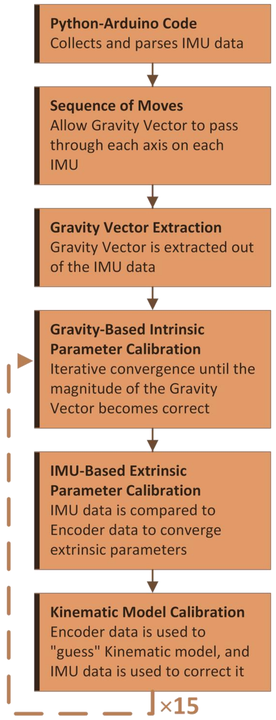
To fully **calibrate the IMUs on an arm**, and to allow for a seamless integration of the data they provide, they must be calibrated both **intrinsically and extrinsically**:

- ***Intrinsic Calibration:*** Calibrate the bias, scale factor, misalignment and non-orthogonality within the sensor itself

- ***Extrinsic Calibration:*** Calibrate the position and orientation of the IMUs with respect to the encoders

To negate the need for an expensive, external calibration device, the **following method was developed to calibrate the IMUs while they are on the arm itself**:

Flow Chart 1. Method of In Place Calibration:



Observability issues were found, meaning that **some parameters could not converge** due to the **arm's motion restrictions**.

However, **three solutions were found**:

- The **arm is unable to move** in that way due to its own physical limits, so those **parameters are not needed anyways**

- **Convergence can be reached** with multiple **iterations of the calibration** (**~15 times**)

- For drone flight, the **drone motion enables the missing degrees of freedom**, so all **parameters can be successfully calibrated**!

A great method was found and was accessible, done in place and easy-to-use!

Results

- It was found that the **IMUs can be calibrated in-place using the Gravity Vector** and a sequence of moves which **allows all axes on each IMU to sense it**

- Although **some parameters in each IMU cannot be calibrated**, these parameters are **never used** because the arm **is incapable of moving in that way**; once that **degree of freedom is available** (like on a drone or when moving the Test Rig), the **IMUs can be calibrated with the same method**

- The **calibration worked both intrinsically and extrinsically**, and these calibrations were **verified by** the **convergence of the internal IMU parameters and the URDF convergence**, respectively

- **This research is extremely monumental** as it allows for the calibration of IMUs in the direction of movement, allowing a **quicker, cheaper and more intuitive alternative to the usual method!**

Table 1. Kinematic Error $(^\circ/s)$ using different levels of IMU Calibration:

Method	IMU 1 (kinematic error $(^\circ/s)$)	IMU 2 (kinematic error $(^\circ/s)$)	IMU 3 (kinematic error $(^\circ/s)$)	IMU 4 (kinematic error $(^\circ/s)$)
Without IMU Calibration	51.53	62.63	67.52	73.18
Extrinsic Calibration Only	4.06	5.23	5.84	6.91
Intrinsic + Extrinsic Calibration	3.74	5.14	5.71	6.89

Table 1. reveals the **improving error levels of the IMU readings** as **calibration increase**.

The uncalibrated IMUs are unable to be used, however **intrinsic + extrinsic** calibration heavily **improves their accuracy**.

The **fully calibrated IMUs** display a ***10x reduction*** in kinematic error!

Figure 3. Gyroscope vs IMU Readings of Movement about the Z-Axis:

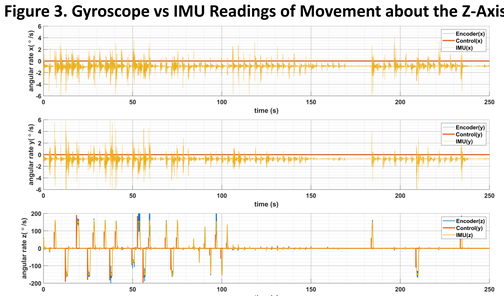


Figure 2. reveals the **advantage of using a calibrated IMU** over pure encoder readings, showing much **more accurately captured motion in the X, Y and Z axes.**

This **research proved extremely valuable** and enables **much more advanced testing** in the field of UAM dynamics and control and beyond!

The results were exceptional and what we had hoped for!

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