A Simple Method for Synchronising Multiple IMUs using the Magnetometer

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ABSTRACT

This paper presents a novel method to synchronise multiple IMU (inertial measurement units) devices using their onboard magnetometers. The method described uses an external electromagnetic pulse to create a known event measured by the magnetometer of multiple IMUs and in turn used to synchronise these devices. The method is applied to 4 IMU devices decreasing their de-synchronisation from 270ms when using only the RTC (real time clock) to 40ms over a 1 hour recording. It is proposed that this can be further improved to approximately 3ms by increasing the magnetometer's sample frequency from 25Hz to 300Hz.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**.

KEYWORDS

imu; wearable; sensors; synchronisation; magnetometer

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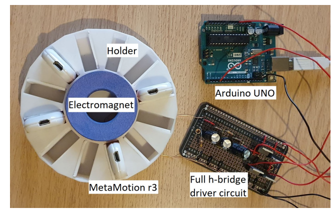

Figure 1: Experimental setup

1 INTRODUCTION

In the last decade there has been a huge growth in applications for IMU-enabled wearable and IOT devices. Applications stretch from early work in human activity recognition [2] to studies measuring the cohesiveness of social interaction [10]. Many such applications require precise synchronisation between separate IMU devices.

Most commercial IMUs include an on-board real-time clock (RTC). Unfortunately, the precision synchrony of an RTC is dependent on the length of the recording, meaning it is not a viable option for longer experiments.

Efforts to overcome the synchronisation problem can be grouped into three categories: network-based, event/gesture-based, or a combination. Much work has been done using Network Time Protocol (NTP) [5, 8, 11] and Precision Time Protocol (PTP) [4] for time synchrony in IoT, however such protocols have been proven to be noisy with errors exceeding 1800ms or impractical for common mobile sensing task [6]. Moreover, most commercial IMU devices do not have network options requiring external network chips to be included. One solution is to use sync events within the data itself, creating a common signal across different sensors and sensor types to facilitate temporal alignment. Kinetic events are most commonly used requiring the experimenter or participant to make a predefined movement, such as clap or hit the table [1, 7–10], or even tap the ear [3]. These kinetic-based events can be disruptive often requiring the subjects to stop what they are doing to perform an action or even in some cases transfer their wearable sensors to holders. The method proposed by this paper would minimise these disruptions and replace them with a wireless solution that requires no new hardware to be added to the commercial IMU devices.

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2 METHOD

A simple electromagnetic pulse generator (EMPG) was built by attaching an electromagnet to an Arduino UNO via a full h-bridge, see fig 1. This EMPG was configured to transmit a 4 period length pulse at 0.5Hz. The electromagnet at 2W has a magnetic field strength of 0.2μT at 11cm. Below 0.2μT the magnetometer fails to measure the pulses giving an active range of 11cm.

Four MetaMotion R3 modules, from Mbientlabs Inc, USA, were setup using an iPad. Each module was configured to logging mode. The accelerometer, gyroscope and magnetometer were activated to record at $25Hz$. The gyroscope was set to $\pm 1600\ ^{\circ}/s$. The accelerometer was set to $\pm 16gs$. The magnetometer's resolution is fixed at $\pm 1300\mu T$. The modules were placed in a holder, see fig 1. The holder is required for the kinetic event; for the EMP event the sensors are only required to be within the active range of the EMPG, removing the time consuming process of securing the devices in the holder.

Two synchronising events were generated at the start and end of the recording. A 4 period-length electromagnetic pulse (EMP) event was generated using the EMPG. A kinetic event as described in [10] was then completed by swiftly lifting and slamming the holder. The devices were then worn by the experimenter for approximately 1 hour of arbitrary movement. Afterwards the devices were returned to the holder and the EMP and kinetic events repeated.

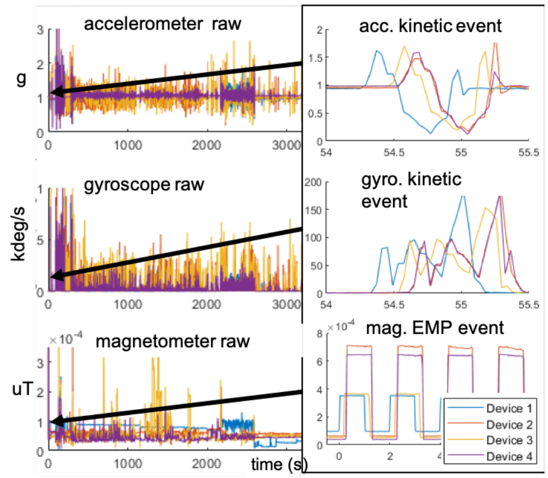

Figure 2: IMU magnitude data highlighting sync. events.

Table 1: Offsets and drift before synchronisation

(Vs. device 1)	1^{st} offset (ms)	2^{nd} offset (ms)	Drift (ppm)
Device 2	270	14	59.949
Device 3	170	19	40.00357
Device 4	260	100	42.5381

The raw 3-axis accelerometer, gyroscope, and magnetometer data of the devices were uploaded to be processed in MATLAB. The magnitude of each sensor was calculated and plotted against epoch time, as determined from the onboard RTC. The IMU amplitude data for the 4 devices are shown in fig 2 with the first kinetic and EMP events magnified.

The rising and falling edges of the EMP events were used to align the plots manually (as done previously using kinetic events [1]). The 1^{st} EMP event was aligned by translating the plots. Both events were then aligned by scaling the plots (pivoted on the 1^{st}).

3 RESULTS

We first report the timings for the two events using the RTC. Table 1 shows the offsets for 1^{st} and 2^{nd} events, alongside clock drift, in parts-per-million (ppm). Note that the offsets are greater at the beginning of the recording than at the end due to the RTC synchronisation being done on the last measurement and computed backwards.

Using these offsets and clock drifts, the EMP events are manually synchronised. Fig 3 shows the EMP events for accelerometer and magnetometer before and after EMP synchronisation.

4 DISCUSSION OF RESULTS

After EMP synchronisation, the offset measured by the kinetic event in most cases is indistinguishable (<3ms). However, device 1 has an offset of 37ms in the first synchronisation window (as visible in the top right kinetic plot of fig 3). The sampling frequency of the magnetometer is the limitation here. With a sample frequency of 25Hz, a precision of around 40ms is expected. In the case of the MetaMotion R3 the magnetometer can be configured to sample up to 300Hz giving a potential precision of approximately 3ms.

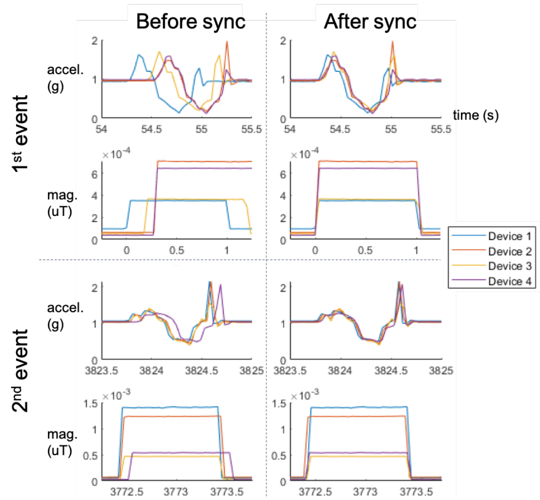

Figure 3: First and second kinetic (accel.) and EMP (mag.) event windows before and after synchronisation.

Note that because there is no ideal ground truth for the timings, all results are calculated using distinguishable features in the data. One of the limitations on using kinetic events is that the signals have slight variations due to noise and micro-vibrations, thus making precise alignment challenging.

Excluding the amplitude of the EMP event, the shape across the four devices is relatively consistent with defined rising and falling edges. These defined edges remove the ambiguity associated with aligning a kinetic event [1].

Because the shape and frequency of the EMP sequence is user-defined, it can be configured to provide additional information, such as unique identifiers to differentiate separate experiments or repeated sync events.

The RTC crystal has a precision of approximately 40ppm, so as the epoch time moves away from the RTC synchronisation point the offset error increases. However, the drift between device 1 and 2 of 60ppm is unexpected, potentially indicating a bad crystal oscillator.

5 CONCLUSION

An EMP-based method to synchronise multiple IMU devices to a precision of 40ms has been described. Unlike the standard method of using only the RTC this method's precision is not proportional to the length of the recordings but instead the sample frequency of the magnetometer.

The method offers a minimally-disruptive approach to create events in the measurements without requiring any retrospective changes to the IMU devices meaning this approach can be accomplished with any commercial IMU device which includes a magnetometer sensor.

Future work will include extending the range of the EMPG, implementing automatic aligning of the synchronisation points and running further tests in a number of working environments.

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