Mobility Characterisation Using Wearable Inertial Sensors

Characterisation of Errors and Noises in Wearable Devices

Megan Kendall*^ and Tecla Bonci*
*Department of Mechanical Engineering, University of Sheffield
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Background

Mobility, medically defined as the '…quality or state of being mobile or movable.' [1], is considered a key health indicator. Reduced walking speed is associated with higher rates of morbidity, mortality, cognitive decline, dementia and falls. Hence, the ability to quantitatively assess mobility could enhance understanding about the development, progression and treatment of conditions which affect mobility e.g. Multiple Sclerosis (MS), Parkinson's Disease and Sarcopenia. For example, 70% of people living with MS report walking difficulties as the greatest challenge of their condition [2]. The Mobilise-D project, of which this work was a part, aims to provide a '…comprehensive system to monitor and evaluate people's gait based on digital technologies.' [3].

Inertial measurements units are wearable devices used for characterising mobility which conventionally comprise an accelerometer, gyroscope and magnetometer (all 3-axis). Microelectromechanical system (MEMS) forms of these sensor units, which exploit emerging microelectronic integrated circuit (IC) and micromachining technologies, are favoured in biomedical applications for their compactness, lightness, low cost and low energy consumption.

Methods

- Sensor errors and noises were investigated based on calibration-like recordings (see Table 1) and a 3D Sensor Model for the accelerometer and gyroscope and a spherical magnetic field mathematical model for the magnetometer.
- An existing code, developed in MATLAB, for metrological characterisation, extracted the relevant information, from a series of static and dynamic calibration tests, to evaluate the primary errors.
- For multiple sensors ('DynaPorts') at 5 research centres, a visual check was performed on the code's graphical output to assess the impact of noise on the calibration tests.
- Improvements, changes and functions were made to improve the validity and reproducibility of the code.

Test Title	Description of Test
Long Static Acquisition	DynaPort placed on flat surface for 7-day data collection period.
2-minute Static Acquisition	For all 3 axes, DynaPort placed on flat surface for 2-minute data collection period. Each axis orientated parallel and anti-parallel to the direction of gravity., resulting in a 6-point calibration procedure.
3-minute Rotation on Record Player	For each axis, DynaPort rotated at a constant angular velocity around that axis for a 3-minute data collection period. Additionally, one stationary 3-minute collection period.
Rotation of the DynaPort	For all 3 axes, rotation of the IMU through 360, from a stationary position of alignment with the direction of gravity
3D Sphere	1-minute 3D rotation of IMU in magnetically clean environment

Table 1: Description of calibration-like recordings analysed by the Metrological Characterisation code

Results

- For the 'Rotation of the DynaPort' test, it was observed that a lower noise level was more easily obtained when rotation was performed about the axis perpendicular to the reference surface.
- Procedural error and nuance were cited as the most likely sources of unexpected or absent signals i.e. the presence, or lack thereof, only 3 rotation signals around 3 different axes (see Figure 2). A function was created to check for these issues and notify the user.
- For the '3D Sphere' test, the start and end of the test period was usually correctly identified but the corresponding start and stop lines were often inappropriately placed in y (see Figure 3). The initially arbitrarily set vertical range was replaced with a generalised algorithm designed to assign appropriate values of vertical amplitude and placement based on the minimum, maximum and equilibrium values of the specific data set.
- For the '2- minute Static Acquisition' test, the primary issue was the failure of the algorithm to correctly identify DynaPort motion either due to missed peaks or misidentification of noise as a peak. A potential solution was offered using the maximum amplitude within the expected test region to exclude the regions where signals with higher magnitude were observed (see Figure 4). However, data sets with very high true peaks within the test region are more liable to exclude true peaks therefore a manual solution was proposed using MATLAB's *ginput* function.
- A new function and script was written to save and graphically collate the statistical output of the metrological characterization code.
- Based on the statistical output, the test procedure with the best reproducibility was identified as the '3D Sphere' test and the most successful test centre was also identified as an example of good procedural practice.

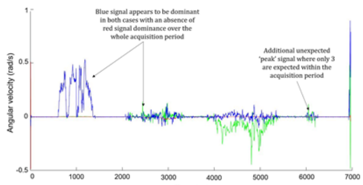

Figure 2: Combined example of the assumed mis-performance of the test procedure generating a) the wrong number of rotation signals and b) 1 rotation around one axis and 2 rotations around the same axis rather than 3 rotations around 3 different axes

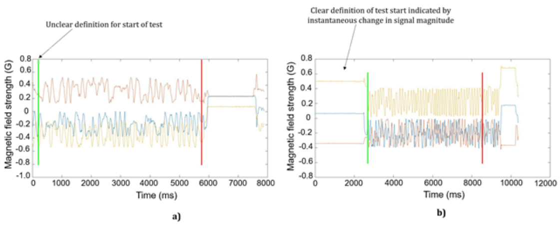

Figure 3: a) Example of amplitude and vertical placement of start and stop lines for the 3D Magnetometer Sphere test b) Improvement achieved through action new generalised algorithm on same data set

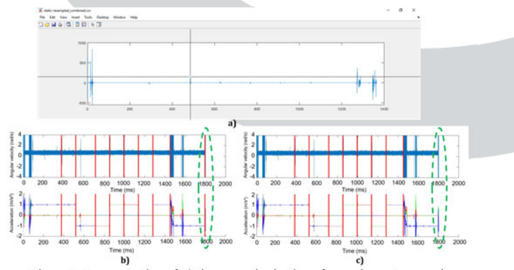

Figure 4: Demonstration of a) The manual selection of a maximum true peak value in order to exclude noisiest initial and final regions, as seen in b) and successfully achieved in c)

Conclusions

Steps were taken to improve on the existing reproducibility of the previously written code for metrological characterisation, looking specifically at the impact of noise on the accuracy of static and dynamic calibration tests, and the potential impact on resulting gait parameters. The largest part of the changes did not have any impact on the physical action of the code, instead making it easier for the user to identify the quality and meaning of the data under attention, particularly important for the sensor's clinical application. Functions were used as often as possible to minimise the structural effect on the original code and maintain its reusability. However, further work is required to make the proposed solutions entirely automated. Examples of experimental practice which produced the most accurate and valid results were recognised, either in individual test methodologies or the most successful research centres. Along similar lines, it was recommended that more care should be taken, when collecting data, regarding the experimental conditions and procedure.

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References

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[2] L. Angelini et al., *Sensors*, 20(79), 2, 2020
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