Automatic Analysis of Movement Variability

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Doctor of Philosophy

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I would like to dedicate this thesis to my loving parents ...

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

Miguel P. Xochicale
June 2018

Acknowledgements

And I would like to acknowledge ...

Abstract

This is where you write your abstract ...

Table of contents

List of figures

List of tables

Chapter 1

Introduction

1.1 Opening hook

1.2 Context

1.3 Gap in the literature

1.4 Research Questions

1.5 Argument

1.6 Outline of logic

Lorem Ipsum is simply dummy text of the printing and typesetting industry (see Section 1.2). Lorem Ipsum [3] has been the industry's Ipsum [1, 4, 5].

Chapter 2

Movement Variability

2.1 Source of Variability in Human Movement

2.2 Sensors

2.3 Variability within and between persons

2.4 Variability for simple and complex activities

Chapter 3

Techniques to measure human movement variability

3.1 Time-domain

3.2 Frequency-domain

3.3 Nonlinear dynamics domain

And now to cite some more people Read [6], Ancey et al. [2]

Chapter 4

Experiments

4.1 Dancing Salsa

4.2 Simple movements

4.3 Human-Humanoid Imitation

4.4 Group Activity in Human-Humanoid Imitation

Chapter 5

Automatic Classification

5.1 Convolutional Neural Networks

5.2 Convolutional Neural Networks Using time-series

Chapter 6

Conclusion

6.1 Reasonably long section title

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References

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Appendix A

Inertial Measurement Units

A list of description for Inertial Measurement Units which includes * on-board processing? * embedded sensor fusion * Sample rate variation and what does it depend on? * What data does it send? Acceleration output?/calibrated data? * What rate did they sample when sending information on Multiple

A.1 Muse

The sample rate for muse sensors goes from 25, 50, 100, 150, and 200 Hz and it depends from 8MHz oscillator which has %0.5 frequency tolerance and $\pm$ 0.2 % frequency shift by temperature -40°C and 80°C and $\pm$ 0.1 % frequency aging.

A.1.1 TODO: present an explanation for the use of time syscronisation in the wireless network

A.1.2 TODO: Present a simple explanation regarding the use of MUSE sensors!

A.1.3 Accelerometer

A.1.4 Angular rate gyroscope

A.1.5 Magnetometer

A.1.6 The IMU signal

A.1.7 Kinematic Parameters

A.1.8 System set-up

A.1.9 System calibration

A.1.10 Output

read Roetenberg2013 for a better structure of the information for the muse section.

A.2 Razor IMU 9dof

A.3 Axivity Sensors

WAX9 Unit price is 149 pounds. It doesnt provide a kinematic chain and there is no online magnetometer calibration.

POSITIVES. Many reserach works has been uused the WAX sensros in many publications: [http://axivity.com/publications]

2009, 1 paper 2011, 4 papers 2012, 4 papers 2013, 19 papers 2014, 10 papers 2015, 32 papers 2016, 48 papers 2017, September, 19 papers

NEGATIVES. There is no validation test against any optical sensor or xsens sensors

A.4 Xsens

accurate and drift free orientation the update rate varies with regard to the number of trackers 1MTw 120Hz 2MTw 120Hz 9MTw 100Hz 10MTw 80Hz 20MTw 60Hz

MTw Awinda DK Lite (E 740) contains: MTw Awinda motion trackers; the awinda USB dongle; and USB charging cable. (E 400) per extra tracker.

The price for 6 motion trackers is E 4390

Benchmark

Shimmer3 (Dublin, Ireland)

BtStream firmware program is used for shimmer configuration and data capture over Bluetooth. The Shimmer unit is within Bluetooth range of the PC (<12m approximately).

rechargeable Lithium Polymer battery 3.7V 450mAh

Capabilities

According tot he User Guide, the output data of the sensors are approximate values

Low Noise Accelerometer A KXRB5-2042 device from Kionix is used

- Zero-output: 1.5 V.
- Full scale range: ±2.0 g.
- Sensitivity: 600 mV/g.

Wide Range Accelerometer SM303DLHC device from STMicro

- Full scale range: ±2.0 g; ±4.0 g; ±8.0 g; ±16.0 g.
- Sensitivity (LSB/g): 1000 (±2.0 g); 500 (±4.0 g); 250 (±8.0 g); 83.3 (±16.0 g).
- Output: 16 bits

The gyroscope on the MPU-9150 chip from Invensense

- Full scale range (deg/sec): ±250; ± 500; ±1000; ±2000.
- Sensitivity (LSB/(deg/sec)): 131 (±250); 65.5 (±500); 32.8 (±1000); 16.4 (±2000).
- Output: 16 bits.

magnetometer LSM303DLHC device from STMicroelectronics

- Full scale range (Ga): ±1.3; ±1.9; ±2.5; ±4.0; ±4.7; ±5.6; ±8.1.
- Sensitivity (X,Y/Z) (LSB/Ga): 1100/980 (±1.3); 855/760 (±1.9); 670/600(±2.5); 450/400 (±4.0); 400/355(±4.7); 330/295 (±5.6); 230/205 (±8.1).
- Output: 16 bits

Noise performance when varying signal bandwidths . the sampling rate for each case was 500 Hz with a low-pass filter for the variation of the bandwidth.

Bandwidth (Hz)	50	100	250
Low Noise Accelerometer RMS noise (m/s^2)	3.51×10^{-3}	5.09×10^{-3}	8.12×10^{-3}
Wide Range Accelerometer RMS noise (m/s^2)	18.6×10^{-3}	27.5×10^{-3}	37.2×10^{-3}
Gyroscope RMS noise (deg/s)	0.0322	0.0481	0.0785
Magnetometer RMS noise (normalised local flux)	0.005	0.0081	0.0129

For further information, please refer to the manufacturer's datasheets.

9 Degrees of Freedom - Razor IMU

Capabilities

triple-axis Digital accelerometer ADXL345 device from Analog Devices.

- Full scale range: ±2.0 g; ±4.0 g; ±8.0 g; ±16.0 g.
- Sensitivity (LSB/g): Min232, Typ256, Max286 (±2.0 g); Min116, Typ128, Max143 (±4.0 g); Min58,Typ64, Max71 (±8.0 g); Min29,Typ32, Max36 (±16.0 g).
- Output: User-selectable resolution: 10-bit or 13-bit

Noise Performance x-,y-Axes. Date rate = 100 Hz for ±2 g, 10-bit. <1.0 LBS rms z-Axes. Date rate = 100 Hz for ±2 g, 10-bit. <1.5 LBS rms

The gyroscope on the ITG-3200 chip from Invensense

- Full scale range (deg/sec): ±2000.
- Sensitivity (LSB/(deg/sec)): 14.375 (±2000).
- Output: 16-bit

Gyro Noise performance
Total RMS noise. 100Hz LPD (DLPFCFG=2). 0.38 deg/sec-rms
Rate Noise Spectral Density. At 10Hz. 0.03 deg/sec $\sqrt{Hz}$
magnetometer. HMC5883L device from Honeywell

- Full scale range (Gauss): ±8.
- Sensitivity (LSB/Gauss): Min230,Max1370 (±8)
- Output: 12-bit ADC

Noise Floor (Field resolution) VDD=3.0V, GN=0, No measurement average, Standard Deviation 100 samples. Typ: 2 milli-gauss. https://www.sparkfun.com/products/10736

IMU WAX9 sensor from axivity (Newcastle, UK)

The devices are £149.00 each (excluding VAT). plus delivery charge of £9.99
Physical Parameter: Dimensions 23x32.5x7.6 (mm) Weight 7g

Typical Capabilities

Accelerometer: ± 2 / 4 / 8g (14 bit resolution). Range setting Convert to g Dynamic range 2 divide by 16384 ± 2g 4 divide by 8192 ± 4g 8 divide by 4096 ± 8g

Gyro: ± 250 / 500 / 2000 dps (16 bit resolution) Range setting Convert to deg/sec Dynamic range 250 multiply by 0.00875 ± 250 dec/sec 500 multiply by 0.01750 ± 500 dec/sec 2000 multiply by 0.07000 ± 2000 dec/sec

Magnetometer: ± 1uT steps (1 mGs, milli-gauss). (16 bit resolution) The range of the sensor is ± 20,000 (2 mT or 0.2 Gs).

Temperature Range: 0 - 65 °C (0.1°C resolution) Pressure: 30-110 kPA (1Pa resolution)

Battery Life: Hibernate 56 days LE Connected (50Hz stream) 6 Hours

Sample rate: The data rate is set by the RATEX variable in samples per second (default 50 Hz).

The sensors on the WAX9 are all digital sensors with their own independent sample clocks.

The sensors each have their own independent internal sample rates because of the sampling scheme described above. Variable Values Effect Accelerometer rate 12 50 100 200 400 800

Internal rate Hz Accelerometer range 2 4 8 Range in +/-g Gyroscope rate 100 200 400 800 Internal rate Hz Gyroscope range 250 500 2000 Range in dps Magnetometer rate 5 10 20 40 80 Internal rate Hz

http://axivity.com/userguides/wax9/technical/

WAX9 has different operating sample frequencies which is considered to be booth as a disadvantage and adtange.

IMU EXL-S3 sensor from exel (Bologna, Italy)

EXLs3 1 to 9 pieces for Euros 230 each. EXLs3KIT1 1 to 9 pieces for 384

*Features

Module size 54 mm x 33 mm x 14 mm Module weight 22 g 32-bit MCU, Cortex-M3 @72 MHz 3-axis accelerometer with selectable full-scale range (±2 / ±4 / ±8 / ±16 g). 3-axis gyroscope with selectable full-scale range (±250 / ±500 / ±1000 / ±2000 dps) 3-axis magnetometer ±1200 dps Orientation estimation with Kalman filtering and quaternion output. Sampling rate up to 200 Hz for raw data and 100 Hz for orientation data. Various data packet format available BluetoothTM 2.1 class 1. Up to 7 nodes at the same time can stream data to the same host. 1GB Flash Memory (USB Mass Storage) for data storage Docking station with micro-USB connector for battery recharging and log-file downloading. Battery operating time 3h

SAMPLE RATE

200 Hz (100 Hz if a packet with orientation is chosen) 100 Hz 50 Hz 33.33 Hz 25Hz 20Hz 16.67 Hz 12.5 Hz 10 Hz 5 Hz 300 Hz (No magnetometer data, 100 Hz if a packet with orientation is chosen)

Odroid myAHRS+

£69.52 Ex Tax: £57.93 We offer free shipping (delivery up to 5 working days) to all UK destinations.

myAHRS+ is a high performance AHRS(Attitude Heading Reference System).

the following connectivity options are available: - USB : Virtual COM PORT - UART : Standard baud rates up to 460800 bps - I2C : up to 1kHz

Unfortunately we are unable to offer technical support on the ODROID range of products. Clive - Lilliput UK

* Sensors - Triple axis 16-bit gyroscope : ± 2000 dps - Triple axis 16-bit accelerometer : ± 16 g - Triple axis 13-bit magnetometer : ± 1200 uT

* On board software - Exteneded Kalman filter - max 100 Hz output rate Attitude : Euler angle, Quaternion Sensor : acceleration, rotation rate, magnetic field

user-programmable gyro full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) Gyro sensitivity (LSB/°/sec) N/A Gyro Rate Noise (dps/ Hz) 0.005

a user-programmable accelerometer full-scale range of ±2 g, ±4 g, ±8 g, and ±16 g, Accel Sensitivity (LSB/g) N/A and compass with a full scale range of ±1200 uT.

A.5 benchmark

Sensor	Price*	Connectivity	ACC	GYR	MAG	Sample rate Hz	Temp.	battery time	API
9 DOF Razor	£59.99	USB,Bluetooth 2.1, LE	Full-scale range: $\pm$ 2 g Sensitivity: 256 LSB/g ADCs: 10-bit	Full-scale region: $\pm$2000 dps Sensitivity: 14.375 LSB/dps ADCs: 16-bit	Full-scale region: $\pm$8 Gauss Sensitivity: 230 to 1370 LSB/gauss ADCs: 12-bit	50	–	–	C++ Android ROS
myAHRS+	£69.52	USB,UART,I2C	Full-scale Range: $\pm$16 g Sensitivity: (2048 LSB/g) ADCs: 16-bit	Full-scale region: $\pm$2000 dps Sensitivity: 16.4 LSB/dps ADCs: 16-bit	Full-scale Range: $\pm$ 1200 T Sensitivity: 0.3 T/LSB ADCs: 13-bit	max 100	-40 to +85°C Res: 340 LSB/°C	–	C++ Python ROS
EXLs3	384 euro $\approx$ £291	Bluetooth 2.1	Full-scale range: $\pm$ 2/ 4/8/16 g	Full-scale range: $\pm$ 250/ 500/1000/2000 dps	Full-scale range: $\pm$1200 dps	5, 10, 12.5, 16.67, 20, 25, 33.33, 50, 100, 200, 300	–	3h	–
WAX9	£178.8	Bluetooth 2.1 and LE	$\pm$ 2/4/8g Resolution: 14-bit	$\pm$ 250/500/2000 Resolution: 16-bit	Range $\pm$ 1mT Resolution: 16-bit	1 to 400	0 - 65°C	6h	C# iOS App
Shimmer3	503.07 euro ** $\approx$ £381	USB,Bluetooth 2.1	$\pm$ 2/4/8/16 g Sensitivity: 1000(2g) /500(4g)/250(8g)/ 83.3(16g) LSB/g ADCs: 16-bit	Range: $\pm$ 250/500/ 1000/2000 Sensitivity: 131(250) / 65.5 (500) 32.8(1000) / 250 (2000)LBS/g ADCs: 16-bit ADCs: 16-bit	Range: $\pm$1.3/1.9/2.5/4.0/ 4.7/5.6/8.1 Ga Sensitivity (X,Y/Z) (LSB/Ga): 1100/980(1.3), 855/760(1.9) 670/600(2.5), 450/400(4.0) 400/355(4.7), 330/295(5.6) 230/205 (8.1) ADCs: (16 bits)	10.24 to 1024	–	14h15m (@51.2Hz)	Matlab LabVIEW C# Android

*Incl. Tax, ** Incl. shipping *** g is the acceleration due to gravity

Appendix B

How to install LaTeX

Debian/Ubuntu:

```
sudo apt-get install texlive texlive-latex-extra
sudo apt-get install psutils
```

Appendix C

Installing the CUED class file

LaTeX.cls files can be accessed system-wide when they are placed in the <texmf>/tex/latex directory, where <texmf> is the root directory of the user's TeXinstallation. On systems that have a local texmf tree (<texmflocal>), which may be named "texmf-local" or "localtexmf", it may be advisable to install packages in <texmflocal>, rather than <texmf> as the contents of the former, unlike that of the latter, are preserved after the LaTeXsystem is reinstalled and/or upgraded.