User Centred Networked Health Care
A. Moen et al. (Eds.)
IOS Press, 2011

doi:10.3233/978-1-60750-806-9-897

Using a Robotic Arm to Assess the Variability of Motion Sensors

Lukas GORZELNIAK[a,b,1], André DIAS[c], Hubert SOYER[d], Alois KNOLL[e] Alexander HORSCH[a,c]

[a] *Institut für Medizinische Statistik und Epidemiologie, Technische Universität München, Munich, Germany*
[b] *Institut für Epidemiologie, Helmholtz Zentrum München, Munich, Germany*
[c] *Depts. of Computer Science & Clinical Medicine, University of Tromsø, Tromsø, Norway*
[d] *Fakultät für Informatik, Technische Universität München, Munich, Germany*
[e] *Institut für Informatik VI, Technische Universität München, Munich, Germany*

Abstract. For the assessment of physical activity, motion sensors have become increasingly important. To assure a high accuracy of the generated sensor data, the measurement error of these devices needs to be determined. Sensor variability has been assessed with various types of mechanical shakers. We conducted a small feasibility study to explore if a programmable robotic arm can be a suitable tool for the assessment of variability between different accelerometers (inter-device variability). We compared the output of the accelerometers GT1M and GT3X (both ActiGraph) and RT3 (Stayhealthy) for two different movement sequences.

Keywords. Accelerometer, validation, robot, inter-device-variability

1. Introduction

Motion sensors ease the assessment of physical activity (PA) and provide objective recording of the PA components: intensity, frequency and duration. A common type of motion sensors is accelerometers. They vary in size, sampling rate, proprietary movement detection algorithms, calibrations, access to raw sampling data and output variables, i.e. S.I. units, or proprietary counts or vector magnitude units (VMUs). Previously published studies on reliability of accelerometers have analyzed data generated by human motion in scenarios with standardized conditions for each subject [1, 2]. In these studies the possible variability among the sensors (of the same type) is measured under controlled conditions.

To assess the measurement errors of the accelerometers, devices have been mounted on vibration machines such as jigs or shakers, in order to generate acceleration data under controlled conditions [3]. However, to the knowledge of the authors, there is no study comparing the variability of the accelerometers GT1M, GT3X (ActiGraph) and the RT3 (StayHealthy) (details see section 2.1) by using an industrial robot for carrying out clearly defined and reproducible movements. Robots

[1] Lukas Gorzelniak, IMSE Klinikum rechts der Isar der TU München (Bau 523), Ismaninger Str.22, D-81675 Munich, Germany.E.mail: gorzelniak@imse.med.tu-muenchen.de.

work at a very high precision. They can be programmed for simple to complex motion sequences along different spatial axes, and thus have the potential of a better simulation of human and artificial movements than shaker devices. The aim of this paper is to examine the variability of the GT1M, GT3X and the RT3 accelerometers by using an industry robot for defined and repeatable movements.

2. Material and Methods

2.1. Accelerometers

For this exploratory study, 11 piezoelectric triaxial RT3 (Stayhealthy, Monrovia, CA, USA), 5 biaxial GT1M and 5 triaxial GT3X accelerometers (ActiGraph LLC, Pensacola, FL, USA) were used. The RT3 records activity in 3 orthogonal directions at a sampling rate of 1Hz. The measured accelerations are converted to a digital representation, then processed as activity counts, and finally stored as VMUs. The GT1M is a micro-electromechanical system which measures acceleration in the vertical and horizontal plane at a sampling rate of 30 Hz. PA is filtered and expressed as activity counts, which is a quantification of the amplitude and frequency of the detected accelerations summed over a user-specified time interval. The GT3X is the successor of the GT1M and can assess activity in 3 orthogonal directions.

Both ActiGraph accelerometers support the PA representation in terms of VMUs. All accelerometers in our study have been customized at one second post-filtered recording as it is the highest frequency in common to all sensors with VMUs output.

2.2. Industrial Robot

For defined and repeated movements the industrial robot TX90 (Stäubli Robotics, Pfäffikon, Switzerland) was used. The robot has an articulated arm and can execute movements in 6 degrees of freedom with a repeatability precision of ± 0.03 mm. The high degree of freedom can approximate (mimic) human movements by the robot.

2.3. Accelerometer Attachment

For a rigid attachment of the sensors, a single RT3 holder was screwed on the robotic arm. GT1M and GT3X accelerometers were attached to the same holder by using double-sided Velcro tape. This provided a stable attachment of the sensors (Figure 1).

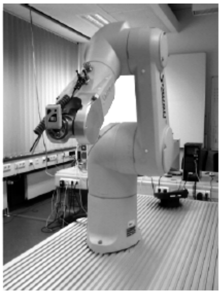

Figure 1. Robotic arm with a single RT3 device attached.

The robot was mounted on a laboratory table and programmable through a cable connected interface.

2.4. Protocol

Single accelerometer units were consecutively mounted on the robotic arm at exactly the same position before the programmed motion was executed.

Acceleration data for two types of movement were recorded for each device during a motion sequence at two randomly selected speeds of the robot: The first sequence consisted of simple movements along each axis, beginning at the resting position of the robot. The second sequence was "random" with components along all axes. The sequences were chosen to assess each axis individually and combined. We did not try to mimic human movement in this study.

The two sequences were repeated three times after short breaks of no movement at both speed levels. The robot program had to be started manually (for different speeds) thus, the data among the accelerometers were not exactly synchronized, causing a varying period of inactivity (activity gap). This gap was used to assess the signal-to-noise ratio and discarded for the comparison of the VMUs output. The gap location was known because all sequences had exact durations. The first non-zero value in the data defined the beginning of the time series. In order to evaluate the variability of the three accelerometers, descriptive statistics and illustrative figures were used.

3. Results

As the output scale differs between devices of different manufacturers, a comparison was conducted based on relative rather than absolute values. All accelerometers recorded movements in VMUs, but differed in their co-domain due to different manufacturers or different numbers of measurement axes. The GT3X recorded the highest accelerations during the specified motion sequence (10.77 ± 0.29 VMU mean), reaching the highest peaks (71.80 ± 4.55 VMU max) compared to the GT1M (7.13 ± 0.21 VMU mean; 66.52 ± 10.67 VMU max) and the RT3 (5.31 ± 0.86 VMU mean; 34.91± 6.28 VMU max), all values ± standard deviation, respectively (see Table 1).

The variability of the mean VMUs recorded during both types of movement was about 40 ± 24% in the RT3, 8 ± 15% in the GT1M, and 6 ± 11% in the GT3X. This is illustrated in Figures 2-4, in which data from each sensor type is plotted in a separate graph. Ideally, only a single line should be visible in each plot. Taking the displacement in the synchronization into account, the GT1M and the GT3X accelerometers overlapped fairly well in the graphs. Peaks and breaks before each repetition can be identified by small discrepancies. For the RT3 accelerometers, no clear line of measurement is observable, and small amounts of motion were continuously recorded during breaks. These are assumed to be noise.

The Signal-to-Noise ratio calculated from data within the interval of no movement between the motion sequences can be found in Table 1. Both ActiGraph accelerometers identified the rigid period more precisely than the RT3. Except for one device, all RT3 accelerometers showed non-zero values for the noise standard deviation (see Table 1).

Table 1. Accelerometer output for the entire repeated movement sequence with the robotic arm

Sensor Name	Number of Values	Mean VMUs	Standard Deviation (SD)	Maximum	Noise SD	Signal-to-Noise Ratio
I RT3	124	6,35	6,95	27,39	2,20	2,88
II RT3	140	6,81	7,09	32,50	4,61	1,48
III RT3	138	5,36	6,59	31,40	2,00	2,68
IV RT3	118	4,46	6,78	37,00	0,00	-
V RT3	136	5,93	7,83	46,17	3,20	1,85
VI RT3	137	4,73	5,93	31,13	1,34	3,53
VII RT3	129	4,12	6,96	43,46	4,80	0,86
VIII RT3	138	5,65	7,61	29,77	2,98	1,90
IX RT3	119	4,44	6,39	29,00	2,32	1,91
X RT3	139	4,87	6,57	41,23	3,71	1,31
XI RT3	130	5,65	6,56	35,00	3,48	1,62
I GT1M	135	7,14	14,56	58,00	0,00	-
II GT1M	134	7,13	16,88	82,00	0,00	-
III GT1M	133	6,85	14,35	62,00	0,00	-
IV GT1M	133	7,08	14,71	73,00	0,00	-
V GT1M	136	7,43	14,95	57,58	0,00	-
I GT3X	134	11,01	18,76	75,00	0,00	-
II GT3X	134	10,34	17,47	67,00	0,00	-
III GT3X	134	10,60	18,86	78,00	0,00	-
IV GT3X	134	10,91	19,68	69,00	0,00	-
V GT3X	134	10,97	18,55	70,00	0,00	-

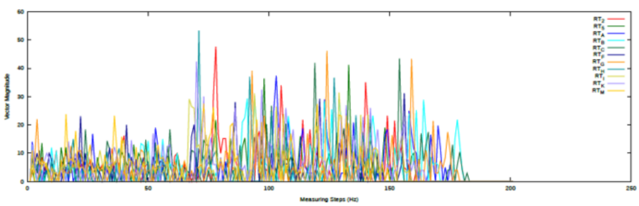

Figure 2. Plotted VMU data assessed during the movement sequence for each RT3.

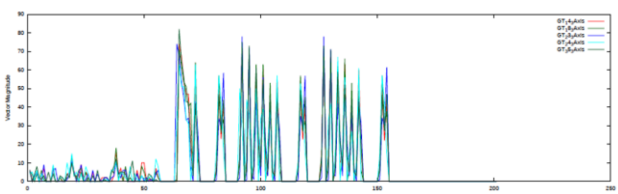

Figure 3. Plotted VMU data assessed during the movement sequence for each GT1M.

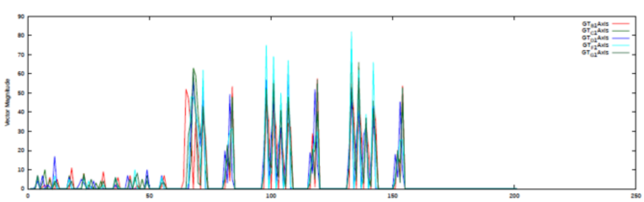

Figure 4. Plotted VMU data assessed during the movement sequence for each GT3X.

4. Discussion

Our results indicate that the data acquired by the RT3 accelerometers are less reliable than data provided by the GT1M or the GT3X. The RT3 units produced a higher noise ratio during our experiments and, in agreement with previous reports [3], we found a greater inter-unit-variability compared to the ActiGraph accelerometers. The robot provides an objective comparison method and can be programmed to mimic human movements.

As this was our first attempt to use a robot for exploratory purposes, the protocol contains several drawbacks: The robot was mounted on a steel table and during the faster motion sequence, movements of the robot are likely to have caused vibrations on the table. This probable noise may have decreased the accuracy of the accelerometer output. Therefore, we advise to use a rigid, grounded positioning, e.g. by mounting it on a block of concrete. Alternatively, the vibrations of the placement ground, as well as the robot itself, should be measured by mounting additional accelerometers.

Unfortunately, in this initial experiment we did not record the movement from the robot data interface, which could have served as gold standard. Regarding the movement sequence, artificial breaks should be avoided to eliminate the synchronization burden. Last but not least, the signal-noise-ratio was computed from no-motion intervals with varying length. In future studies this will be done in a more standardized way.

5. Conclusion

Using an industrial robot to perform repeating movements at a very high accuracy for testing different accelerometers is a promising method and generated reliable results. Although we did not assess intra-unit-variability of different motion sensors in this study, we were able to compare inter-unit-variability for two similar movement types in three different accelerometers, despite the limitations in the study protocol. Continuation of these studies is work in progress.

Acknowledgements: This research was funded/supported by the Graduate School of Information Science in Health (GSISH) and the TUM Graduate School. The authors thank Martin Eder.

References

[1] Guy C. le Masurier, Sarah M. Lee, and Catrine Tudor-Locke, Motion Sensor Accuracy under Controlled and Free-Living Conditions, Med Sci Sports Exerc. 2004 May;36(5):905-10.
[2] Bassett DR Jr, Ainsworth BE, Swartz AM, Strath SJ, O'Brien WL, King GA,Validity of four motion sensors in measuring moderate intensity physical activity, Med Sci Sports Exerc. 2000 Sep;32(9 Suppl):S471-80.
[3] Powell SM, Jones DI, Rowlands AV, Technical Variability of the RT3 Accelerometer, Med Sci Sports Exerc. 2003 Oct;35(10):1773-8.