Evaluation of KINECT and SHIMMER Sensors for Detection of Gait Parameters

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Keywords: Motion and Gait Analysis, KINECT and SHIMMER Sensors, Low-cost Sensors, Health Applications.

Abstract: Detecting gait parameters is possible using various sensors based on different physical principles. In our investigation a visual system, the Microsoft KINECT, and an inertial sensor system with SHIMMER 9DoF-sensors, are used for capturing the gait of various persons. Both systems have a small form factor and are affordable regarding cost. Hence these are well-suited for mobile applications in the health care environment. Using these low-cost sensor systems, motion capture and analysis can be done in hospitals, physiotherapy units or nursing homes. This paper focusses on the comparison of detected gait parameters by analyzing statistical parameters. The examination of accuracy of both systems is carried out in two steps; first by initially measuring the gait of a small group of volunteers and second of a larger group. The noise is also examined which has to be filtered out in the preprocessing procedure. The choice of filter impacts the detection of gait parameters. As a result the noise is characterized rather nonspecifically in both systems. As expected, the gait parameters determined by the systems are not identical, but similar. The deviations vary in the specific gait parameters; some are less error-prone than other.

1 INTRODUCTION

Nowadays smart, mobile sensors are applicable in health care. In previous papers their applicability was discussed and first results were shown (see (Orlowski et al., 2012)). In this paper the algorithms used for the automatic detection of gait parameters are introduced based on the analysis of the normed gait cycle by (Perry, 2010). Perry calculated the mean joint angles of the foot, knee, thigh and hip from the gait of 55 subjects. Derived values of those data are used to check the correctness of the algorithms. The given normed gait cycle consists of a stance and a swing phase. The stance starts with putting the heel on the ground (initial contact, IC) and ends with the detachment of the toe from the floor (terminal contact, TC). The TC is the beginning of the following swing phase which ends with IC. While one foot is in the swing phase, the other has full contact to the floor. Perry et al. subdivided the stance in five, and the swing in three phases. In our investigation only three of eight phases are considered. In addition to stance and swing the midswing, the middle third of the swing phase, is investigated. The midswing begins when the swinging foot crosses the standing one and ends when the

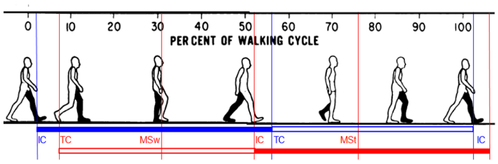

Figure 1: Gait cycle - left (black) and right (white) leg with the swing and stance phase marked by colored stripes and IC, TC, midswing and -stance (Murray and Kory, 1964).

"swinging limb is forward and the tibia is vertical" (Perry, 2010). It is the interval from about 75-87 % of the gait cycle.

Figure 1 shows a whole stride for each leg (left - black, right - white) and the percentage of walking cycle. An overlap of the stance phases of both legs is identifiable. During normal walking, the swing phase is always shorter than the stance, and the swing phase of one leg is within the stance phase of the other. A 40 to 60 percent relationship between swing to stance phase is generally assumed (Perry, 2010).

This paper includes a comparison of the gait parameters of the Kinect and SHIMMER sensors based on the data of a step sequence of 26 volunteers. Furthermore, the sensor noise is investigated through separate experiments as the choice of the filter influences

Orlowski K. and Loose H..
Evaluation of KINECT and SHIMMER Sensors for Detection of Gait Parameters.
DOI: 10.5220/0004227901570162
In *Proceedings of the International Conference on Bio-inspired Systems and Signal Processing* (BIOSIGNALS-2013), pages 157-162
ISBN: 978-989-8565-36-5
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the quality of the results. The accuracy of the sensors is evaluated using statistical values.

2 SYSTEMS AND EXPERIMENTS

2.1 Systems

For motion capture and analysis different sensor types are used, which can generally be distinguished due to different recording principles and fields of application. The Microsoft KINECT sensor system (KINECT) and the Shimmer^{TM}sensors (SHIMMER) are predestined for mobile health applications because of their small size (see Fig. 2) and the comparatively low cost. While KINECT is a visual system based on an absolute reference system, the SHIMMER (9-DoF-sensor) is an inertial system working with a relative reference system. That system calculates incrementally the position of the sensor by knowing the initial position.

The depth image of the KINECT is produced by measuring the distortion of the reflected dots from the pseudo-random beam pattern sprayed out from the IR laser (Taylor, 2011). Further information on the used systems can be found in earlier papers (Orlowski et al., 2012; Orlowski and Loose, 2012)

2.2 Experiments

Preliminary investigations were done to determine the noise of the sensor systems. For this experiment a dummy (see figure 2) was used. In contrast to a human test person moving slightly during standing, a skeleton always rests. The KINECT is able to detect correctly the skeleton and to capture the stands. For measuring the SHIMMER sensor noise, the calibrated sensor is placed on a table. The results of these analyses are describe in the following subsection.

To assess the determination of gait parameters using KINECT and SHIMMER sensors, two steps have been carried out: first the gait of a small group of volunteers is measured for an initial assessment of the setup and algorithms, thereafter the data of a larger group of healthy subjects is evaluated.

Within the small group the step sequence of six healthy subjects (3 M, 3 F, mean age: 29.8) is simultaneously captured with both systems. Due to the restricted capturing area of the KINECT the step sequence consists of one to three steps each leg, varying in step length. The KINECT is placed in front of the walking line at a defined height. The person walks toward the KINECT until a distance of 80 cm is reached. During the walking experiment the proband

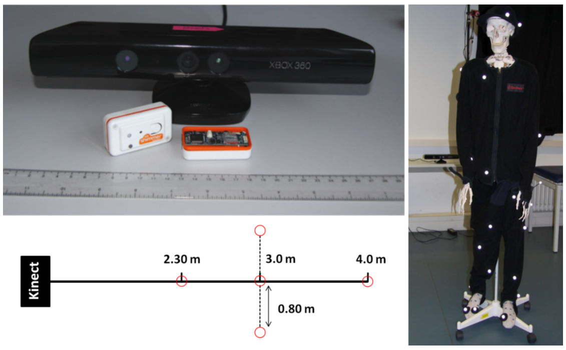

Figure 2: The Microsoft KINECT and two SHIMMER sensors (left). The unmoved dummy used to determine the KINECT sensor noise (right). Below: Experimental setup for noise evaluation with marked dummy positions.

wears two SHIMMER 9-DoF-sensors which are fixed above the ankle on each leg. A start and stop synchronization is not implemented; the systems are started and stopped manually. After the initial assessment the gait of 26 healthy students (20 M, 6 F, mean age: 24.1)) was captured. There were no special in- or exclusion criteria for the choice of the volunteers.

2.3 Noise Evaluation

2.3.1 KINECT

In contrast to the publication of (Khoshelham and Elberink, 2012), the sensor noise of the KINECT is reviewed by measuring the skeletal data of the non-moving dummy. To verify the hypothesis that the noise is dependent on the distance, the skeleton was recorded at five positions (see figure 2). To eliminate random noise of a single KINECT, the setup was repeated with two other KINECT systems. Three 30-second-datasets at each given distance with a frame rate of 30 Hz were recorded.

The noise signal of selected joints and their frequency spectrums were examined. Most of the frequencies of the noise signal are below 5 Hz with a more or less normal distribution. The reason for the slightly higher proportion of low frequencies might be a drift. The mean, standard deviation (std), minimum and maximum are determined as statistical values. The mean of the standard deviation of the hip is ± 1.3 *mm*, of the shoulder ± 2.7 *mm* and of both ankles ± 3.4 *mm*.

Figure 3 shows the box plots of the nine recordings. The samples of the selected joints of the nine recordings are each summed up to one vector consisting of about 8100 samples. The median value is close to zero because the data is shifted by its mean. Obviously, the deviations of the left and right side are sim-

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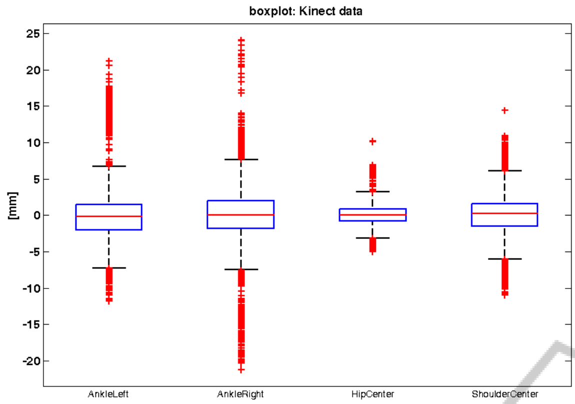

Figure 3: Box plots: noise of both ankle, hip and shoulder summarizing the measurements of 3 KINECT (dist 3 m).

Table 1: Mean of the standard deviation of the noise and its relative value depending on the distance.

Dist [mm]	**left Ankle** (relErr)	**right Ankle** (relErr)	**Hip** (relErr)	**Shoulder** (relErr)
2300	1,5 mm (0,07 %)	2,3 mm (0,1 %)	0,9 mm (0,04 %)	1,4 mm (0,06 %)
3000	3,1 mm (0,10 %)	3,4 mm (0,11 %)	1,3 mm (0,04 %)	2,7 mm (0,09 %)
4000	6,1 mm (0,15 %)	10,5 mm (0,26 %)	3,4 mm (0,09 %)	5,0 mm (0,12 %)

ilar with the exception of more outliers on the right side. The center of the shoulder has larger deviations than the hip center. The deviations including the outliers of the hip and shoulder are much smaller than those of both ankles.

Further evaluations compare the dependency of the noise on different distances. Even when using the smoothing parameter of the KINECT SDK for less skeletal jitter (see Microsoft KINECT SDK API Reference or (Fernandez, 2011)), the noise grows with the distance. Table 1 contains the calculated mean of the standard deviation of the recordings at different distances as well as the relative errors based on the respective distances.

2.3.2 SHIMMER

The noise of four SHIMMER sensors was determined. After sensor calibration a 25-second recording was performed. The signals of the gyrometer were transformed to the frequency domain. Examining the recorded noise of the gyrometer, the noise could be classified rather nonspecific. It is more or less normal distributed and has a few distinct peaks. Similar

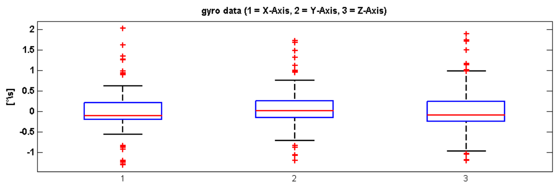

Figure 4: Box plots of the noise of the gyrometer.

to the KINECT noise evaluation, statistical values are determined for all noise signals. Figure 4 represents a summary of the statistical evaluation of the noise signals. All angular velocity signals in x, y and z are summed up to one vector each, and box plots were created. The plot contains the box plots of the angular velocity. Obviously, there are no significant differences between the three axes. The standard deviation of the angular velocity is $\pm 0.3\ ^{\circ}/s$.

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3 METHODS

3.1 Normed Gait Cycle

Using the mean joint angles provided by Perry et al., different data, such as angular velocity, horizontal movement and velocity, are derived from the mean joint angles of the left leg (see figure 5) using the limb length of a subject (ankle-hip: 88 cm, ankle-knee: 41 cm, knee-hip: 47 cm, foot: 28 cm) . Since the speed of a normal gait is defined at 1.3-1.6 m/s (Oeberg and Oeberg, 1993), we choose an uniform forward motion of the hip at 1.4 m/s (see figure 6 (below)). The values of derived velocity are negative because the distance to the sensor is reduced during the measurement.

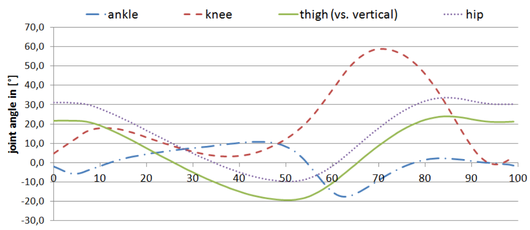

Figure 5: Mean joint angles of the normed gait cycle.

All diagrams in figure 6 as well as the walking cycle in figure 1 show that the stance phase of the left leg is approximately between 5 and 60 % of the gait cylce. The swing phase starts directly after the stance phase and is not yet completed at 100 %. The angular and the horizontal velocity are around zero during stance since the distance to the sensor does not change. The middle diagram, depicting the horizontal movement of the foot, ankle, knee and hip, shows

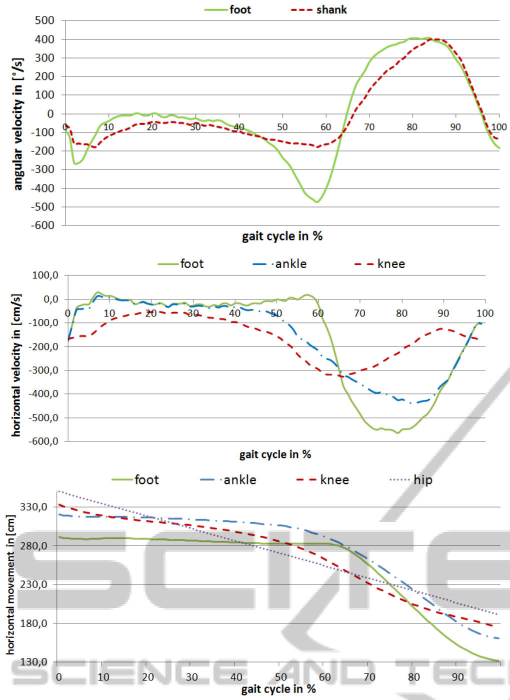

Figure 6: Calculated angular velocity (above) of the shank and foot, horizontal velocity (middle) of foot, ankle and knee and horizontal movement (below)

a nearly constant distance around 3 m from 5 to 50-60 % of the gait cycle. After analyzing the normed gait and the derived values, conclusions for the determination of gait parameters can be drawn. It is possible to convey characteristics of the gait which can be extracted automatically from the measured data of the KINECT and SHIMMER gyroscope.

A gait cycle consists of a stance and a swing phase and can be characterized by its length and duration. From the angular velocity of the shank, the beginning (IC) and end (TC) of the stance phase as well as the middle of swing phase (midswing) can be determined. In contrast to the definition of midswing as a phase (Perry, 2010), midswing is used as a characteristic point of the swing phase. At the beginning and end of the stance phase local minima occur in the angular velocity. The midswing is characterised by a local maxima (see figure 7).

The beginning and end of the swing phase can be detected in the velocity of the foot motion using a threshold. During swing phase this threshold is exceeed. The beginning and end of the stance result in the preceding swing phase parameters. In figure 7 the lime, solid curve represents the velocity of the foot, the dashed line the used threshold. The red circles show where the threshold is exceeded.

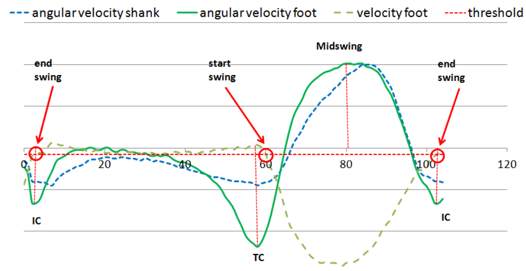

Figure 7: Velocity and angular velocity with marked parameters and used threshold.

3.2 Determination of Gait Parameters

3.2.1 SHIMMER

The swing and stance phases are determined by identifying the characteristic points from the data of the gyroscope. Figure 8 shows signals captured during normal walking. The angular velocity captured with SHIMMER is similar to those of the normed gait cycle (compare figure 7 and figure 8).

The IC, TC and midswing points are determined using an adapted algorithm analogical to that proposed by Greene et al. (Greene, 2010). First disturbances are minimized by a low-pass filter (5th order Butterworth filter, corner frequency: 5 Hz). Then the correctness of the polarity of the signal has to be checked using the formula for the skewness $(mean(x) - median(x))$. If the skew value is negative and the absolute value of the minimum is greater than the absolute value of the maximum, the signal is mirrored at the x axis. An additional criterion $(abs(min(x)) > abs(max(x)))$ is used. The combination of both criteria can change the polarity of the signal. The local maxima and minima are searched within the signal. Each local maximum stands for the midswing of a swing phase. The preceding local minimum of the midswing point is the TC, the succeeding local minimum represents the IC.

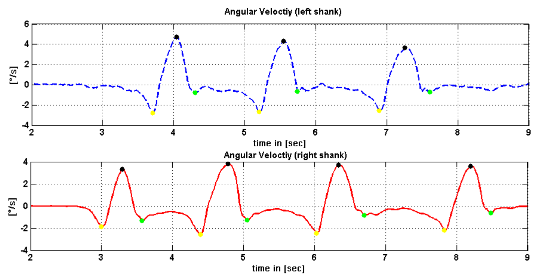

Figure 8: Angular velocity of the left/right lower leg with marked features: IC-green, TC-yellow, midswing-black.

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3.2.2 KINECT

The start and end of a swing phase, which correspond to the terms inital and terminal contact (IC/TC), are calculated from the ankles‘ forward motion.

The captured data are filtered by a mean filter of length five which is applied through convolution. The smoothed signal of the forward motion of the left (blue-dotted) and right (red) ankle is displayed above in figure 9. As mentioned before, to determine the start and end points, the first discrete derivative is calculated. The result of the derivation is shown in the lower plot in figure 9. At first the local minima are detected to determine the number of steps for each leg. That information is necessary for the detection of start and end points of each swing. We assume that the local minima in the first derivative represent the midswing points. An experimentally determined threshold is each time adapted to the minimum of the two global minima of the derivative of the right and left signal ($th = -0.499 * max$) to find all start and end points of the swing phases.

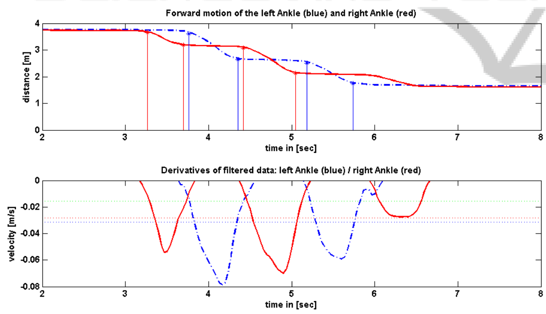

Figure 9: Forward motion of the both ankles of a step sequences of one person: distance and velocity (below)

The upper plot of figure 9 contains the detected start and end points of the swing phase. The constant parts represent the stances, the small decreasing parts the swing phases. The foot as well as the ankle move only slightly during the stance phase while the movement is clearly visible during the swing phases. The step sequence begins with the right leg after an initial recovery (about three seconds). Three right steps and two left steps have be made during the short walking.

4 RESULTS

4.1 Introductory Remarks

As mentioned before the experiments were done in two steps. First an initial assessment was performed with a small group of volunteers to check the systems and the used algorithms. Then, the gait of a larger group was captured under the same conditions.

The captured data were visually surveyed to identify data with measuring failures such as storage errors, early breaks of capturing and data with a disturbed initial recovery. Recordings with such failures were excluded from the assessment and evaluation. After removing erroneous data, 55 datasets are investigated and the characteristic points (IC, TC and midswing) can be detected.

4.2 Comparison and Statistical Evaluation

The IC, TC and midswing points were detected using the described algorithms. The duration of the swing and stance phase as well as the distance between midswing points were calculated. The deviations between both systems were measured determining the absolute error in seconds. The existing deviations are due to the preprocessing steps, algorithms and the accuracy of the systems.

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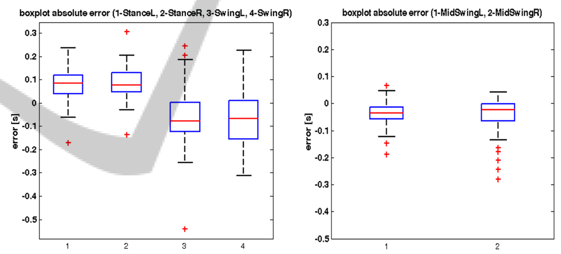

Figure 10: Box plots of the absolute errors between gait parameters detected from SHIMMER and KINECT data. Left: 1-Stance left, 2-Stance right, 3-Swing left, 4-Swing right, Right: 1-Midswing left, 2-Midswing right

Figure 10 provides information about the deviations of both systems/algorithms during measurement and shows the absolute error measured for the parameters: stance left (1) and right (2), swing left (3) and right (4) as well as midswing left (1) and right (2). The absolute error constitutes the difference between the parameters determined from the data of both systems. The absolute error of the swings is greater than those of the stances. The large deviations in the swing phase result from the fact that the pull of the foot to the end position of the recording is most of the time not correctly covered by the KINECT (see figure 9). Contrary to the SHIMMER, the KINECT algorithm does not recognize the last swing due to the used threshold. A reduction of the threshold to 35% of the global minimum leads to the recognition of the swing, but the duration of that swing differs significantly from that determined by SHIMMER. That could be reasoned by the more difficult recognition of the last swing. The algorithm has to be optimized regarding that problem.

The mean absolute error at stance phases is 0.084 s (± 0.07 s) (left) and 0.078 s (± 0.07 s) (right) as well as at swing phases are -0.053 s (± 0.13 s) (left) and -0.053 s (± 0.12 s) (right). The distance between the midswing points was also considered. As expected, this gait parameter is less prone. This is reflected in the right plot. The mean absolute error for the distance of midswing points is -0.038 s (± 0.04 s) (left) and -0.042 s (± 0.06 s) (right).

5 DISCUSSION

The evaluation of noise provides no clear results that the signals captured with KINECT and SHIMMER include a specific type of noise. The noise of the KINECT depends on the subjects distance to the recording unit. The greater the distance, the stronger the influence of noise. Regarding other influences, the environment, in which the measurements are conducted, has to be investigated in further experiments.

The evaluation of derived values of the mean joint angles have shown that the signals measured with KINECT and SHIMMER are usable for the detection of gait parameters. In general the detected points are correctly determined. The detected IC, TC and midswing points represent characteristic points of the swing and stance. They can be used to characterize the gait and calculate the length and duration of each swing or stance. The quality of the detection depends on the signals' frame rate and the noise.

Statistical values are used to assess the derived gait parameters. The absolute errors were determined by calculating the absolute difference of the gait parameters determined from the KINECT and SHIMMER data. The duration of the swing and stance phase is not identical but similar with small deviations. The deviations of the swing phase is greater than those of the stance phases due to the detection problem of the last swing. The differences between the distance of the detected midswings are much smaller than those of the swing and stance phase. The different frame rates (KINECT: 30 Hz, SHIMMER 51.2 Hz) can be a reason for the deviations because the temporal resolution is different and the accuracy is not the same.

6 CONCLUSIONS

This paper presents the influence of noise of both sensor systems. A further component of the paper is the evalution of the normed gait cycle given by Perry (Perry, 2010) and Murray (Murray and Kory, 1964). Based on the evaluation, the correctness of the developed algorithm was verified. They have been used to determine the gait parameters duration of swing and stance phases and distance between midswings. The investigation was carried out in two steps. At first the gait of a small group of volunteers was measured and investigated to check for necessary adaptions on the algorithms. Consequently, the algorithms were adapted and additional functions were developed to ensure a semi-automatic evaluation of amount of data. Then, in a second step, the gait of 26 healthy students was recorded and analyzed. The results of the comparison are shown.

In further experiments, the comparison with a gold standard as well as with an established mobile sensor systems, such as xsens[1], has to be applied to assess the quality and correctness of the data. Moreover, the detection problem of the last swing has to be solved.

REFERENCES

Fernandez, D. (2011). Skeletal tracking fundamentals (beta 2 sdk). http://channel9.msdn.com/Series/KinectSDK Quickstarts/Skeletal-Tracking-Fundamentals. Online: 16.02.2012.

Greene, B. e. a. (2010). An adaptive gyroscope-based algorithm for temporal gait analysis. *Med Biol Eng Comput*, 48:1251–1260.

Khoshelham, K. and Elberink, O. (2012). Accuracy and resolution of kinect depth data for indoor mapping applications. *Sensors : journal on the science and technology of sensors and biosensors : open access*, 12:1437–1454.

Murray, M.P.; Drought, A. and Kory, R. (1964). Walking patterns of normal men. *J Bone Joint Surg Am*, 46A:335 – 360.

Oeberg, T.; Karsznia, A. and Oeberg, K. (1993). Basic gait parameters : Reference data for normal subjects, 10-79 years of age. *Journal of Rehabilitation Research and Development*, 30(2):210–223.

Orlowski, K. and Loose, H. (2012). Low-cost locomotion sensors. *Proceedings of the 13. Nachwuchswissenschaftlerkonferenz 2012*, 13.

Orlowski, K., Loose, H., Otte, K., Mansow-Model, S., and Thiers, A. (2012). Kinect and shimmer sensors in motion analysis in health applications. *Proceedings of BIOSIGNALS 2012, Int. Conference on Bio-Inspired Systems and Signal Processing, Vilamoura, Algarve, Portugal, 1-4 Feb. 2012*, pages 226–231.

Perry, J. (2010). *Gait Analysis - Normal and Pathological Function*. Slack Inc.

Taylor, T. (2011). Kinect for robotics. http://blogs.msdn.com/b/msroboticsstudio/archive/2011/11/29/kinect-for-robotics.aspx. Online: 24.01.2012.

[1] http://www.xsens.com/