Real-time PC application development for evaluating hands rotations using inertial sensors

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Abstract – Nowadays, modern technology can be used in medical facilities to treat patients and evaluate the progress of the treatment of special ailments such as Parkinson's disease or epilepsy; where individuals cannot hold their hands in a stable position because of their sickness. The approach of this paper deals with the stability of human wrists with the use of two Shimmer3 Electrocardiography (ECG) Units to determine inclination angles. An application will be developed with C# that runs on a Windows Computer; therefore, sensor measurements are sent wireless through a Bluetooth connection. A patient has to hit segments that light up in an area during a recorded sensor measurement series. For each Shimmer device, there is an area in that the inclination angles are represented between -90° and +90°.

1. Introduction

The subject of this paper is to identify if a patient is able to stabilize the wrist for a specific time in a coloured segment. In contrast, it will be also proved if the accuracy of inclination angles from a Shimmer device is relatively accurate to the inclination angles of a mechanical angle meter.

2. Shimmer3 EXG

A Shimmer3 EXG Unit is a wireless wearable device of the company Shimmer from Dublin in Ireland (see figure 1). It provides a configurable digital front-end, that is optimised for the measurement of physiological signals for ECG and EMG. In this paper, inclination angles are measured and evaluated with the Shimmer3 EXG Unit.

Figure 1: Side-view from the Shimmer3 EXG Unit [1].

The device is a highly configurable sensor module which can be used in a diversity of data capture scenarios. The unit includes a magnetometer, gyroscope, and accelerometer, which means, each of them is a configurable 3-axis sensor. The Shimmer device sends the measurements to the computer or android device wireless, via Bluetooth. This allows you to do exercises without being connected with lines to the computer [1]. The following information in table 1 describes the configuration from the Shimmer unit, that is directly read with the Shimmer API.

Sample Rate [Hz]	1	10.2	51.2	102.4	204.8	256
	512	1024				
Accelerometer [g]: (g ≈ 9.81 m/s²)	±2	±4	±8	±16		
Gyroscope [dps]: (degrees per second)	250	500	1000	2000		
Magnetometer [Ga]: (Gauss)	±1.3	±1.9	±2.5	±4.0	±4.7	±5.6
Baud Rate:	1200	2400	4800	9600	19200	38400
	57600	115200	230400	460800	921600	

Table 1: Information from the Shimmer API about the sensor configuration.

3. Inclination Angles

The Shimmer device uses an algorithm that is proposed from Sebastian O.H. Madgwick, Andrew J.L Harrison and Ravi Vaidyanathan in 2011 on the IEEE international Conference on Rehabilitation Robotics in Zürich, Switzerland; which means a quaternion is calculated from the accelerometer, gyroscope and magnetometer. The proposed method is called magnetic, angular rate and gravity (MARG) [2].

In this paper we will work on a 2D surface, therefore quaternion's are converted into the Euler angles roll (θ), pitch (φ) and yaw (ψ) [3]. Figure 2 shows the orientation of the inclination angles in relation to the Shimmer3 EXG Unit.

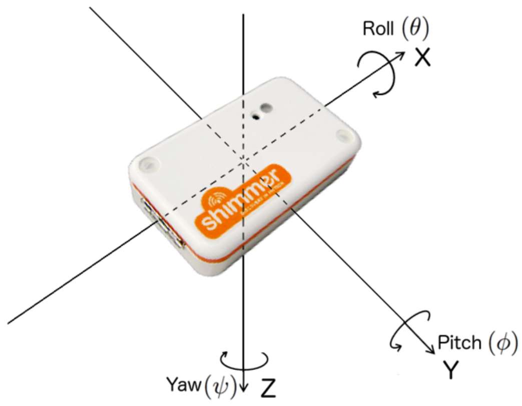


Figure 2: Representation from the roll, pitch and yaw angles in relation to the Shimmer3 EXG Unit [4].

4. Program Features

The main features of the proposed application of this paper are to measure the inclination angles of two Shimmer3 EXG Units and represent it on a surface; thereby it depends on the difficulty as five up to thirty-six different angles has to be hit by a laser beam inside an 180° area (half circle).

Every segment has got a middle point, during a data stream; a laser beam is displayed (see figure 3 b). At recording, a segment that has to be hit changes their colour into red (see figure 3 d), when the segment is getting hit by the laser beam, the colour becomes green (see figure 3 e). For the three difficulties, there are different segment sizes, easy 30° (figure 3 a), middle 10° (figure 3 b) and hard 5° (figure 3 c).

Segments light up for a configured time between eight and forty seconds; within a setup recording time between 1:00 minutes and 5:00 minutes. A coloured segment has to be hit for at least one to five seconds, depends on the configuration before the evaluation starts for each segment. It also can be configured, how much time before the next segment lights up, the evaluation will be stop (0.5 - 2.0 seconds).

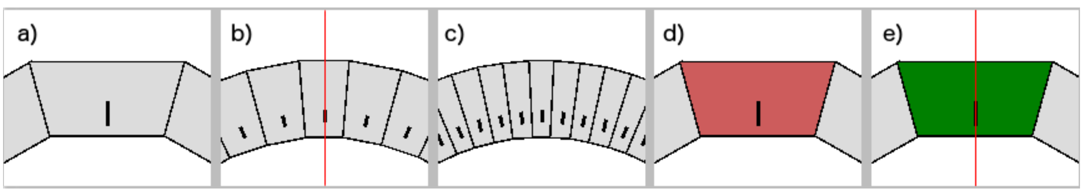


Figure 3: Different segment size, from easy 30° (a), over middle 10° (b), up to 5° hard (c). A laser beam represents the current inclination angles of the Shimmer3 EXG Unit (c). A segment that has to be hit will be coloured in red (d) and if the laser beam hits, the segment will change the colour to green (e).

The precision of the resulting inclination angles of the Shimmer3 EXG Units can be affected in two ways. First, the angular accuracy in seven different decimal places (1.0°, 0.5°, 0.2°, 0.1°, 0.05°, 0.02° or 0.01°), and second, the mean value of the received sensor measurements (1-10 measurements) can be composed.

To adjust the Shimmer3 EXG Unit, the sensitivity of the accelerometer, magnetometer and gyroscope can be configured. To set up the count of sensor measurements or a faster data transfer, there are options for the baud rate and sampling rate.

After a sensor measurement series, the collected data is getting recorded into an SQL database, and the evaluation for each row can be analysed.

5. Segments

Points for the segments have to be calculated. Each seg-ment is a trapezium and draws by four points. Figure 5 a-c show points that have to be computed for the opinions; easy, middle and hard. For instance, in figure 5 c the first element needs to have two points of -90° and two points of -82.5°. Furthermore, the short line in the middle of each segment is also a construct of two points, which are calculated by the angle of two outer points of a segment. For example, the first segment in figure 5 b is between the angles -90° and -75°. Therefore, the middle line is a construct of two points at the angle -82.5°.

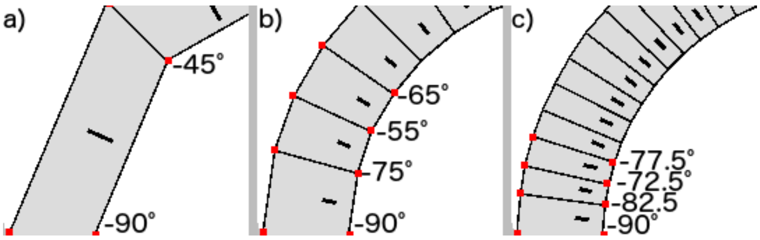


Figure 4: Each outer point of the segment has to be calculated to identify how to draw a segment (a = easy (30°); b=middle (10°); c = hard (5°).

6. Recording

The illustration in figure 5 shows the main program in the extended view during a recording of a sensor measurement series. For the approach in this paper, there are five timers active during a sensor measurement series which runs every 100 milliseconds, if they are activated.

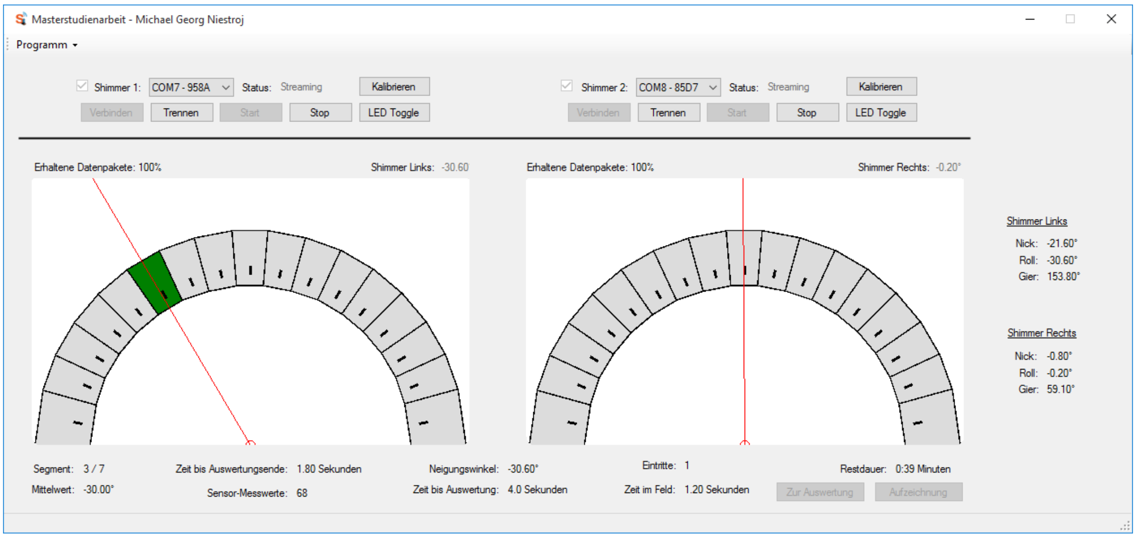


Figure 5: Extended main frame during a running sensor measurement series.

The timer class (System.Timer) that is integrated in C# is inaccurate because C# is not a real-time programming language, and Windows 7 or 10 are not real-time operating systems [5]. As a result, the timer classes run out of time. For instance, after 5:00 minutes of application time, a stopwatch will show 5:44 minutes. For the purpose of this paper, it is necessary to use an accurate extern clock generator such as the clock generator of a Shimmer device. Each sensor measurement data that is received by a Shimmer device includes a time stamp. The Shimmer clock has a frequency of 32768 Hz. After a sensor measurement is received, the difference between the last and current sensor measurement is calculated. The Shimmer device 1 and 2 are sending at a running data stream continuous sensor measurements to the Shimmer API according to the sampling rate. The refresh rate of a drawn area is thereby to be set at a limit of 25 pictures per second.

During an active evaluation for a segment, the resulting inclination angle is inserted into the list. Before a new segment will be set, first the mean value, variance and standard deviation have to be calculated for the recorded inclination angles of this segment because only these three values are saved as a row into a database. At the end of the sensor measurement series the data will be written into an SQL-database.

7. Evaluation

When the evaluation frame is open (see figure 6), firstly, all available sensor measurement series are read from the SQL-database and insert into the drop-down element in the format “date timestamp (recording time, segments)”. The “id” of the last sensor measurement series is the reference for the default evaluation. After selecting another sensor measurement series, the reference will be set to the new “id”.

The detail information about a sensor measurement series is read from a second SQL-table by using the “id” as reference to get relevant data rows. Finally, the mean values are calculated and represented at the bottom of the frame, and a pie chart shows the number of evaluated segments as a hit rate.

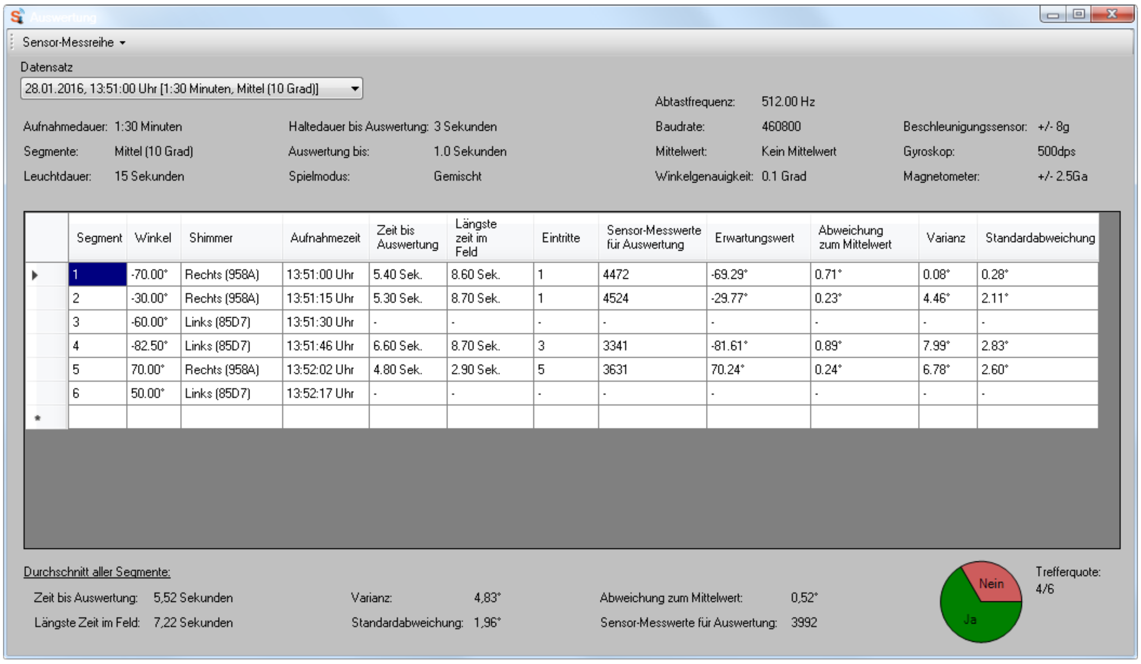


Figure 6: Evaluation of a sensor measurement series.

8. Results

Inclination Angles

In this test a Shimmer device is attached to a rotatable plate, and then a mechanical angle meter is also used to set the plate into the right inclination angle (see figure 7). After that, the data stream is started in the application of this paper. When a Shimmer device settled down, the inclination angle was noted.

By looking at table 3, both Shimmer devices are showing similarities. At a given angle at 0°, the inclination angles of both Shimmer devices were at around 0°. At a given inclination angle at 45°, the inclination angles of both Shimmer devices were at around 42.5°. At a given inclination angle at 90°, the inclination angle of the Shimmer device 958A was around 83.6° and of Shimmer device 85D7 at around 86.8° (here shows the Device 85D7 better results). However, at the given inclination angle -90°, the results were again similar with -86.0° for Shimmer device 958A and around 87.4° for Shimmer device 85D7. Therefore, it is conceivable that the Shimmer device 85D7 is better calibrated that Shimmer device 958A. The calibration is carried out with the "Shimmer 9DoF Calibration V2.8" tool for Microsoft Windows of the company Shimmer [6].

Figure 7: Experimental setup to prove the inclination angles of a Shimmer device.

Set Angle	Shimmer Device ID	
	958A	85D7
0°	≈ 0°	≈ 0°
15°	≈ 14.5°	≈ 14.5°
-15°	≈ -14.5°	≈ -14.7°
30°	≈ 28.4°	≈ 28.6°
-30°	≈ -28.4°	≈ -28.9°
45°	≈ 42.2°	≈ 42.5°
-45°	≈ -42.4°	≈ -42.9°
60°	≈ 57.2°	≈ 56.4°
-60°	≈ -56.7°	≈ -57.6°
75°	≈ 71.4°	≈ 72.0°
-75°	≈ -71.2°	≈ -72.0°
90°	≈ 83.9°	≈ 86.8°
-90°	≈ -86.0°	≈ -87.4°

Table 2: Evaluation of the inclination angles accuracy.

Real-time Support

In this experiment we will discover how many sensor measurements we can receive per second when both Shimmer devices (958A and 85D7) are connected. For that test, a Broadcom Bluetooth 2.1 USB device is used with Microsoft Windows 10. Table 3 indicates the results of this laboratory experiment. The table shows that with a default baud rate of 115200 (Bits per second), the Shimmer devices can function at up to 256 Hz. Above this sampling rate, the Shimmer API shows a defect received data packet range for both Shimmer devices. Trials with a higher baud rate of 230400 for the sampling rate 512 Hz provide stabilized results at 100 % received data packets. With a baud rate of 230400 and 1024 Hz, sensor measurements cannot be received. However, by increasing the baud rate to 460800 or 921600, around 98 – 99 % of the sensor measurements can be received.

		Received Data Packets	
Sampling Rate	Baud Rate	Shimmer 985A	Shimmer 85D7
1 Hz	115200	100 %	100 %
10.2 Hz	115200	100 %	100 %
51.2 Hz	115200	100 %	100 %
102.4 Hz	115200	100 %	100 %
204 Hz	115200	100 %	100 %
256 Hz	115200	100 %	100 %
512 Hz	115200	-	-
512 Hz	230400	100 %	100 %
1024 Hz	230400	-	-
1024 Hz	460800	98-99 %	98-99 %
1024 Hz	921600	98-99 %	98-99 %

Table 3: Laboratory experiment to get the maximum possible sampling rate when two Shimmer devices are connected.

To summarize table 3, the highest sample rate for each Shimmer device must be set at 512 Hz in order to receive all sensor measurements. A sampling rate above 512 Hz, provides an inaccuracy of about 1 – 2 %, which means that of 1024 sensor measurements, around 10 – 20 measured values are lost. Therefore, it is possible to accurately read 512 sensor measurements of each Shimmer device in one second. In other words, every 0.001953125 seconds, or alternatively, every 1.95 milliseconds, a sensor measurement is received by the Shimmer API, which is by all means a real-time application for the purpose of this paper.

Timer Accuracy

The next experiment will test the customized timer clock in comparison with a stopwatch. In that case, we will look at the remaining time of a sensor measurement series since all active timers during a sensor measurement series are set to the same tick rate. The timer tick is set to 100 ms, meaning that 3000 ticks equal 5 minutes.

Table 4 shows the comparison between the represented time of the application of 5:00 minutes and a stopwatch. The columns “Tick” and “3000 Ticks” indicate the calculated error for a given sampling rate after 100 milliseconds and 5 minutes, respectively. Looking at the data rows, the calculated error is equal to the time measured by the stopwatch, which means that the timer function is very accurate. Furthermore, it can be said that the timer function is more accurate at a higher frequency.

		Error Calculated	
Sampling Rate	**Stopwatch**	**Tick (100 ms)**	**3000 Ticks (5 minutes)**
1 Hz	-	0.9 s	2700 s
10.2 Hz	9:48 m	96.0784 ms	288.24 s
51.2 Hz	5:51 m	17.1875 ms	51.56 s
102.4 Hz	5:23 m	7.4219 ms	22.57 s
204 Hz	5:07 m	2.5391 ms	7.61 s
256 Hz	5:05 m	1.5625 ms	4.69 s
512 Hz	5:05 m	1.5625 ms	4.69 s
1024 Hz	5:02 m	0.5859 ms	1.76 s

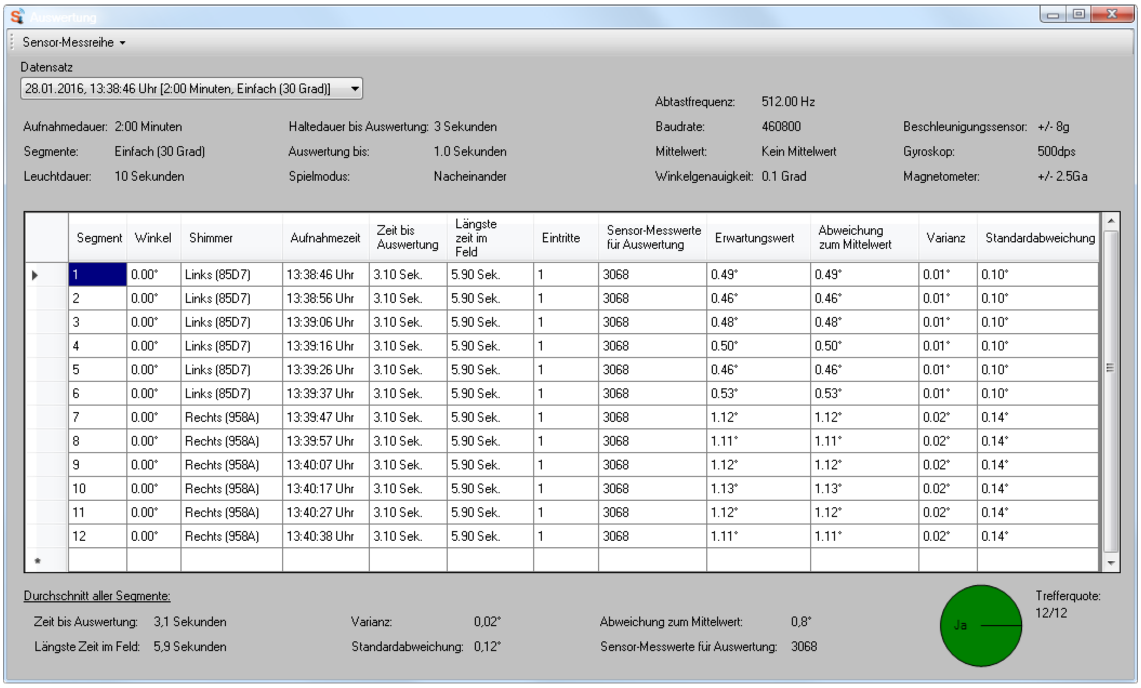
Table 4: Timer accuracy of the C# application of this paper.

Why do higher sampling rates provide an accurately timer function? The answer is quite simple: the timer runs after 100 ms at the earliest time, so a higher frequency is closer to 100 ms. For instance, if a specific sampling rate such as 102.4 Hz is set, then one step is 0.009765625 seconds or 1 / 102.4 Hz. After 10 steps, the value is appropriated to 0.09765625 s, which is less than 0.01 s or 100 ms. After another run, the value is 0.107421875 s (107.421975 ms), and the timer will run because it is more than 100 ms. The remnants of 7.421875 ms represent the error time period after 100 ms, and after 5 minutes (3000 ticks = 3000 * 100 ms), the error is summed and shows a calculated error of 22.57 s, which represents the exact time of the stopwatch (other sampling rates errors are calculated using the same principle).

For an appropriate result, therefore, the sampling rate is set to at least 204 Hz. Sampling rates below 204 Hz should be avoided because the error time period then becomes inacceptable.

Sensor Measurements

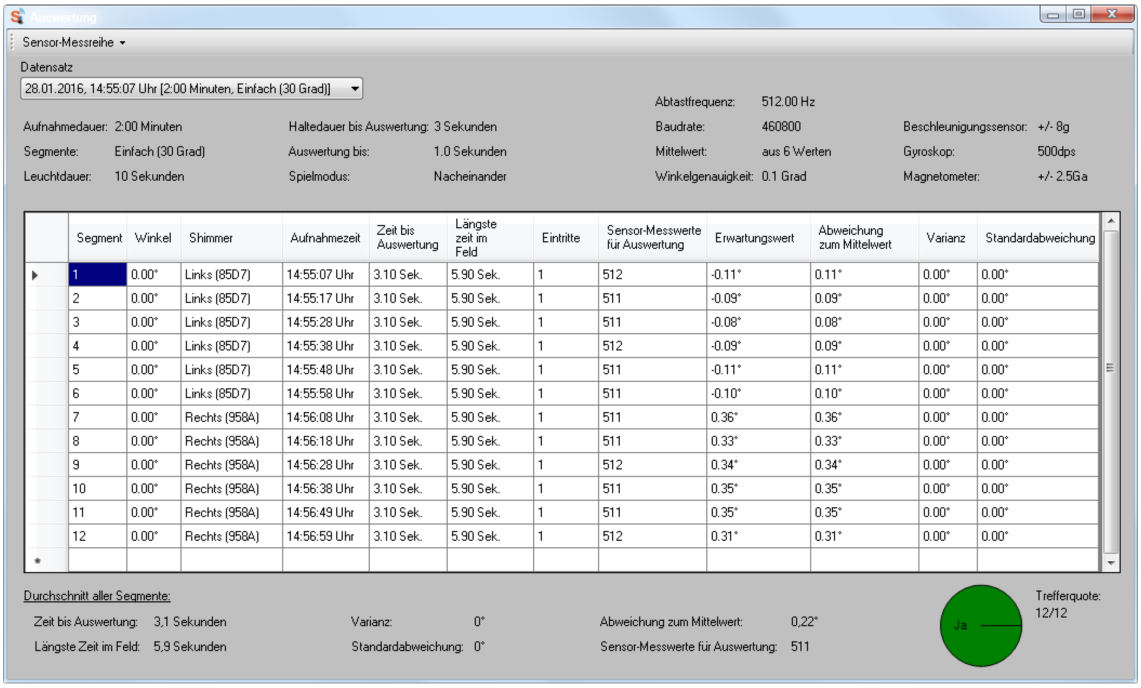
The figures 8 and 9 indicate the evaluation of two sensor measurement series with no mean value and with a mean value of 6 values, respectively. For this experiment, the configuration is customized to a segment lights up time at 10 seconds, a holding time for each segment at 1 second, and the time to stop the evaluation before the next segment lights up is set at 3 second. In sum, there are 6 second evaluation times (10-1-3 [seconds]) for each of the 12 segments because the recording time is set to 2:00 minutes (120 [seconds] / 10 = 12). Furthermore, the coloured segment is set at 0° and the Shimmer devices lie on a surface, so that the resulting inclination angles are about 0°. That means that if a segment lights up, then a device will hit this segment in next to no time.



Segment	Winkel	Shimmer	Aufnahmezeit	Zeit bis Auswertung	Längste zeit im Feld	Eintritte	Sensor-Messwerte für Auswertung	Erwartungswert	Abweichung zum Mittelwert	Varianz	Standardabweichung
1	0.00°	Links (85D7)	13:38:46 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.49°	0.49°	0.01°	0.10°
2	0.00°	Links (85D7)	13:38:56 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.46°	0.46°	0.01°	0.10°
3	0.00°	Links (85D7)	13:39:06 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.48°	0.48°	0.01°	0.10°
4	0.00°	Links (85D7)	13:39:16 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.50°	0.50°	0.01°	0.10°
5	0.00°	Links (85D7)	13:39:26 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.46°	0.46°	0.01°	0.10°
6	0.00°	Links (85D7)	13:39:37 Uhr	3.10 Sek.	5.90 Sek.	1	3068	0.53°	0.53°	0.01°	0.10°
7	0.00°	Rechts (958A)	13:39:47 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.12°	1.12°	0.02°	0.14°
8	0.00°	Rechts (958A)	13:39:57 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.11°	1.11°	0.02°	0.14°
9	0.00°	Rechts (958A)	13:40:07 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.12°	1.12°	0.02°	0.14°
10	0.00°	Rechts (958A)	13:40:17 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.13°	1.13°	0.02°	0.14°
11	0.00°	Rechts (958A)	13:40:27 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.12°	1.12°	0.02°	0.14°
12	0.00°	Rechts (958A)	13:40:38 Uhr	3.10 Sek.	5.90 Sek.	1	3068	1.11°	1.11°	0.02°	0.14°

Figure 8: Evaluation with no mean values, 6 seconds evaluation time, and a sampling rate of 512 Hz.

As we can see in figure 8, each of the 12 data shows time to evaluation as a value of 3.10 seconds, and as a value for the longest time period inside an area by 5.90 seconds. In that time, each segment in the left picture box received 3068 sensor measurements of the Shimmer device (Shimmer Left (85D7)) and in the right picture box as well (Shimmer Right (958A)), which is a very accurate result.



Segment	Winkel	Shimmer	Aufnahmezeit	Zeit bis Auswertung	Längste zeit im Feld	Eintritte	Sensor-Messwerte für Auswertung	Erwartungswert	Abweichung zum Mittelwert	Varianz	Standardabweichung
1	0.00°	Links (85D7)	14:55:07 Uhr	3.10 Sek.	5.90 Sek.	1	512	-0.11°	0.11°	0.00°	0.00°
2	0.00°	Links (85D7)	14:55:17 Uhr	3.10 Sek.	5.90 Sek.	1	511	-0.09°	0.09°	0.00°	0.00°
3	0.00°	Links (85D7)	14:55:28 Uhr	3.10 Sek.	5.90 Sek.	1	511	-0.08°	0.08°	0.00°	0.00°
4	0.00°	Links (85D7)	14:55:38 Uhr	3.10 Sek.	5.90 Sek.	1	512	-0.09°	0.09°	0.00°	0.00°
5	0.00°	Links (85D7)	14:55:48 Uhr	3.10 Sek.	5.90 Sek.	1	511	-0.11°	0.11°	0.00°	0.00°
6	0.00°	Links (85D7)	14:55:58 Uhr	3.10 Sek.	5.90 Sek.	1	511	-0.10°	0.10°	0.00°	0.00°
7	0.00°	Rechts (958A)	14:56:08 Uhr	3.10 Sek.	5.90 Sek.	1	511	0.36°	0.36°	0.00°	0.00°
8	0.00°	Rechts (958A)	14:56:18 Uhr	3.10 Sek.	5.90 Sek.	1	511	0.33°	0.33°	0.00°	0.00°
9	0.00°	Rechts (958A)	14:56:28 Uhr	3.10 Sek.	5.90 Sek.	1	512	0.34°	0.34°	0.00°	0.00°
10	0.00°	Rechts (958A)	14:56:38 Uhr	3.10 Sek.	5.90 Sek.	1	511	0.35°	0.35°	0.00°	0.00°
11	0.00°	Rechts (958A)	14:56:49 Uhr	3.10 Sek.	5.90 Sek.	1	511	0.35°	0.35°	0.00°	0.00°
12	0.00°	Rechts (958A)	14:56:59 Uhr	3.10 Sek.	5.90 Sek.	1	512	0.31°	0.31°	0.00°	0.00°

Figure 9: Evaluation with a mean value of 6 values, 6 seconds evaluation time, and a sampling rate of 512 Hz.

In figure 9, the columns “time to evaluation” and “longest time period inside an area” show the same accurate time periods as shown in figure 8. The inclination angles are therefore a mean value of 6 values, which usually required 511.33 (3068 / 6) received sensor measurements. As we can see, the amount of received sensor measurements fluctuate between 511 and 512. That is also a very accurate measurement because 3068 / 6 is not exactly 511. The effect is that sometimes more/less values are included into the mean value calculation, within a time period, which infer 511 and 512.

Although the timer functions work accurately, we can see in figure 8 and 9 in the column for the recording time that the time period between two rows is regularly 10 seconds. However, it is possible for the time period to be 11 seconds. The recording time is read directly by a Windows operating system. In that case, it it is hard to estimate if the clock of a Shimmer device is inaccurate or if the Windows system time is inaccurate.

9. Conclusion

In conclusion, the approach of this paper depicts a sophisticated solution to analyse the stability of human wrists with the use of two Shimmer3 EXG Units. For instance, the application can be used for medical therapies in the case of Parkinson's disease or epilepsy. Therefore, the test person has to hit a specific inclination angle and hold the wrist in a stable position. After the recording, it is necessary to examine the sensor measurement data. The timer functions are accurate, allowing the same number of sensor measurements to be received within a certain time period.

During the evaluation of sensor measurements of a segment, the standard deviation and variance is calculated. Therefore, the wrist position at rest can be analysed by observing the appropriate data columns in the evaluation frame.

In further work, the application could be extended with the use of ECG sensor measurements. The Shimmer devices have connectors, allowing them to work with ECG. With the use of ECG sensor data, a time sensitive aspect would become a part of this work. In addition, an extended evaluation could represent a possible stress factor that might cause hasty movements.

Another opportunity for further research is to work with Shimmer's integrated EMG sensors. In that scenario, biomedical sensor pads are attached along the arm muscles. When the wrist revolves, then a muscle contraction will be measured and evaluated.

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