Izmir Institute of Technology

Faculty of Engineering

Department of Mechanical Engineering

ME 457 – Introduction to Biomechanics

Final Report

Part II:

Group No: 4

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Abstract: A set of daily activities were measured using Qualisys and Rokoko. The measurements obtained by the latter are compared to the former using various metrics, mainly the Bland-Altman plot. Rokoko data was confirmed to fit the standards set by Qualysis. The joint angles over time during several daily activities were observed.

1. Introduction

The focus of the previous report has been mainly around the acquisition process of motion capture (**mo-cap**) data. The methods of mo-cap that are employed for the subject of the report are one marker-based system, Qualisys motion capture system, and the markerless system, Smartsuit Pro by Rokoko. The data was collected for two subjects over two separate sessions. The subjects emulated daily life activities, such as lifting an object off the ground, or walking over an obstacle. The full list of activities is included in appendix A.1.

New and groundbreaking systems and equipment in the field of mo-cap are developed as the technology progresses. This necessitates the evaluation of the said new systems, and with no recorded ground truth to compare to, the next best comparison reference is the gold-standard system in a field. In this case, the results obtained from Rokoko will be compared to those from the Qualisys system.

The focus of the following analysis is mainly around the lower body.

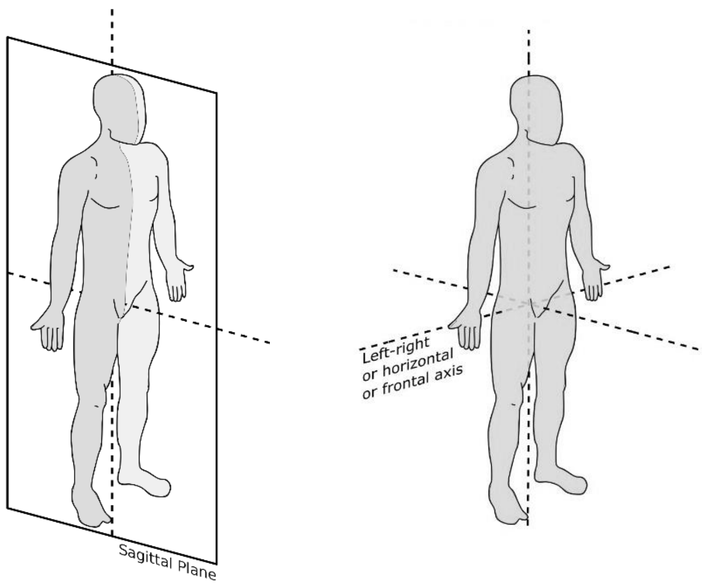

Figure 1: The sagittal plane (a) and the frontal axis (b) shown [1].

2. Planes and Axes

The data was analyzed with relation to the sagittal plane, with rotations around the mediolateral axis, as this was the most relevant axis with regards to the motions employed, where the largest relative deviations are observed. More specifically, knee and hip flexion angles in this case.

As both systems use different reference points for joint angle measurements the data must be processed before the ranges of motion are compared. In Rokoko, the joints and bones are recorded with respect to the preceding element (position and orientation of femur with relation to pelvis —which refers to flexion, if examined in the sagittal plane—, for instance). This is the case since there exists a hierarchy of bones with the torso as the main branch. This is not the case in Qualisys, where the angles measured are absolute with relation to the global coordinate system set within the calibration process.

2.1. Virtual3D Data Acquisition Procedure

Data recorded with the Qualisys motion capture system was used as input for the software Visual3D Professional™, a software designed to be utilized for biomechanical modeling, kinematics and kinetics analysis [2]. The Qualisys motion capture procedure was outlined in the previous report, and is therefore omitted for brevity. Additional screenshots could not be obtained due to the limited time provided on the laboratory computer, in which Visual3D was installed. The first step in processing the Qualisys data when processing Qualisys data via Visual3D was the selection of the preset pipeline named "Biomechanics_final.v3s". This pipeline contains the functions that otherwise would have been manually executed in order. The intermediate steps such as importing and selecting files are omitted for brevity.

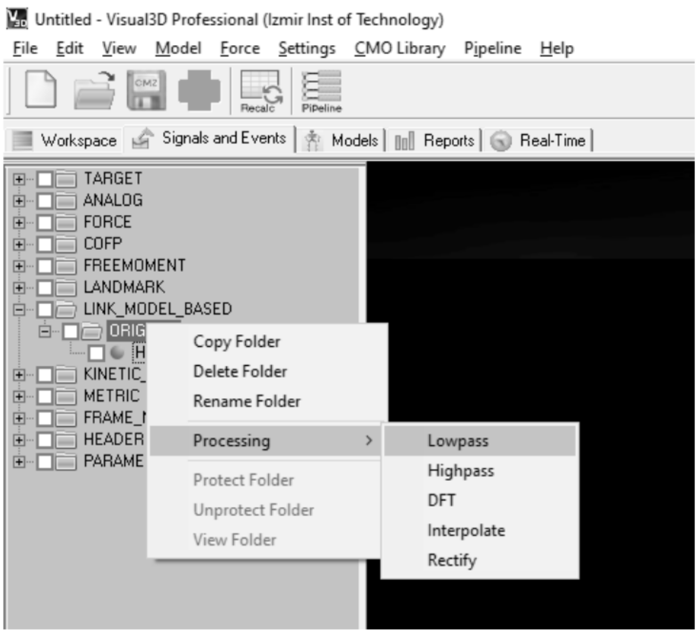

Figure 2: Processing drop-down menu in Visual3D Professional.

The data is processed using a lowpass filter. The reason behind this is that 98% of motions executed by humans fall below 10 Hz, with normal gait frequencies between 4 and 6 Hz [2]. The measurements contain noise at higher frequencies, which are to be mitigated and ideally eliminated. The loss of valuable information contained within the data begins at cutoff frequencies of around 5 Hz.

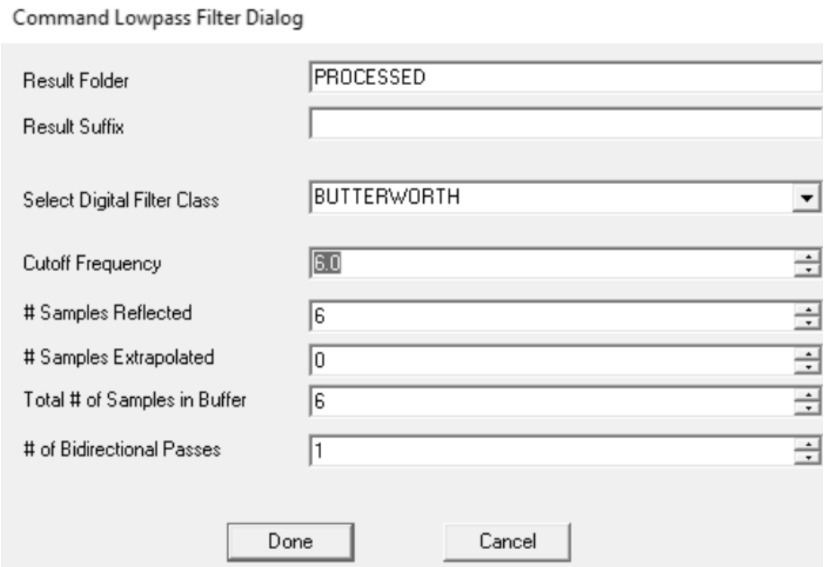

Figure 3: Processing filter settings. Cutoff frequency is set to 6 Hz.

The processing settings described above were applied to each of the following: ankle, knee and hip angles for each leg. Following that, the data was exported as ".tsv".

2.2. Rokoko Data Acquisition Procedure

Markerless motion capture procedure using Rokoko was outlined in the previous report, and is therefore omitted in the current one. The data obtained previously was batch-processed with the following settings under the "Live filters" drop-down menu.

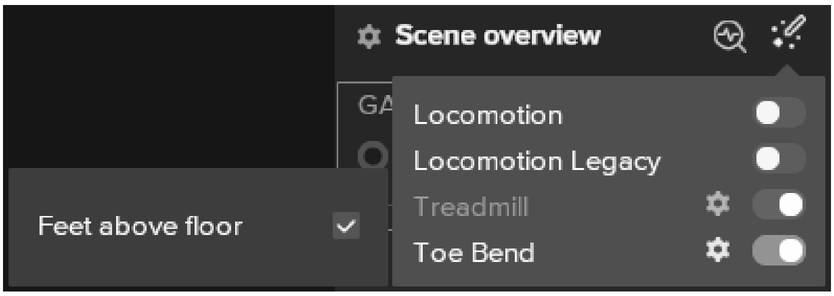

Figure 4: Post-processing filters used within Rokoko Studio.

The setting "Treadmill" made it so that the model is always centered at the origin of the global coordinate frame. And the settings "Toe Bend" and "Feet above floor" corrected for the stiff foot modeling on the ground contact due to a lack of toe sensors, and the frames where the feet of the subject appeared to phase through the ground respectively.

In Rokoko Studio, the movement of consecutive skeleton elements do not use the same reference frame as the Visual3D software, and therefore to establish agreement, Rokoko results were inverted to reflect the industry standard of taking the flexion angles as deviation from the previous segment's axis in the freely bending direction [3, 4].

Rokoko offers the choice to export each body element position/angle into one file. The chosen file format was ".csv". The data were then graphed, and the cycles of motion were determined along with the visual reference in Rokoko Studio for validation.

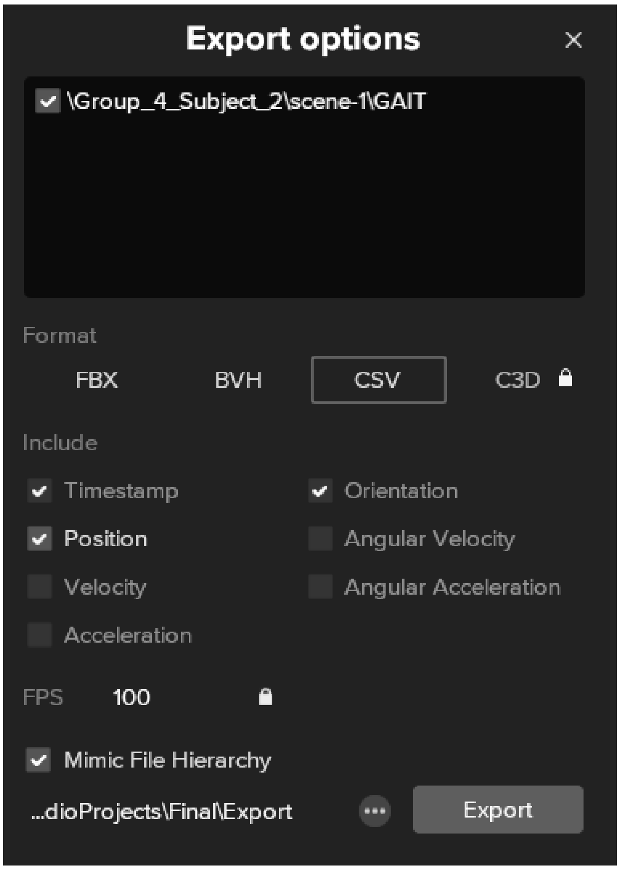

Figure 5: Export settings used within Rokoko Studio.

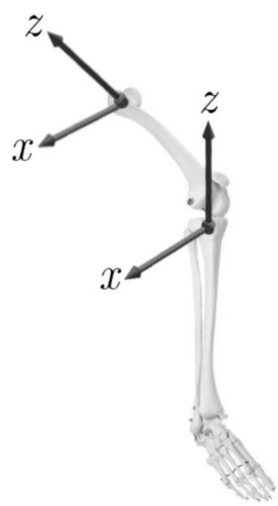

Figure 6: Hip and knee joints and their local coordinate systems

3. Range of Motion (ROM) and the Bland-Altman Plot

Range of motion, or ROM, is the range of values (position, angle) of an element observed during a particular instance of motion, as shown in figure 7.

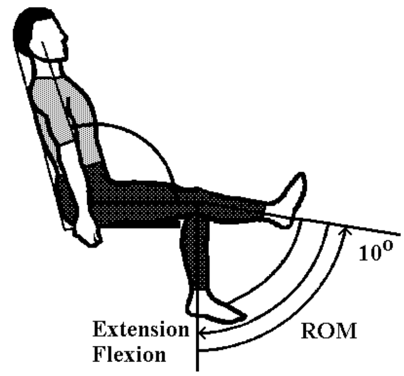

Figure 7: Rapid knee flexion-extension and its corresponding range of motion [5].

For any given cycle of motion, it is expressed as

$$ROM = \text{max. value of data - min. value of data} \tag{1}$$

The ROM values measured are expected to be less than the full range of motion of a joint due to the nature of the motions executed.

To compare the Rokoko with Qualisys, Bland-Altman plots are used. The Bland-Altman plot is a quantitative representation of how closely an assay matches another. In this case Rokoko is compared to Qualisys, which is assumed to be the ground truth. A Bland-Altman plot is obtained from the following calculations.

For all cycles, the difference of the data between the two systems are calculated, and are averaged.

$$\text{Difference} = \text{ROM}_\text{Q} - \text{ROM}_\text{R} \tag{2}$$

Where subscripts Q and R represent the data from Qualisys and Rokoko respectively.

$$\text{Mean} = \frac{(\text{ROM}_\text{Q} + \text{ROM}_\text{R})}{2} \tag{3}$$

For five cycles, bias is calculated as

$$Bias = \frac{1}{N}\sum_{i=1}^{N}(\text{ROM}_\text{Qi} - \text{ROM}_\text{Ri}) \tag{4}$$

Where i denotes the No. of cycle and N denotes the total number of cycles in the calculation. Then, (sample) standard deviation, S, of the differences is calculated. Followed by upper and lower limits, U and L.

$$S = \sqrt{Variance} = \sqrt{\frac{\sum_{i=1}^{N}(\mathrm{Difference_i} - \mathrm{Bias})^2}{(N-1)}} \tag{5}$$

$$U = Bias + 1.96 \cdot S \tag{6}$$

$$L = Bias - 1.96 \cdot S \tag{7}$$

Should a minimum of 95% of the data falls within the upper and lower limits, the data being compared to the ones considered truth is deemed replicable data.

4. Graphs

This section contains the Qualisys and Rokoko for a joint flexion over time, followed by the Bland-Altman chart associated with the two. Qualisys data are shown in red and the Rokoko data are shown in blue. Horizontal lines show upper and lower limits of motion within the cycle. Five cycles each from every motion for knee and hip joints are included. The justification for the selection of these joints is provided in the following sections (see Appendix A.5 for the remaining data).

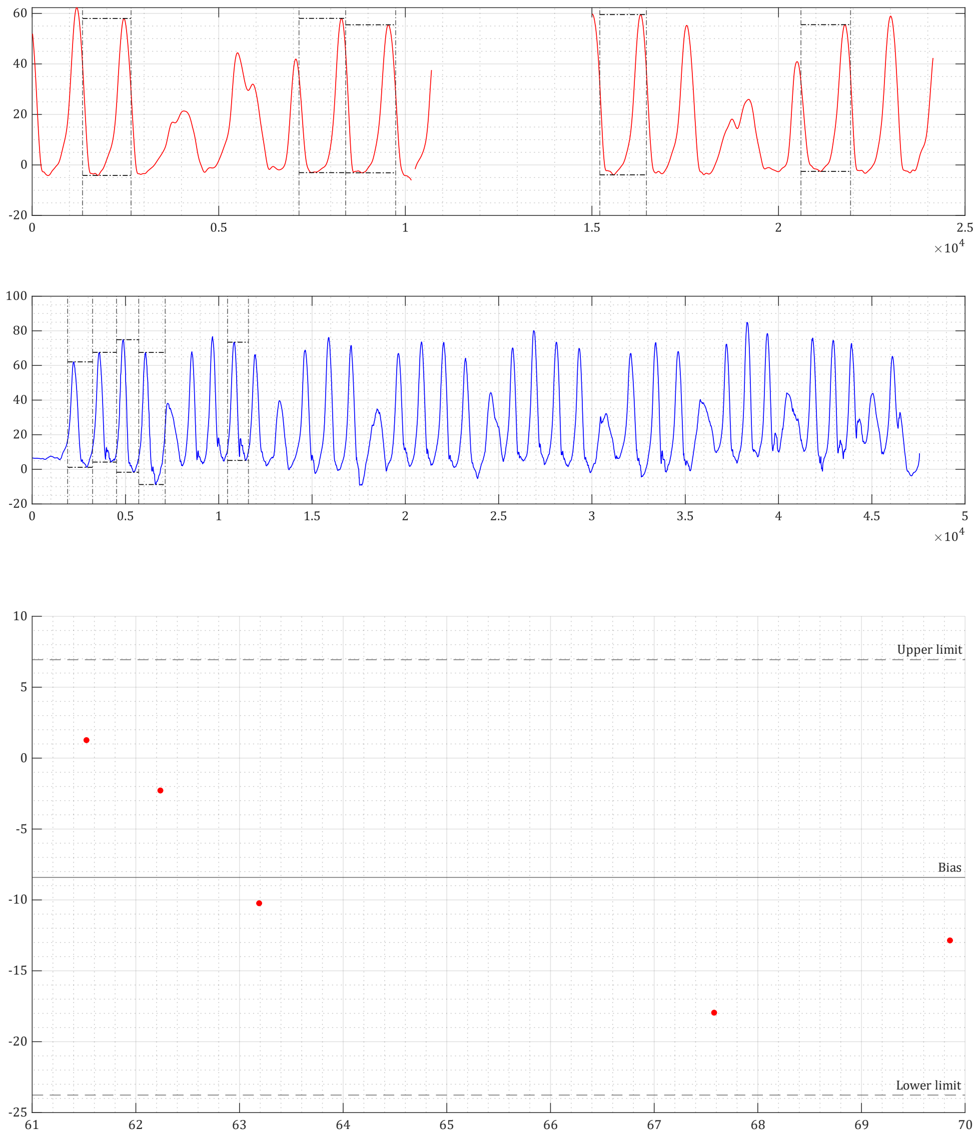

Figure 8: Left knee flexion of subject A during gait.

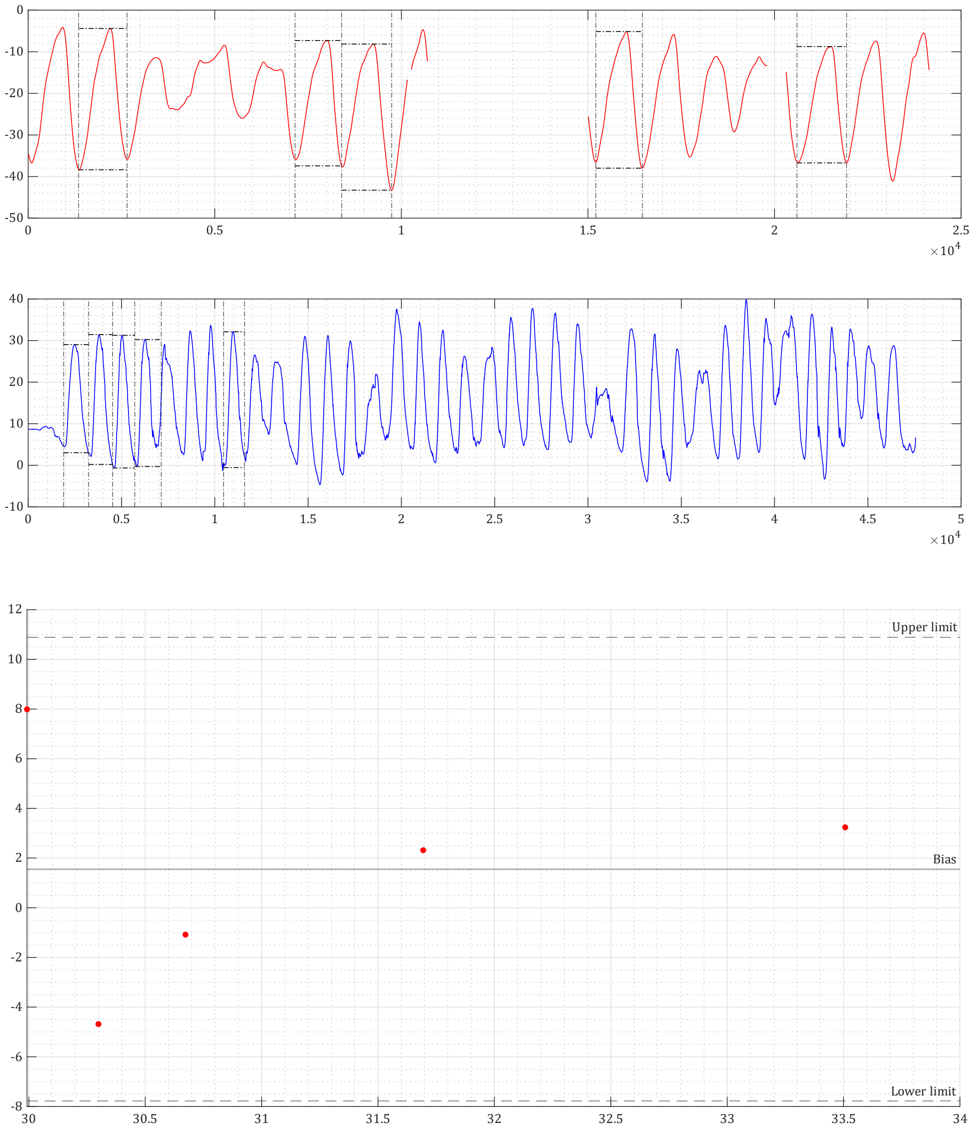

Figure 9: Left hip flexion of subject A during gait.

5. Discussion

All of the motions in the list of activities (see appendix A.1) have been executed and measured for both subjects successfully. Some activities were not applicable for measurement in Qualisys, and are therefore measured for Rokoko only. The motions chosen to be analyzed under this report are the following: gait, ruku, and Asian style sitting. The three motions have been chosen for specific reasons. Gait analysis was required by the course. Asian style sitting was chosen since it was the motion in which the greatest hip and knee mobility were observed. And ruku was chosen to ascertain whether the analyses could be executed even for minor ranges of motion, in contrast to the Asian style sitting.

For the purposes of the analyses, the joints of the left leg were chosen, as subject B was impaired by the slashing of skin caused by the marker cluster in the right lower-leg mid-session, which caused unnatural motion of the right leg. Therefore, all analyses were done for the left leg for both subjects for all motions to maintain comparability. In all motions, the hip and the knee joints were deemed most fit for the motions chosen, since the motion of the foot is partially or fully affected by ground contact in every cycle, and the ankle movement was observed to have a small delay with relation to foot position.

For some motions, stark disparities between the Qualisys and Rokoko data were observed. There are few causes that contribute to such discrepancies, such as the fact that the rigid marker clusters impeded the full flexion of the knee. The trim build of subject A allowed for free movement with Qualisys, whereas the bulkier thighs and calves of subject B caused to straps that fasten the marker clusters to come free and the sharp corners to dig into the skin at full flexion, causing uncoordinated movement. No movement restriction was noted during sessions in which Rokoko was used. Additionally, the data acquisition process was divided into two different sessions per subjects due to time limitations. As a result of the long wait in between the sessions, subjects inevitably will move in a non-identical fashion, for instance, motion frequency and movement amplitudes may differ more than they would otherwise have throughout a single session.

Unexpected motions were observed in the Rokoko Studio interface during recording. Such motions were more emphasized on and around the force plate. The software interface displayed notifications of magnetic interference during these observations. It is therefore presumed that the measurements of the Smartsuit were affected by the force plate.

6. Conclusion

Rokoko is a markerless inertial motion capture system that utilizes a suit fitted with sensors aligned to body elements, which has the distinct advantage of not requiring precise environmental setup and arduous calibration. The question the analysis attempted at answering is whether these advantages come at a price, in this case, quality of measurement.

In evaluating the performance of Rokoko, it is compared against the performance of Qualisys motion capture system, which is currently considered the gold-standard of mo-cap technology. The metric of comparison between the two assays used is the Bland-Altman plot, which can be interpreted to assess how closely Rokoko measurements agree with Qualisys measurements.

The results from Rokoko data were shown to have been affected by some factors such as magnetic interference, which were addressed in this report. Other reasons have been noted to cause discrepancy between the two measurement systems, though not to an extent that analysis is hindered.

In light of the analyses conducted, it can be said that although Rokoko is affected by magnetic effects, it can reasonably emulate the measurement quality of Qualisys, and therefore may be proposed as a somewhat suitable replacement. It is still the case that Rokoko is more well suited for artistic and visual effects (VFX) usage, as opposed to biomechanical analysis. This is supported by the segments that Rokoko markets towards [6]. Although it is more expensive and labor-intensive, Qualisys showed little to no shortcomings in terms of either recording or processing quality, which is preferable to convenience in the field of biomechanics.

References

[1] File:Anatomical Sagittal plane-en.svg. Wikimedia Commons [online]. [Accessed 7 January 2022]. Available from: https://commons.wikimedia.org/wiki/File:Anatomical_Sagittal_Plane-en.svg [virt3d] Motion Inc.. C [online]. [Accessed 6 January 2022]. Available from: https://c-motion.com/

[2] KHUSAINOV, Rinat, AZZI, Djamel, ACHUMBA, Ifeyinwa and BERSCH, Sebastian. Real-time human ambulation, activity, and physiological monitoring: Taxonomy of issues, techniques, applications, challenges and limitations. Sensors. 2013. Vol. 13, no. 10p. 12852–12902. DOI 10.3390/s131012852.

[3] KIM, Jong Hyun and WON, Byeong Hee. kinematic on ankle and knee joint of post-stroke elderly patients by wearing newly elastic band-type ankle–foot orthosis in gait. Clinical Interventions in Aging. 2019. Vol. Volume 14, p. 2097–2104. DOI 10.2147/cia.s222087.

[4] TORRICELLI, Diego, CORTÉS, Camilo, LETE, Nerea, BERTELSEN, Álvaro, GONZALEZ-VARGAS, Jose E., DEL-AMA, Antonio J., DIMBWADYO, Iris, MORENO, Juan C., FLOREZ, Julian and PONS, Jose L. A subject-specific kinematic model to predict human motion in exoskeleton-assisted gait. Frontiers in Neurorobotics. 2018. Vol. 12. DOI 10.3389/fnbot.2018.00018.

[5] PONTAGA, Inese. Hip and knee flexors and extensors balance in dependence on the velocity of movements. 2021. Biology of Sport. 21.

[6] Rokoko user stories. Rokoko User stories [online]. [Accessed 8 January 2022]. Available from: https://www.rokoko.com/users

Appendix

A.1. List of motions

Subject A

Activity No.	Activities	Duration/Repetition	
		Qualisys	SmartSuit
1	Stoop Lifting	30/5	45
2	Squat Lifting	60/11	45
3	Obstacle Crossing	45/5	45
4	Rukû' and I'tidâl	35/10	45
5	Rukû' to Sujūd	60/12	45
6	Sujūd	45/8	45
7	Asian Style Sitting	60/14	45
8	Cycling	60/NA	45
9	Crossed-Legged Sitting	-	45
10	Timed Up and Go	-	45
11	Chair Transfer	-	45
12	Climbing Stairs	-	45

Subject B

Activity No.	Activities	Duration/repetition	
		Qualisys	SmartSuit
1	Stoop Lifting	30/5	30
2	Squat Lifting	60/11	30
3	Obstacle Crossing	45/5	30
4	Rukû' and I'tidâl	35/10	30
5	Rukû' to Sujūd	60/12	60
6	Sujūd	45/8	45
7	Asian Style Sitting	60/14	45
8	Cycling	60/NA	60
9	Crossed-Legged Sitting	-	60
10	Timed Up and Go	-	60
11	Chair Transfer	-	60
12	Climbing Stairs	-	60

A.2. Ranges of motion of corresponding cycles for Qualysis and Rokoko data.

				Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Subject A	GAIT	Hip	***ROM Q***	33.98643	30.13141	35.12625	32.85172	27.95686
			ROM R	25.99785	31.21429	31.88793	30.53659	32.64137
		Knee	***ROM Q***	62.15733	61.09505	58.60218	63.42565	58.07181
			ROM R	60.88972	63.37822	76.55479	76.28167	68.30742
	RAI	Hip	***ROM Q***	53.82493	50.73348	52.69723	50.73535	48.82944
			ROM R	55.77259	53.91944	56.5623	54.25662	58.37059
		Knee	***ROM Q***	5.956316	7.698091	7.21069	7.624855	7.098013
			ROM R	9.221706	9.421054	9.221054	7.715397	6.703551
	AST	Hip	***ROM Q***	120.4215	123.6096	102.3218	99.95154	115.8791
			ROM R	104.9832	109.8691	111.7103	115.0395	110.1403
		Knee	***ROM Q***	132.3838	131.6128	124.4385	117.2879	132.9018
			ROM R	128.2132	135.6589	140.1907	141.8403	138.4082
Subject B	GAIT	Hip	***ROM Q***	38.93987	36.91663	35.60164	33.77166	37.49636
			ROM R	41.61769	37.9263	39.44592	39.83888	39.0021
		Knee	***ROM Q***	61.72724	60.55945	63.42565	58.73525	58.82671
			ROM R	66.38667	72.983	70.07959	46.8844	68.69951
	RAI	Hip	***ROM Q***	45.08432	44.5246	45.93436	48.04313	46.94776
			ROM R	14.44775	15.57001	17.87396	16.99598	16.94777
		Knee	***ROM Q***	8.907615	10.06294	10.10066	9.637326	10.84836
			ROM R	21.00532	25.2666	16.47947	13.81036	12.9745
	AST	Hip	***ROM Q***	103.8288	104.1846	105.686	106.0398	98.85213
			ROM R	70.92697	71.88227	69.91771	70.55329	72.11548
		Knee	***ROM Q***	107.6747	106.8324	111.31	110.7377	113.314
			ROM R	130.5781	128.4397	128.2016	131.7316	132.0526

A.3 Timestamps of the cycles for QTM and Rokoko studies for both subjects

File		Subject A		Qualysis		Rokoko	
Qualysis	Rokoko			Start	End	Start	End
Rep 2	GAIT 1	Gait	Cycle 1	1350	2650	1900	3240
			Cycle 2	7150	8400	3240	4520
			Cycle 3	8400	9740	4520	5710
			Cycle 4	15210	16460	5710	7130
			Cycle 5	20600	21930	10470	11590
Rep 1	Ruku 1	RAI	Cycle 1	5150	9500	5840	8690
			Cycle 2	9500	14090	8690	11580
			Cycle 3	14090	19070	11580	14670
			Cycle 4	19070	23730	14670	17830
			Cycle 5	23730	28510	17830	20970
AST_Q	AST 1	AST	Cycle 1	14290	19920	6120	9990
			Cycle 2	19920	25200	9990	14500
			Cycle 3	35540	40190	14500	19440
			Cycle 4	40190	44800	19440	24380
			Cycle 5	44800	50710	24380	28681

File		Subject B		Qualysis		Rokoko	
Qualysis	Rokoko			Start	End	Start	End
GAIT_Q	GAIT 1	Gait	Cycle 1	2390	3570	2880	4070
			Cycle 2	8900	10110	4070	5290
			Cycle 3	15280	16480	5290	6540
			Cycle 4	16480	17680	6540	7730
			Cycle 5	21420	22610	10200	11410
RAI_Q	Ruku 2	RAI	Cycle 1	4700	7500	2600	6250
			Cycle 2	7500	10390	6250	9750
			Cycle 3	10390	13640	9750	13680
			Cycle 4	13640	16820	13680	18200
			Cycle 5	16820	20090	18200	22100
AST_Q	AST 1	AST	Cycle 1	5820	10850	5960	10430
			Cycle 2	10850	15700	10430	14720
			Cycle 3	15700	20180	14720	19210
			Cycle 4	20180	24440	19210	23600
			Cycle 5	24440	28080	23600	28250

A.4. MATLAB function to obtain comparison subplots along with cycle and ROM lines.

```
[rom1,rom2]=rom_compare(motion1,motion2,time1,time2)
motion1(:,1) = motion1(:,1)*10;
motion1(:,2) = motion1(:,2);
motion2(:,2) = -1*motion2(:,2);
subplot(2,1,1);
plot(motion1(:,1),motion1(:,2),'r','LineWidth',1); grid on; grid minor;

ut1 = unique(time1);
for i = 1:length(ut1)
  xline(ut1(i),'-.','LineWidth',1);
end
hold on;
rom1 = zeros(1,length(time1(:,1)));
for i = 1:length(time1(:,1))
  x = [time1(i,1) time1(i,2)];
  y1 = max(motion1(time1(i,1)/10:time1(i,2)/10,2));
  y2 = min(motion1(time1(i,1)/10:time1(i,2)/10,2));
  plot(x,[y1 y1],'-.k','LineWidth',1);
  plot(x,[y2 y2],'-.k','LineWidth',1);
  rom1(i)=y1-y2;
end
clear i x y1 y2;
hold off;
subplot(2,1,2);
plot(motion2(:,1),motion2(:,2),'b','LineWidth',1); grid on; grid minor;
ut2 = unique(time2);
for i = 1:length(ut2)
  xline(ut2(i),'-.','LineWidth',1);
end
hold on;
rom2 = zeros(1,length(time1(:,1)));
for i = 1:length(time2(:,1))
  x = [time2(i,1) time2(i,2)];
  index1 = find(x(1) == motion2(:,1));
  index2 = find(x(2) == motion2(:,1));
  y1 = max(motion2(index1:index2,2));
```

```
    y2 = min(motion2(index1:index2,2));
    plot(x,[y1 y1],'-.k','LineWidth',1);
    plot(x,[y2 y2],'-.k','LineWidth',1);
    rom2(i)=y1-y2;
  end
  hold off;
  end
```

A.5. MATLAB function to generate Bland-Altman plot of given ranges of motion

```
function blandaltmanplotgen(rom1,rom2)
diffrom = rom1-rom2; meanrom = (rom1+rom2)/2;
S = std(diffrom); b = mean(diffrom);
upper = b + 1.96*S; lower = b - 1.96*S;
x = meanrom; y = diffrom;
scatter(x,y,500,'.','r'); grid on; grid minor; hold on;
yline([upper lower],'--',{'Upper limit','Lower limit'})
yline(b,'-',{'Bias'}); hold off;
end
```

A.6. Joint angles and Bland-Altman plots

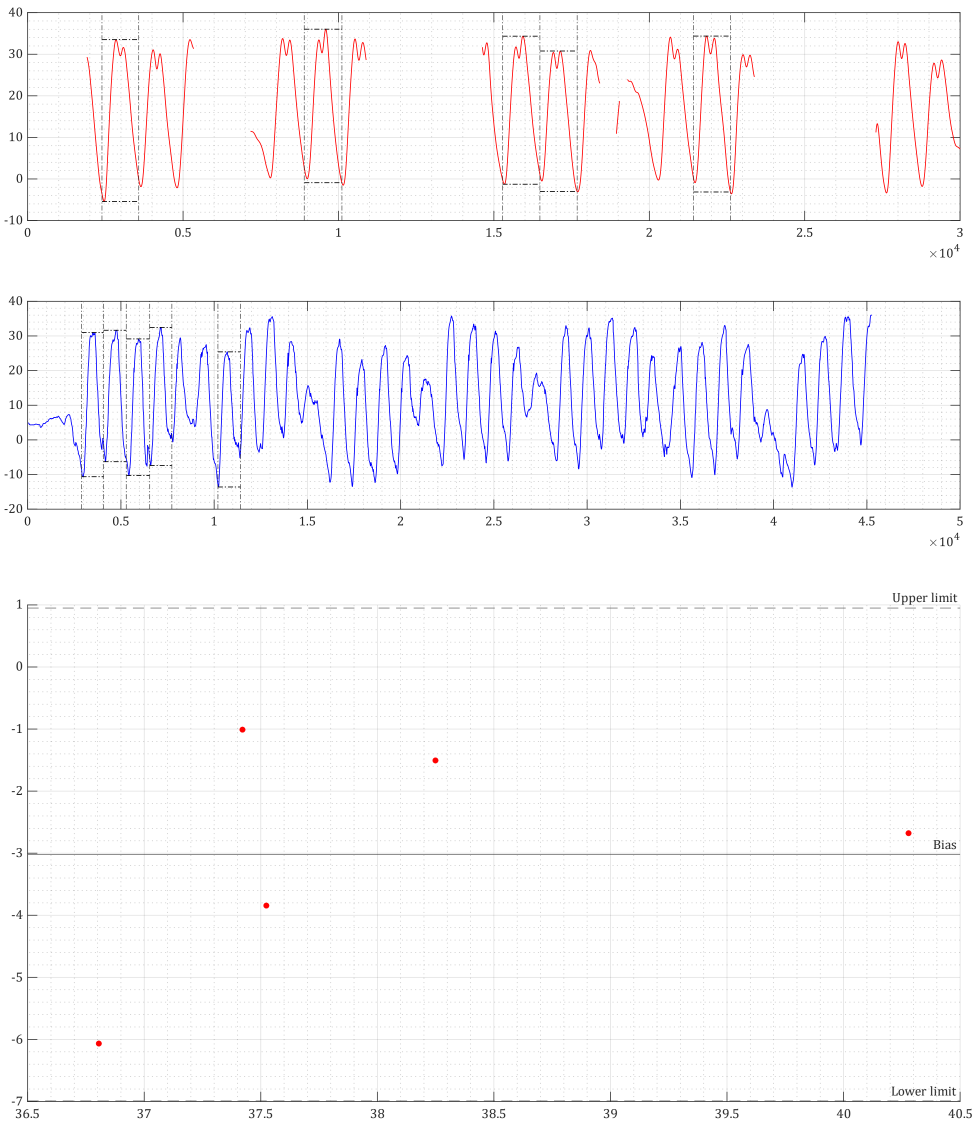

Figure 10: Left hip flexion of subject B during gait.

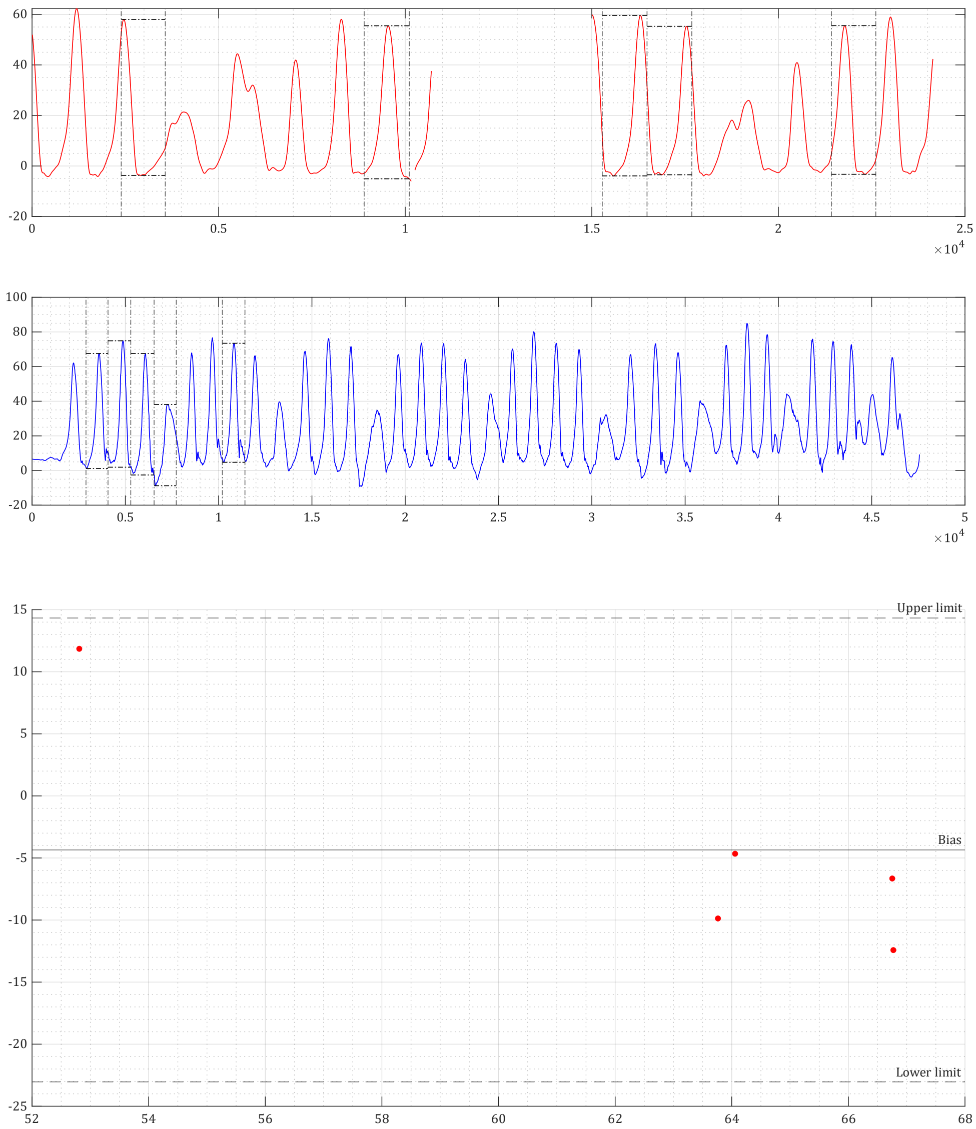

Figure 11: Left knee flexion of subject B during gait.

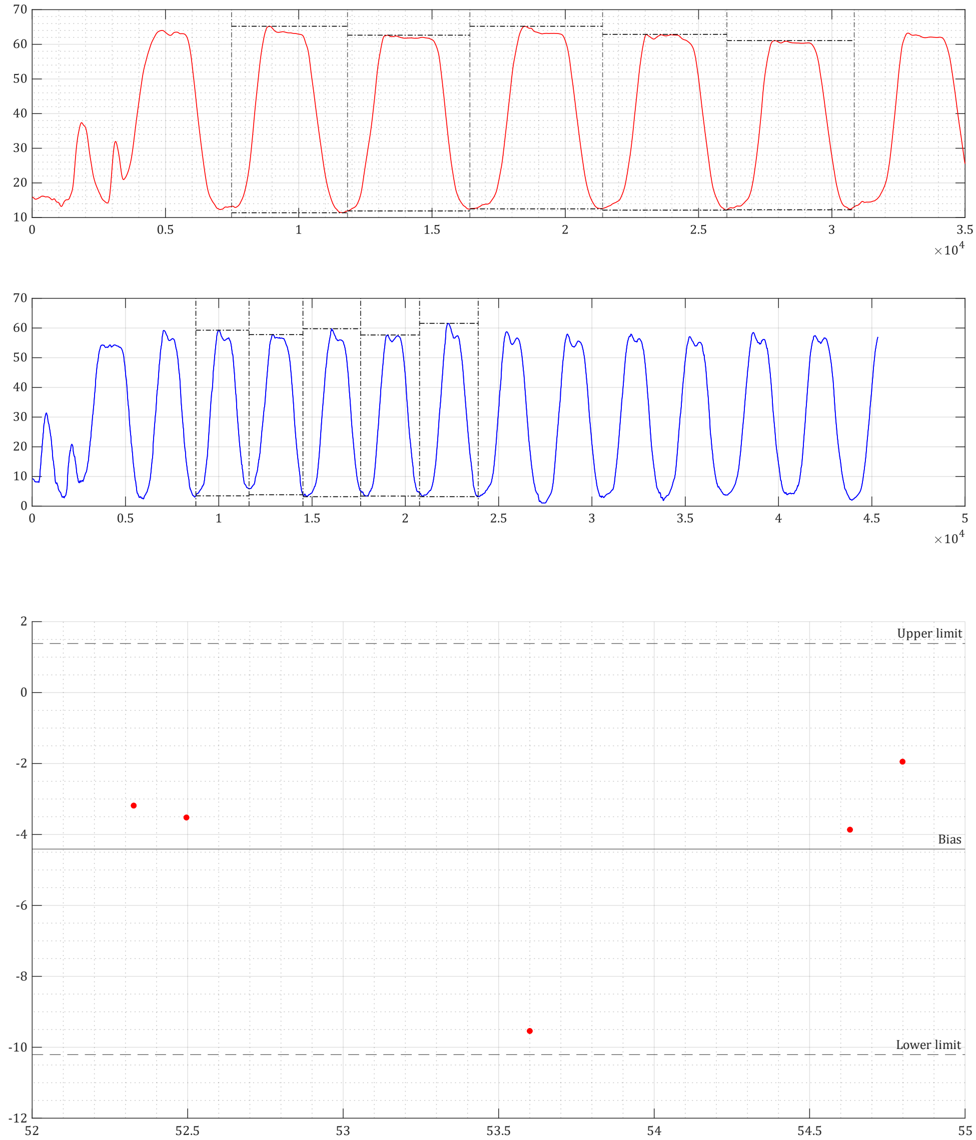

Figure 12: Left hip flexion of subject A during ruku.

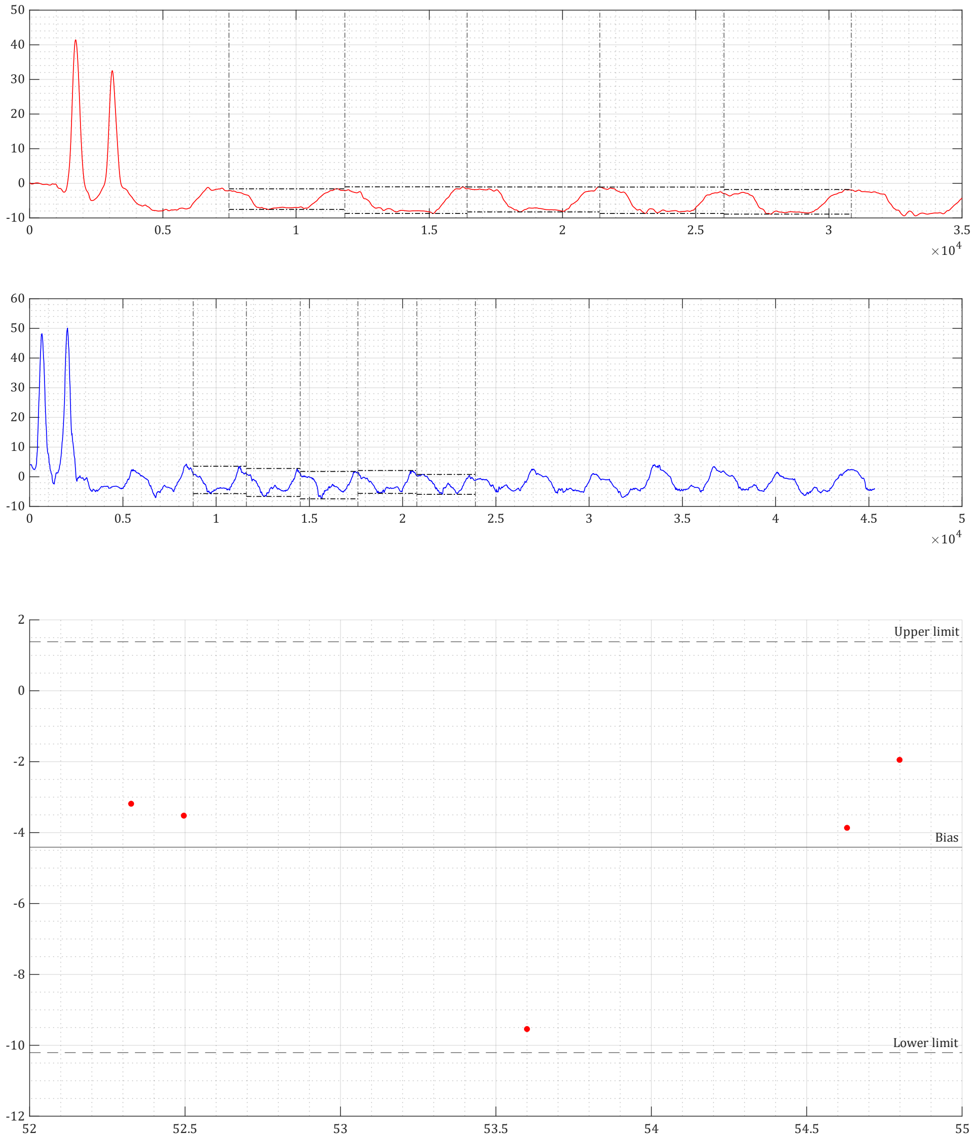

Figure 13: Left knee flexion of subject A during ruku.

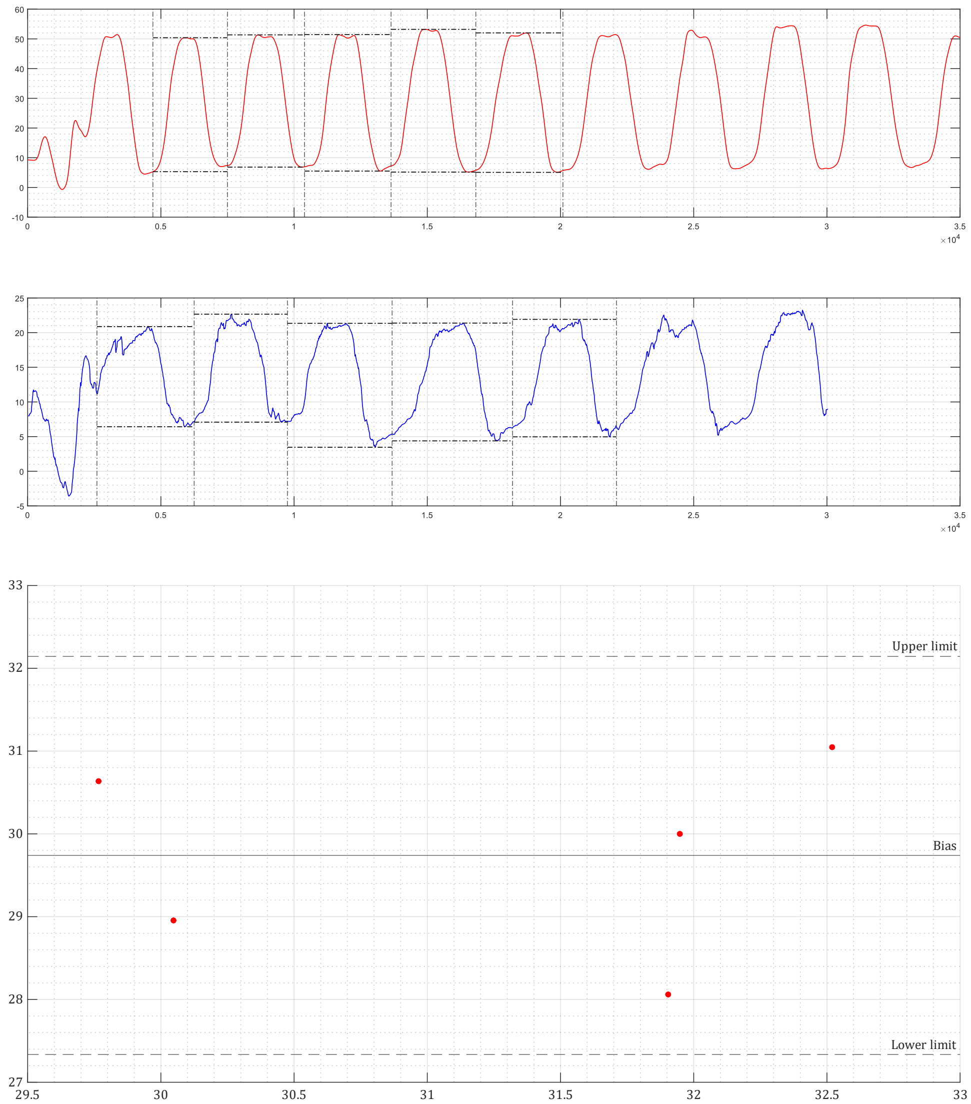

Figure 14: Left hip flexion of subject B during ruku.

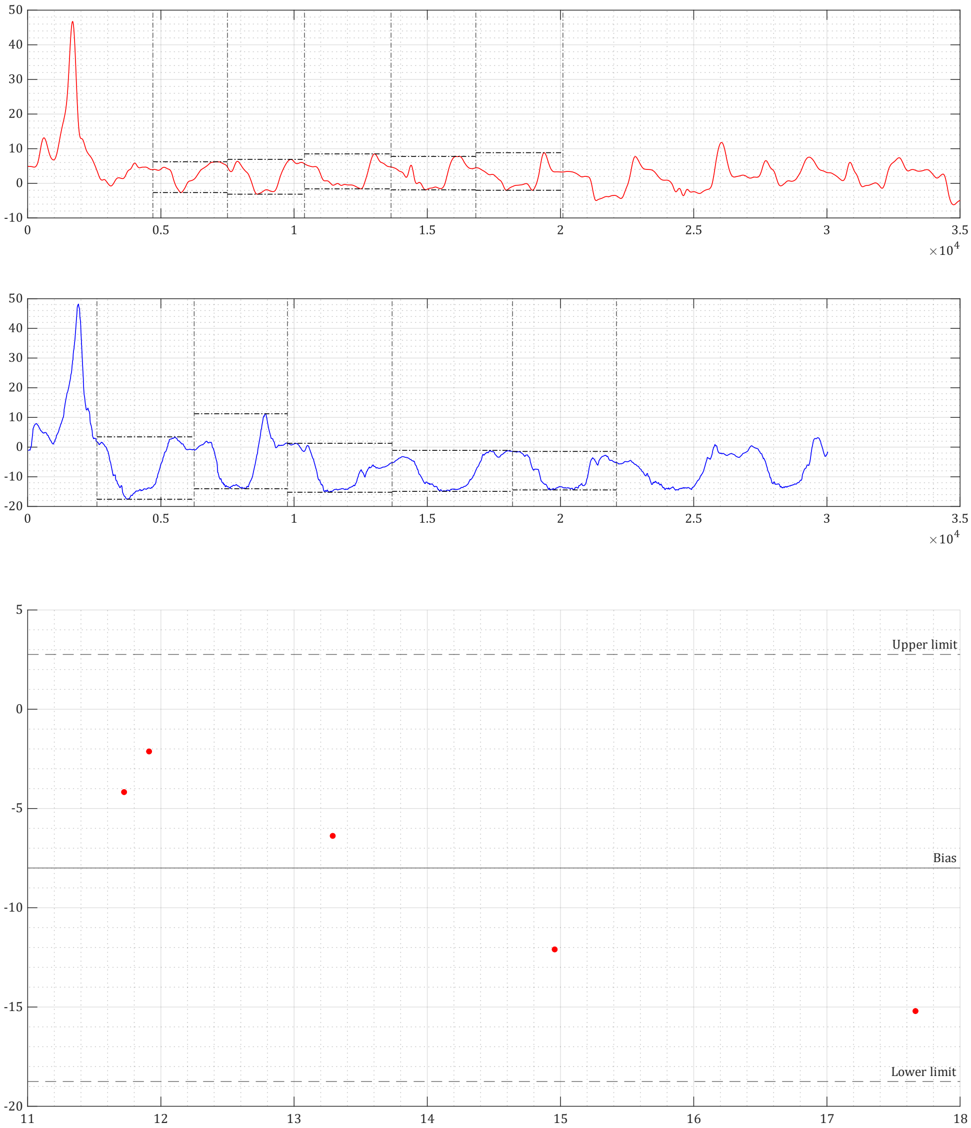

Figure 15: Left knee flexion of subject B during ruku.

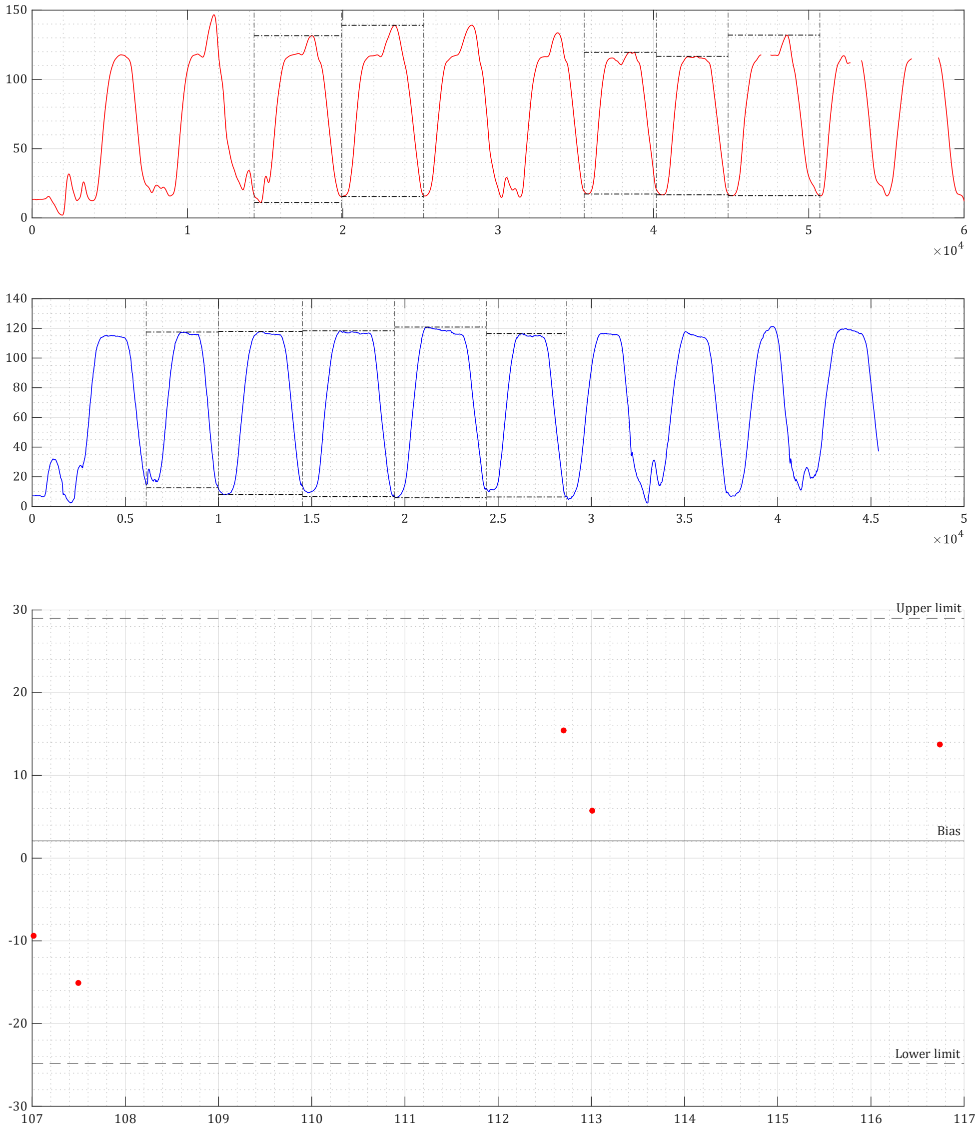

Figure 16: Left hip flexion of subject A during asian style sitting.

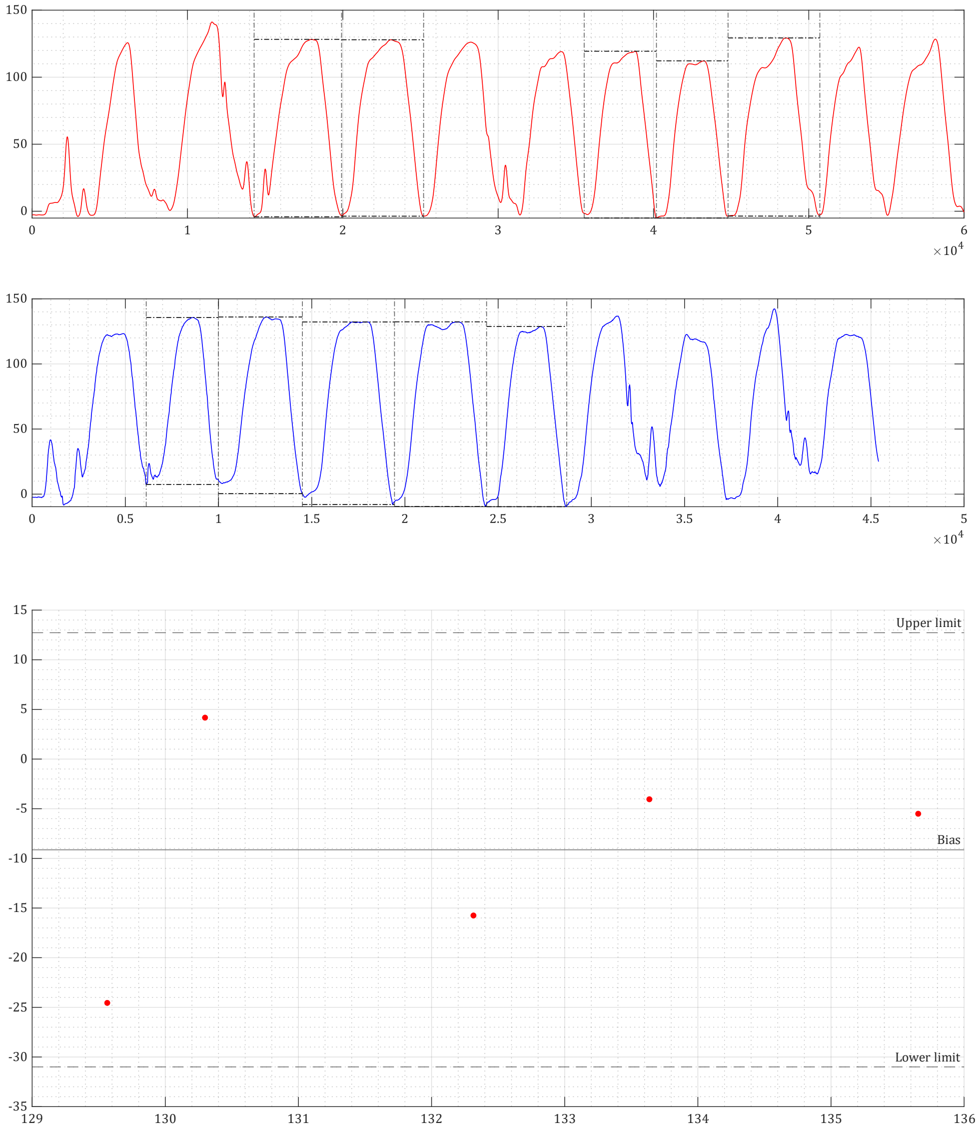

Figure 17: Left knee flexion of subject A during asian style sitting.

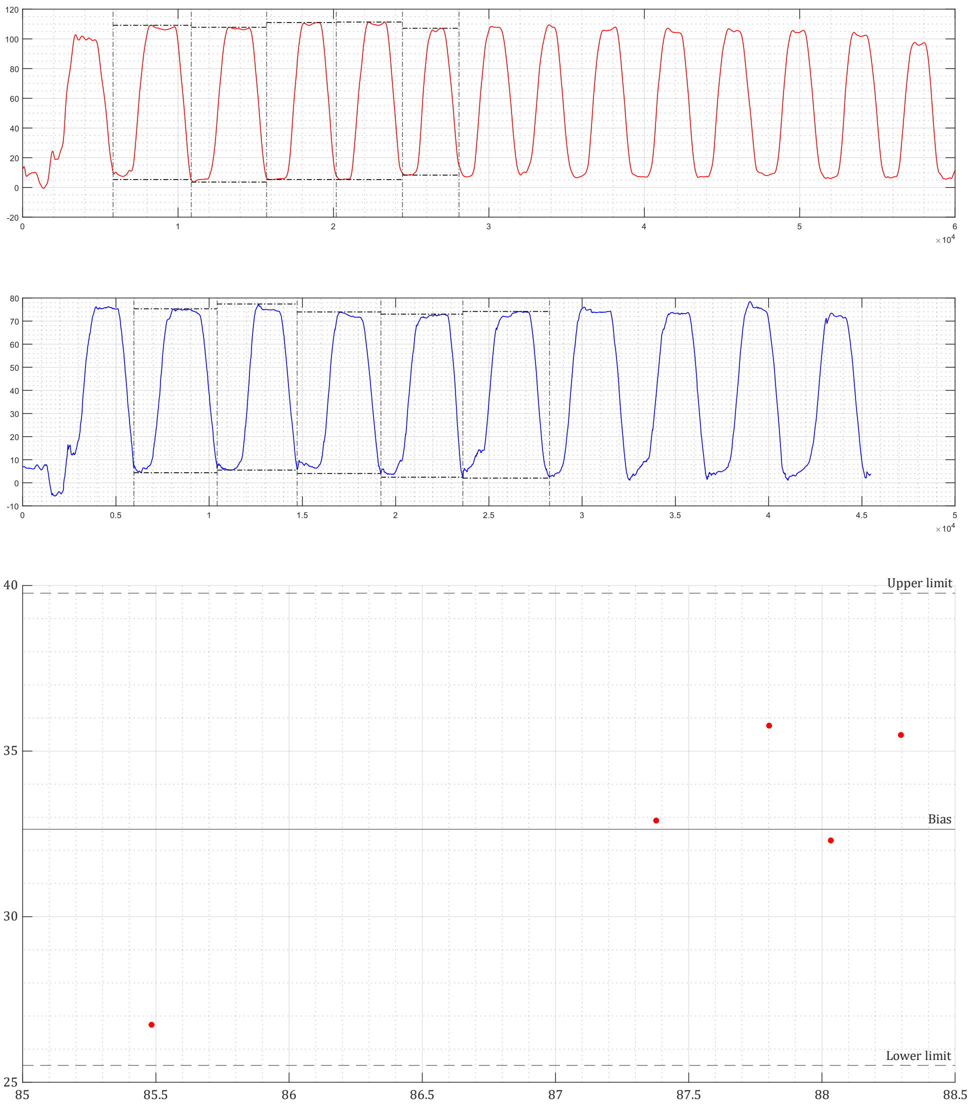

Figure 18: Left hip flexion of subject B during asian style sitting.

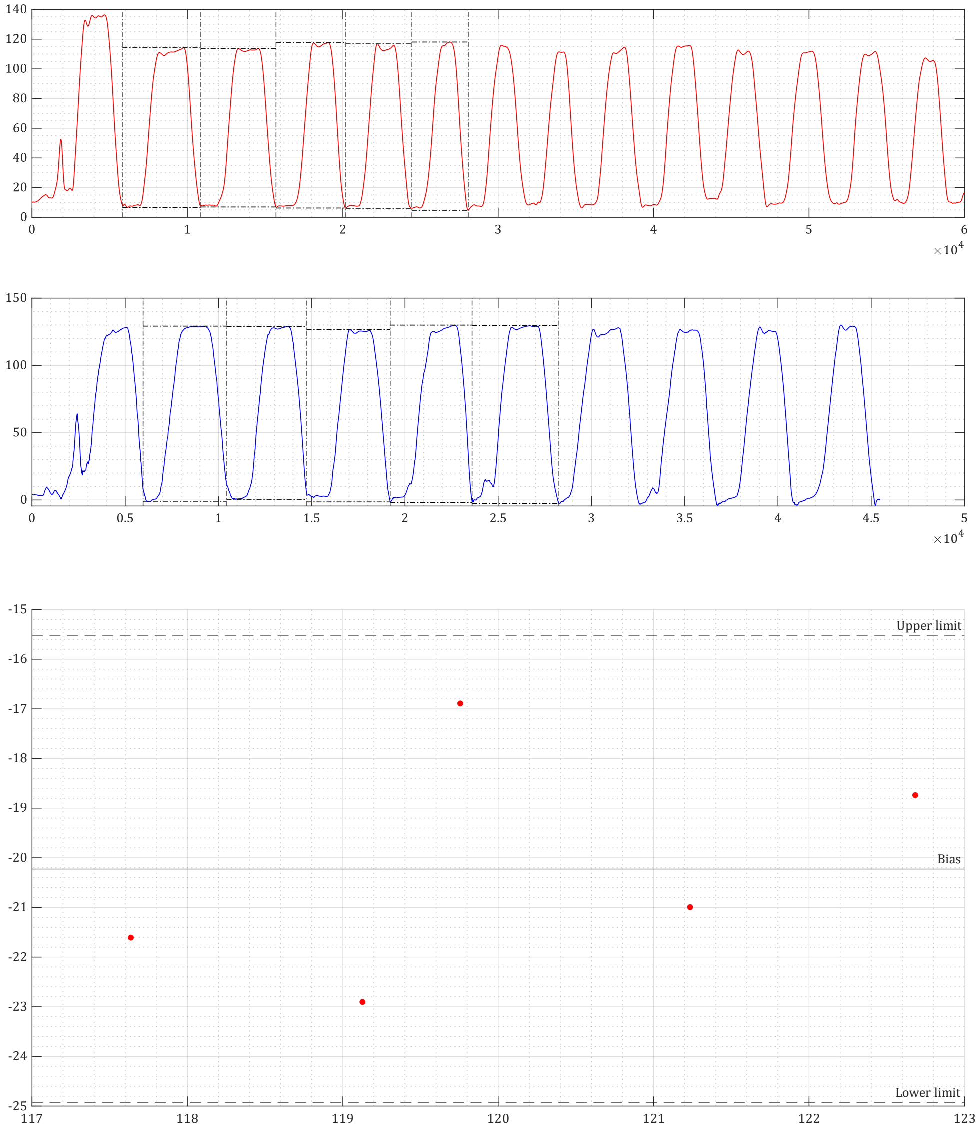

Figure 19: Left knee flexion of subject B during asian style sitting.