Comparison and evaluation of biomechanical parameters of motion capture systems

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Abstract

The present study is an under development research project, which's goal is to evaluate kinematic and anthropometric data from Microsoft Kinect. MS Kinect is already being studied since its release (2010), once it is an inexpensive alternative to the available motion capture (MOCAP) systems found in the market. The validation of its biomechanical characteristics will allow its use in gathering information to complement Ergonomic Work Analysis and other user research that provide product and work environment diagnosis through postural and dynamic assessment.

MS Kinect was used through iPi Soft, since it can acquire depth data from two consoles at the same time and due to the fact that its biomechanical model has a similar joint configuration, as opposed to other applications and motion recognition software. MS Kinect's data were compared with MVN Xsens inertial MOCAP system and 2D data based on video recording in two laboratorial experiments and a study-case based in work environments of oil and gas laboratories in the Ergonomic Work Analysis (EWA) context. A 3D Digital Platform has been developed in order to democratize information acquired from the different 3D systems without changing original data, allowing them be compared with the same output.

This paper presents methodology and results from the laboratorial experiments through two static comparisons and one dynamic. The static comparisons were: joint angles in selected static postures, where 2D data were used in the sagittal plane; and segments dimensional data, where the first goal of comparison was to ascertain if MS Kinect through iPiSoft considered the segments as rigid bodies, and the second was held using the volunteer's real dimensions, extracted with anthropometers in order to validate anthropometric data. Since each 3D system has its own local coordinate system, the dynamic comparison was based on global orientation as set in the 3D Digital Platform. Differences between the biomechanical models were considered and only joints that represented the same anatomical points were compared. Results have shown similar values and variations between the systems. Therefore, it is a valid MOCAP alternative in the means of kinematic and anthropometric analysis.

Keywords: motion capture, biomechanical analysis, MS Kinect, inertial

1. Introduction

Modeling human motion is a complex task, not only due to the amount of muscles, bones, joints and the idealization of its characteristics but mainly since each individual has its own movements. The human gait is considered as a form of biometric identifier, once each of our dimensions, as well as volumetric features, age and sex determine the way we move. (Chamberlain 2009)

From a design perspective, motion capture (MOCAP) has the potential to expand user research approach in new products development, in the design of more intelligent human-computer interfaces and interpretation of mobility disorders. (Xin et al. 2007; Dockstader and Tekalp 2002)

Knowledge and assessment of biomechanical characteristics can serve as a tool for understanding how individuals or populations interact with objects and environments, therefore, allow designers to project more efficient situations. In the Ergonomic Work Analysis context, MOCAP can provide means for postural, dynamic occupation, workflows and reaches assessment through a large set of data, which eliminates the need for individually analyzing each frame of interest, eliminating researcher bias, minimizing efforts and saving time. (Pastura et al. 2012)

When used in virtual simulations, the introduction of MOCAP in Digital Human Models (DHM) can aid the evaluation of new work layouts without them existing physically. They can also serve as a tool for training new personnel, once expertises or the specific way someone performs a task can be recorded. (Santos et al. 2013)

Aside technological limitations, (e.g. inertial systems are disturbed by metallic surfaces, or optical systems suffer from occlusion areas), the available systems in the market are yet expensive, usually demanding a high learning time and are not adaptable. The release of MS Kinect introduced the possibility to change biomechanical scenario. This video game console has been studied in this field of study due to its known advantages such as low cost, markerless and open source features. (Fernandez-Baena, et al. s/d; Chang et al. 2011; Berger et al. 2011)

The present study aims to compare, through biomechanical parameters, MS Kinect with MVN Xsens inertial system and 2D data based on video recording. The relevance of biomechanical study field for this research is the possibility to accurately evaluate kinematic and anthropometric parameters acquired from the devices.

The inertial system MVN Biomech was chosen due to its proved reliability when compared to other systems (Kider et al. 2008). In the referred study, limitations were found in two situations: proximity to metals, which disturbs the magnetic field and vertical displacement, thus succeeded in spatial orientation, occlusion areas and precision of anatomical points, which does not mean that no there was no error.

The use of 2D kinematic data acquired from video camera was chosen since it's the traditional way to assess kinematic parameters.

Being based on an open source framework, MS Kinect allows applications to be developed for different purposes. Since developing an application was not in the scope of this study, a research was performed in order to select the most adequate software. The requisites for the software were (1) the ability to capture with two consoles, in order to reduce possible occlusion areas and obtain 3D data from two depth sensors; (2) a biomechanical model with similar anatomical references to allow comparison with the inertial system's model; and (3) the possibility to export data in compatible format (FBX or BVH).

OpenNI framework and Primesense's NITE were the first alternative, but the biomechanical model offers tracking of 15 joints, without any reference to the clavicle and only one in the torso. (Fernandez-Baena, s/d). Also, when this research was conducted, capturing with two consoles was still unstable using this framework. The solution found was iPiSoft's, which consists in a two-software system. The first records information from two consoles, both calibration and action scenes, and the second processes these data. After a successful trial run, iPiSoft granted a courtesy license for the development of this research.

In order to compare the data acquired from the systems, a 3D Digital Platform was developed. This platform is based on a game engine and can be considered a neutral ground for importing data from different MOCAP systems. It calculates kinematic parameters from the data files (global orientation, global rotation, local angular velocity and joint rotation) and converts them into a file that can be imported in a database with common aspects for comparison and statistical analysis.

The Platform reconstructs the body segments based on the data file in a biomechanical model, where data are conserved from the original model, minimizing error accumulation - which happens specially when re-targeting is done.

Global orientation axes of the platform were set using ISB recommendations. (Wu et al. 2002)

2. Methods and materials

The study is based in two experiments and a study-case based in work environments of oil and gas laboratories in the Ergonomic Work Analysis (EWA) context. This paper will only expose methods and results from the laboratorial experiments, as for the study-case is still being conducted.

Both experiments were held in controlled environments, meeting repeatability conditions, as described by ASTM standards (ASTM 177-10). The systems used are described in the following subsections.

2.1. MS Kinect through iPiSoft

MS Kinect through iPiSoft's process begins with recording the background without the object of study in order to eliminate excessive noise. A calibration scene is then produced, which consists in recording a 2D rectangular marker in order to allow the system, in the post processing, to identify the edges of this object and align the images acquired from the sensors. This alignment results in a 3D point cloud. If any of the consoles change positioning, a new calibration scene must be recorded.

The object of study is then recorded performing a T pose before, after or in between the task performed. With the calibration settings, the biomechanical model can be positioned in the resultant point cloud during T pose and movement can be tracked. (iPiSoft wiki 2012)

2.2. MVN Biomech

The inertial system's process consists in positioning the sensors in the volunteer's body followed by calibration. Calibration consists in the input of subject's measurements and adopting T, N and squat poses. No post processing needed.

2.3. 2D video recording

2D video recording begins with selecting the predominant plane of movement. In the case of these experiments, sagittal plane was selected. Next, anatomical markers referents to the recorded plane were positioned in the subject's body.

This system also requires a calibration scene for the post-processing. In this scene, a known sized marker is positioned beside the object of study. Whenever this object of study changes its displacement – the same goes for camera positioning, a new calibration scene is needed. The post-processing of video data is performed frame by frame, where static postures of interest are chosen and biomechanical model is positioned, producing angular data.

2.4. Comparisons

Data acquired were compared through three parameters:

a) Global Displacement (dynamic): one limitation found was regarding the local coordinate systems original from the biomechanical models, which are different from each other. Therefore, only global displacement was compared.

b) Segments dimensional comparison (static)

The first goal of this comparison was to ascertain if MS Kinect through iPiSoft considered the segments as rigid bodies, since the movement is tracked in the post-processing through the resultant point cloud.

The second goal was to compare both 3D systems segments measurements outputs, comparing them with the volunteer's real dimensions. These dimensions were acquired with the use of anthropometers. Studies of the biomechanical models' anatomical points were considered when taking subject's measurements.

c) Joint and segment angles (static): using 2D video recorded data, joint angles were compared using the sagittal plane. Other comparisons were also held between the 3D systems: joint angles extracted from the plane determined by the joint of interest and its adjacent joints; and segment angles, in order to determine segments inclination in the orthogonal planes.

Due to differences between the biomechanical models, trunk inclination was extracted using the International Standard (ISO 11226, 2000).

2.5. Experiments

The pilot experiment was held in order to obtain setup information from the systems working simultaneously, as well as eventual limitations in their use. A volunteer was asked to perform walking movements over a treadmill, and then calibrated and recorded with the three systems. Calibration procedures from both 3D systems invalidated the data acquired. The inertial system had disturbances caused by the structure of the building, as for MS Kinect suffered from reflection areas caused by materials and the environment. 2D video recording was successful but due to the invalidations of 3D data, further analyses were not performed.

The mentioned invalidations resulted in a set of restrictions that were met in the second controlled experiment. These were: (1) a space with a minimum of 8m^2 to allow different positioning of the consoles (80^o - 90^o or 160-180), apart 3,5 meters from the subject each. This criterion was set in order to reposition the consoles if necessary; (2) the metallic structure should not interfere in the magnetic field of the inertial system, therefore it should be tested before the actual experiment; and (3) the environment should not have reflexive materials or high incidence of sunlight, which would prevent depth data from being recorded properly.

The second experiment was held in a location that met these criteria. A volunteer was asked to perform load lifting tasks with three different sized boxes (20, 30 and 40cm wide), weighting 5kg each, from the floor, up to the elbow bent at 90 degrees and back to the floor from a fixed location. This set of movements was chosen in order to obtain kinematic parameters from arms and column inclination, knees bending as well as evaluate how the devices capture object interaction.

MS Kinect consoles were positioned at 80-90 degrees from each other, at a 3,5m distance from the volunteer and calibrated. Calibration results given by the system resulted in an average angle error between the consoles of 0,05 degrees and average position error of 0,012 meters.

MVN Biomech and 2D video recorded the whole session, whilst iPiSoft was started before each movement, where the volunteer was asked to perform T poses at beginning and end of task in order to have synchronism points and also to position iPiSoft's biomechanical model.

A valid observation regarding subject's T pose calibration is that it needs to be adopted at least one time in order to position the biomechanical model. Subsequent opportunities guarantee tracking reference points if any occlusion were to happen in the post-processing.

Filters were used in data acquired from both 3D systems: MVN Biomech processed the captured data with LXSolver, which minimizes soft tissue artifacts and joint laxity (MVN Technologies, 2009). IPiSoft provides jitter filters in order to reduce data noise. Jittering was used at a low level, eliminating only excessive noise thus avoiding data altering.

3. Results

Two of the three captures acquired from iPiSoft/Kinect showed valid tracking for comparison. The movements with the larger box (40cm wide) had limitations regarding occlusion areas caused both by the box, and by the volunteer's own body. This occlusion resulted in lower-limb data invalidation.

3D MOCAP data were then imported in the 3D Digital Platform for further analyses, displayed as follows:

a) Global displacement (dynamic)

Global displacement was compared through three of movements: (1) upper-limb during shoulder horizontal adduction, with extended elbows and neutral wrist; (2) upper-limb during shoulder adduction, with slightly flexed elbows and neutral wrist; and (3) lower-limb during squat, with hips, knees and ankle flexion.

In this paper, results from left elbow (movements 1 and 2) and left knee (movement 3) are graphically represented bellow:

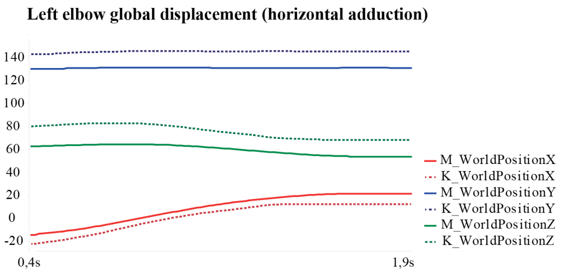

Figure 1. Representative graphic of left elbow global displacement from both systems.

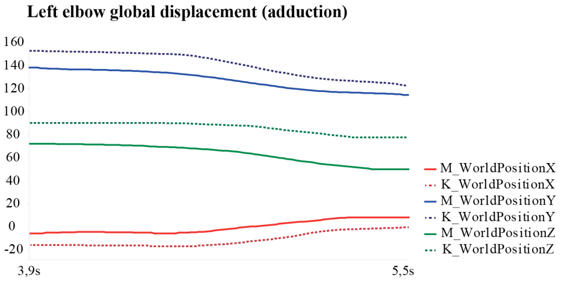

Figure 2. Representative graph of left elbow global displacement from both systems.

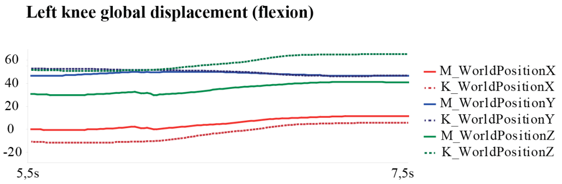

Figure 3. Representative graph of left knee global displacement from both systems.

b) Segments dimensional comparison (static)

Five static scenes were selected for the static comparisons and reproduced in a 3D software based on joints coordinates given by the Digital Platform:

Scene 0 (time = 0s): Reconstruction of the biomechanical model in T pose, without movement;

Scene 1 (time = 0,3s): Reconstruction of the biomechanical model in T pose with subject's movement;

Scene 2 (time = 2,02s): the subject is standing upright, oriented forwards, with both arms extended forwards perpendicular to the trunk;

Scene 3 (time = 6,06s): the subject is grasping the box on the floor, adopting a semi-crouched position;

Scene 4 (time = 10,21s): the subject is standing upright, oriented forward, holding the box in front of his body with elbows bent;

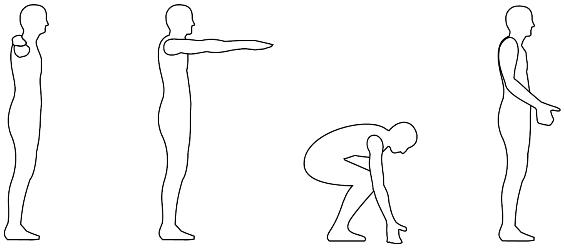

Figure 4. Static postures representation. Scenes 1 through 4. (note: scene 0 is not represented since it has no movement)

To accomplish the first goal, segment measurements from these 5 scenes were extracted. The conclusion is that MS Kinect through iPiSoft maintains the properties of rigid bodies, unless the reference is lost due to occlusion. This could be observed in the Scene 3 of the medium sized box lifting, where elbow and knee references were lost due to occlusion. Since the movement was also tracked backwards, before and after this occlusion, the segments maintained their original dimensions. On the occlusion area, clavicle, knees and hips' representative segments were stretched, altering also their child's joint angles.

In the small box movement, no data was lost and the dimensional comparison is displayed in table 1:

Table 1: results of the segments dimensional comparison. "M" refers to MVN Biomech system values; "K" refers to MS Kinect through iPiSoft; "R" refers to the subject's measures taken with anthropometers. "V1" and "V2" refer to the percentage variation from the subject's real measurements. Negative sign on variation values stands for a smaller segment. All values are in centimeters. (It is important to note that numbers 1 and 2 refer to variable lengths, dependent on subject's posture.)

	Segments	M(cm)	K(cm)	R(cm)	V1 (%)	V2 (%)
1	Total Height	172,7	176,4	177	-2,43	-0,34
2	Trunk Height	50	52,4	53,5	-6,54	-2,06
3	Head	18,4	19,4	21	-12,38	-7,62
4	Left Shoulder	14,7	15,7	15,1	-2,65	3,97
5	Left Upperarm	30,7	30,4	29,9	2,68	1,67
6	Left Forearm	25,2	25,3	25,1	0,40	0,80
7	Left Hip	9,1	11,1	12,75	-28,63	-12,94
8	Left Thigh	43,1	44,3	49,7	-13,28	-10,87
9	Left Leg	41,1	43,5	42,8	-3,97	1,64
10	Left Foot	21,5	17,4	22,4	-4,02	-22,32
11	Right Shoulder	14,7	15,7	15,1	-2,65	3,97
12	RightUpperarm	30,7	30,4	30,4	0,99	0,00
13	Right Forearm	25,2	25,3	25,1	0,40	0,80
14	Right Hip	9,1	11,1	12,75	-28,63	-12,94
15	Right Thigh	43,1	44,3	50	-13,80	-11,40
16	Right Leg	41,1	43,5	43,7	-5,95	-0,46
17	Right Foot	21,5	17,4	22,4	-4,02	-22,32

c) Joint and segment angles (static)

The models reconstructed in the 3D software were projected in the sagittal plane in order to be compared with 2D data. The results of knee, elbow and wrist joint angles can be seen in the following table:

Table 2: results from the comparison of knee, elbow and wrist joint angles in the sagital plane. "M" refers to MVN Biomech, "K" refers to MS Kinect through iPiSoft and "T" refers to 2D video data in the four postures of interest.

Scene		Scene 1	Scene 2	Scene 3	Scene4
R.Knee	M	174,7°	169,1°	80°	174,2°
	K	169,3°	164,9°	74,7°	169,4°
	T	163,3°	163,2°	73,7°	161,7°
R.Elbow	M	-	174,8°	181,6°	195°
	K	-	176,7°	177,9°	179,6°
	T	-	182,1°	172,4°	179,7°
R. Wrist	M	-	165,1°	158,6°	145°
	K	-	179,7°	148,8°	127,1°
	T	-	181,7°	171,9°	128°,1

Table 3 displays results from joint angles acquired from the 3D systems. Each joint angle was extracted from the plane formed by the three points referring to this angle with its adjacent.
Segments inclinations were extracted in coronal (y axis), transversal (z axis) and sagittal (y axis) planes. It's important to notice that these angles were only taken when predominance of movement occurred. The inclinations acquired were: right and left upper leg, right and left lower leg, right and left upper arm, right and left forearm and right and left hand.

Table 3: Joint angles of right and left knees, elbows and wrist, extracted relative to the segments. "M" refers to MVN Biomech and "K" refers to MS Kinect through iPiSoft.

		Scene 0	Scene 1	Scene 2	Scene 3	Scene 4
R.Knee	M	172,8°	172,8°	169°	79,8°	172,8°
	K	169,2°	178,9°	164,8°	72,6°	169,1°
L.Knee	M	170,3°	170,7°	167,7°	82,8°	177,1°
	K	171,5°	178,9°	164°	68,4°	167,9°
R.Elbow	M	165,4°	168,8°	165,1°	158,4°	137,6°
	K	168,6°	179,6°	179,1°	146,3°	125,3°
L.Elbow	M	167,1°	170°	166,2°	163°	145,5°
	K	166,8°	179,8°	153,9°	143,3°	117,1°
R.Wrist	M	175,5°	175,5°	174,5°	175,9°	169,2°
	K	166,6°	176,6°	176,6°	176,6°	176,2°
L.Wrist	M	165,6°	166,3°	172,1°	168,2°	180°
	K	160,6°	176,6°	176,6°	176,6°	175,4°

Due to paper size limitations, results from the segments inclinations acquired in the orthogonal planes from the 3D systems will only be represented through two graphics (Figure 5, 6). Results from the other inclinations showed the same patterns in what concerns similarities in the planes.

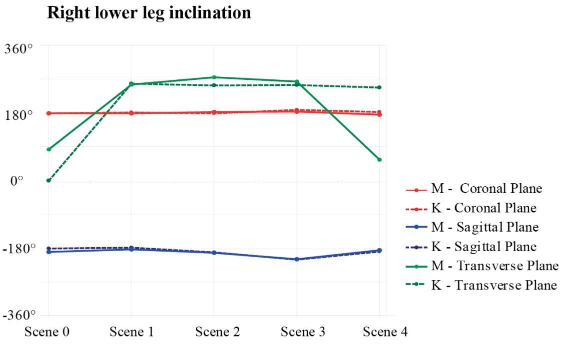

Figure 5. Representative graph of right lower leg inclination related to orthogonal planes of movement from both systems in degrees. "M" refers to MVN Biomech and "K" refers to Kinect through iPiSoft

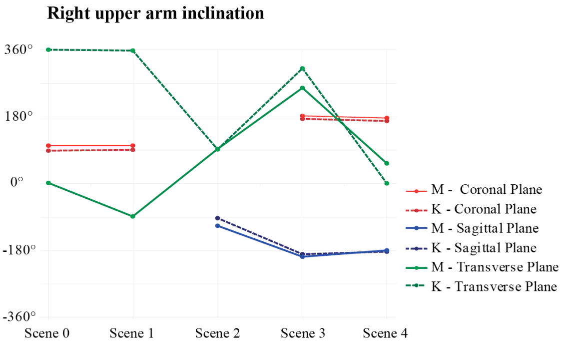

Figure 6. Representative graph of right upper arm inclination related to orthogonal planes of movement from both systems in degrees. "M" refers to MVN Biomech and "K" refers to Kinect through iPiSoft

The last comparison was regarding trunk inclination. In order to acquire these data, International Standard (ISO 11226) definitions were used, where the reference posture considered was the calibration posture of both systems (T pose). Inclination angles were extracted in terms of variation from the reference posture (figure 7) and results are in table 4.

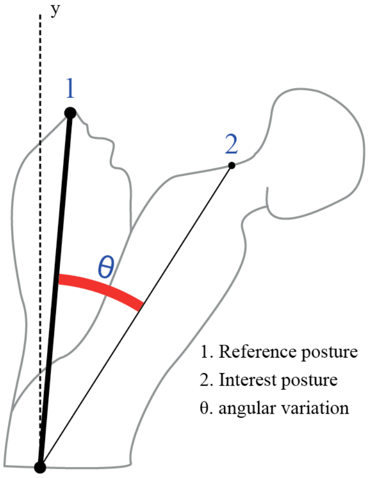

Figure 7. Inclination variation angle (ISO 11226:2000)

Table 7: inclination variation angles. “M” refers to the MVN Biomech and “K” refers to MS Kinect through iPiSoft. Positive angles means trunk extension from the reference posture and negative angles means flexion from the reference posture.

	M	K
Scene 1	0°	0,7°
Scene 2	1,2°	1,6°
Scene 3	-66,1°	-70,4°
Scene 4	1,4°	1,8°

4. Discussion

Global displacement resulted in very similar variation curves, though differences in the in the positioning were already expected due to differences between the biomechanical models.

The results referent to segments measurements showed that 11 out of 17 measurements of MS Kinect through iPiSoft segments dimensions are closer to subject’s real measurements.

The greater variation found in both systems was on the right upper-leg lengths, which were considerable 6,9 cm in MS Kinect through iPiSoft and 5,7cm in MVN Biomech. As for the most accurate segment dimension, in MVN Biomech it was the left forearm (0,1cm) and in MS Kinect the right arm (0cm).

MVN Biomech was most accurate in the dimensions related to upper-limb segments.

Another result of this first comparison was that MVN Biomech’s biomechanical model is laterally symmetrical. Considering that the measurements inputs on the calibration process are mostly from the right side of the body, it can be assumed the correspondence is performed from the right to the left.

The comparison between joint angles using 2D data in sagittal plane has shown to be closest to MS Kinect through iPiSoft’s results, though no real time equipment was used in the activity to ensure this information. Nonetheless, joint angles comparison between the 3D systems did not show many differences.

In the other hand, the most irregular results were found in segment inclination in the transverse plane, which stands for segment adduction, abduction and rotation.

5. Conclusion

From a personal experience in using the inertial system, MS Kinect through iPiSoft can be used as a complementary system.

In the EWA of oil and gas industries laboratories, many activities cannot be captured due to metal-based equipments or where liquids and other potentially damaging materials are used.

Data analyzed in these experiments have shown that MS Kinect through iPiSoft is a valid MOCAP system alternative to those available in the market. Few notations must be made, which are not restrictive to this equipment, such as occlusion areas, proper calibration and environmental settings and also consoles positioning, in order to have a consistent set of data. Another important notation is regarding the biomechanical model, which has original segments rotation characteristics. These should be considered when analyzing kinematics.

It is also important to have a visual reference when analyzing MOCAP data so it can be validated.

Future works of the system’s kinematic and anthropometric accuracy should be performed with a larger group of study in order to have a statistical validation.

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