

Markerless motion capture for 3D human model animation using depth camera

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Abstract

3D animation is created using keyframe based system in 3D animation software such as Blender and Maya. Due to the long time interval and the need of high expertise in 3D animation, motion capture devices were used as an alternative and Microsoft Kinect v2 sensor is one of them. This research analyses the capabilities of the Kinect sensor in producing 3D human model animations using motion capture and keyframe based animation system in reference to a live motion performance. The quality, time interval and cost of both animation results were compared. The experimental result shows that motion capture system with Kinect sensor consumed less time (only 2.6%) and cost (30%) in the long run (10 minutes of animation) compare to keyframe-based system, but it produced lower quality animation. This was due to the lack of body detection accuracy when there is obstruction. Moreover, the sensor's constant assumption that the performer's body faces forward made it unreliable to be used for a wide variety of movements. Furthermore, standard test defined in this research covers most body parts' movements to evaluate other motion capture system.

Keywords: 3D animation evaluation, human computer interaction (HCI), keyframe-based system, microsoft kinect depth camera, motion capture

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1. Introduction

The most common practice nowadays to animate 3D model with human skeleton is using keyframe based system in 3D animation software such as Blender and Autodesk Maya. The system can define each translation and rotation of each human skeleton joints per keyframe or set of keyframes. These sequences of keyframes define the animation. Another technique for creating 3D animation is using motion capture. It eliminates the 3D human models animating process using keyframe based system which is time consuming and requires high level of expertise in 3D animation. There are two types of motion capture, marker based and markerless based motion capture [1]. In marker-based motion capture, every performer must use a special suit with sensors and there are multiple cameras placed in a room to detect them. Although they produce accurate result with fine details, it is very costly and difficult to implement. One product example of this is the Vicon Blade which is used by Bethesda Game Studio [2].

Thus, the research problem is that creating animation of 3D human model by complex keyframe based system requires high end animation software with the high level of expertise, which needs more time and learning curve to create a simple 3D human model animation. Therefore the research objective is to solve the problems by analysing the capabilities of a single Microsoft Kinect v2 sensor as a motion capture device to animate 3D human model by replacing keyframe based animation technique. In our previous research, Kinect is used for several applications such as gaze tracking based on head-pose estimation in advertising area [3] and geometric learning tool for elementary school [4]. By using the Kinect sensor technology, a markerless-based motion capture, which does not require any suit to be worn by the performer, can be implemented [1]. Furthermore, the skill and time requirements of animating 3D human models using keyframe based animation can be eliminated and the complexity for marker based motion capture can be reduced. The sensor is used to replace keyframe based animation technique in order to help people who create 3D human model animation with the decision choosing between the two. A third-party application with MIT license called Kinect Animation Studio was used during the experiment which only focused on capturing

the motion of one performer at a time. The research focused on evaluating the quality, time and cost to produce 3D human model animations using motion capture and keyframe based animation technique. These focuses are based on Martin Barnes' Triangle of Objective / Iron Triangle [5].

Tong et.al. [6] conducted a research on skeleton animation motion data based on Kinect. It converted the original Kinect coordinate data to rotation angles of each human skeleton joint. As an output, a standard Biovision Hierarchy (BVH) motion capture file is produced in real time for animating a 3D human model. It used openNI and NITE program library to access the original human skeleton data from the Kinect. Reference [6] is essential for this research since this research also used similar basic principles in preparing the information needed, such as the length of each bone segment to calculate the initial hierarchical offsets, the basic principles of rotation matrices of Euler angles and the base formula of the relation between joints' coordinate, the local coordinate and the rotation matrix. However, Tong et.al [6] is not calculating each rotation angle.

Therefore, our research also used a method to calculate each rotation angle based on the three-dimensional coordinates obtained from the computations of the tracked marker points using multiple cameras to rotation angles as also mentioned in reference [7]. However reference [7] is used to marker point while our research is used more to markerless point. Another approach is used by Han [8] by converting 2D coordinate to 3D coordinate that reconstruct 3D visual motion from the 2D visual human motion in a sequence of images. Thus, the contribution of this paper is using the basic principles of rotation matrices of Euler angles based on reference [6] and combining with each rotation angle calculation based on reference [7] for markerless motion capture.

2. Proposed Method

As illustrated in Figure 1, to conduct the motion capture (mocap) animation experiment, we used three methods including develop application by processing positional data, develop application by processing quaternion data, and implement Kinect Animation Studio. These three methods will be explained in details in section 2.1. Initial research was done to conduct a study on the fundamental elements of motion capture (motion capture file types, libraries for Microsoft Kinect v2 [9], process of applying motion capture file to 3D human model in Motion Builder, and attempting to create Motion Capture Application that produces BVH file [10]). Motion capture animation experiment was aimed to animate a 3D human model using motion capture technique and produce animation video. Narrated movements (T-pose, walking front and back, jump on the spot (with both legs), jump forward (one leg at a time), saying "no" head rotation, stretching 1 (hand relief), stretching 2 (waist relief), punch 3x, front kick, side kick, soccer-kick ball, T-pose) were defined to cover almost all body parts movement including hand, head, waist, and leg. This may be used as a standard to evaluate the animation quality result of other motion capture system as well. The performer performed the aforementioned movement narration to produce fbx file using Kinect Studio and Kinect Animation Studio [11]. This was then used to animate an inbuilt 3D human model "Aragor" in Motion Builder and an animation video was produced. The whole process was documented using RGB cameras placed on two angles along with screen recording on the computer as illustrated in Figure 2.

Keyframe based animation experiment was aimed to animate a 3D human model using keyframe based animation technique and produce animation video. This was done by a 3D animator expert using Autodesk Maya [12] software based on the reference of the RGB video recordings of the performer's performance from previous experiment. Lastly, an analysis was made based on the two aforementioned experiments to compare the two animation techniques. The animation quality was defined in a scale of 1–10 based on the animation principles using a questionnaire to a 3D animation expert. The time taken was calculated based on the screen recordings from each experiment. The cost of the motion capture animation technique was calculated by adding up the value of the essential hardware with minimum specification while the keyframe based animation technique was calculated based on the estimate fee of 3D human model animation production inquired to the 3D animation expert in the questionnaire.

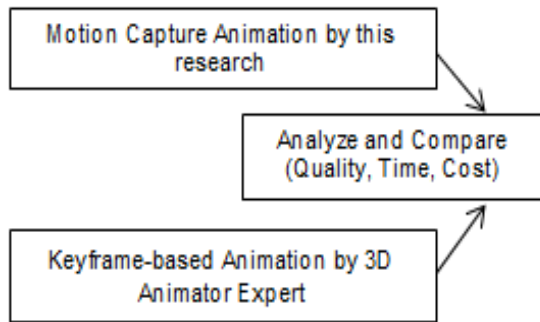


Figure 1. Research process

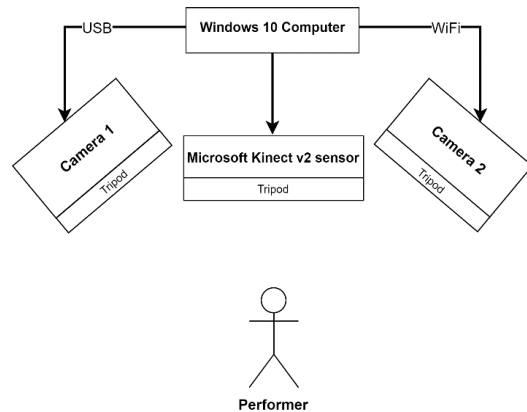


Figure 2. Simple architecture diagram

OpenNI library along with Nite middleware allows developers to access audio, RGB, infrared, depth, and also skeletal information from the Kinect sensor. This was the most popular library to be used by Kinect v1 developers. The main reason for this is because other 3rd party libraries such as OpenKinect [13], LibFreenect [14] often do not support skeletal tracking. Currently, the official Microsoft SDK for Kinect v2 has greatly improved since its previous version. So, it is recommended to just use the Kinect for Windows SDK 2.0 to start development for Microsoft Kinect v2 sensor. When applying a motion file to a 3D human model, several processes (as illustrated in Figure 3 and Figure 4) must be done. A skeleton control rig must be created from the loaded motion file in Autodesk Motion Builder. A skeleton definition template must then be assigned to the control rig as in Figure 4. This is to let Autodesk Motion Builder [15] aware of each specific joint available in the 3D model. Characterizing the skeleton is to lock the skeleton definition which is required before assigning it to a 3D model.

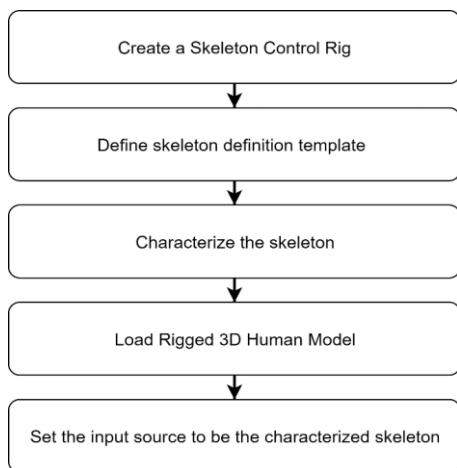


Figure 3. Applying motion file to 3D model in Autodesk Motion Builder process

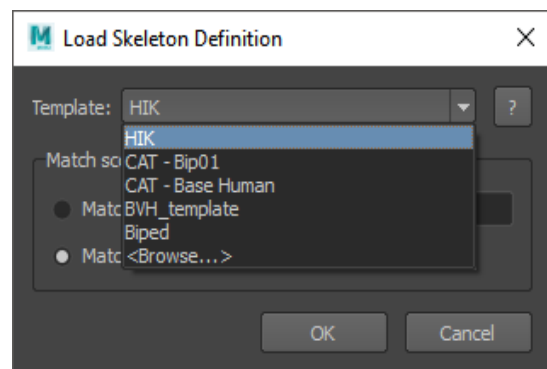


Figure 4. Defining skeleton definition template

2.1. Motion Capture Application Development

A motion capture application was developed for the experiment to produce bvh motion capture file. Figure 5 shows the motion capture application that has been developed. Notice on tracking process has just been completed, 22 frames have been captured in 5 seconds, and both hierarchy and sample motion data has been written to the desired output file formatted (in bvh) can be seen on Figure 6. However, the rotation angle of the joints in motion data is not completely processed to fully represent performer's motion.

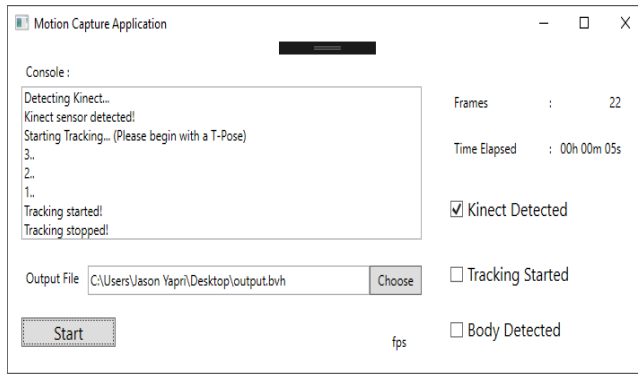


Figure 5. Motion capture application

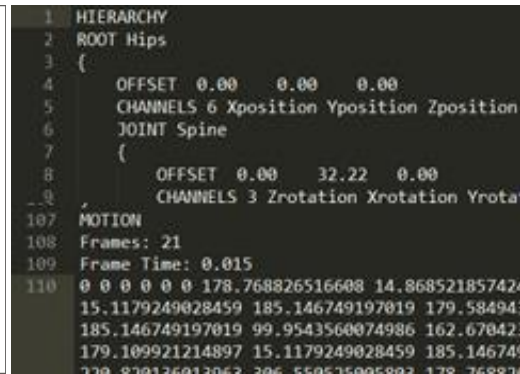


Figure 6. Produced BVH file

BVH file includes hierarchy and motion data as illustrated in Figure 7. The hierarchy data represents the illustration of 3D human model bone posture in T-Pose. Figure 8 shows the first frame of the BVH files with 0-degree rotation in each joint, thus, illustrating the hierarchy data. The bvh file was opened with *bvhacker* (a free source software by *davedub* to view bvh file). The motion data produces a 3D human bones animation. It is represented by the rotation angle in x, y, and z axis of each body joint with the parent joint as the pivot. From the Kinect SDK itself, each body joints coordinate is provided in body data stream and can be used to produce hierarchy data by calculating the length of each bone in the body using (1). There are two main methods to solve the rotational angles required for BVH motion data; processing the positional data and processing the Quaternion data of each joint acquired from the Kinect SDK.



Figure 7. BVH File data structure

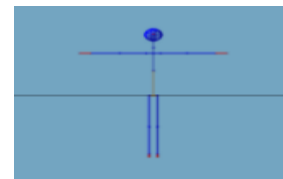


Figure 8. BVH file initial T-Pose stance

$$L_i = \sqrt{(x_{j_{i+1}} - x_{j_i})^2 + (y_{j_{i+1}} - y_{j_i})^2 + (z_{j_{i+1}} - z_{j_i})^2} \tag{1}$$

2.1.1. Solving BVH Motion Data by Processing the Positional Data

Figure 9 shows the illustration of a bone illustrated using cartesian coordinate system where the parent joint is the origin, the initial child joint coordinate / offset (as defined in the hierarchy section) is v and the current child joint coordinate is v' . The figure illustrates front view in which the rotation of z axis can be clearly pictured. When pictured from a different view point, the rotation of another axis can be seen. The main formula of retrieving the rotational angle from two positional vectors is illustrated in (2) and (3). The variable R is rotational matrix consisting of rotational matrix X , Y and Z , illustrated in (4), (5) and (6). Solving it with basic algebra can be very complicated, if not possible as illustrated in (7).

$$v' = Rv \tag{2}$$

$$\begin{pmatrix} x^2 \\ y^2 \\ z^2 \end{pmatrix} = R \begin{pmatrix} x^1 \\ y^1 \\ z^1 \end{pmatrix} \tag{3}$$

$$R(\gamma) = \begin{pmatrix} \cos \gamma & -\sin \gamma & 0 \\ \sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (4)$$

$$R(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha \\ 0 & \sin \alpha & \cos \alpha \end{pmatrix} \quad (5)$$

$$R(\beta) = \begin{pmatrix} \cos \beta & 0 & -\sin \beta \\ 0 & 1 & 0 \\ \sin \beta & 0 & \cos \beta \end{pmatrix} \quad (6)$$

$$R = R(\beta) R(\alpha) R(\gamma) = \begin{pmatrix} \cos \alpha \cos \gamma + \sin \alpha \sin \beta \sin \gamma & \sin \alpha \cos \gamma - \cos \alpha \sin \beta \sin \gamma & \cos \beta \sin \gamma \\ -\sin \alpha \cos \beta & \cos \alpha \cos \beta & \sin \beta \\ -\cos \alpha \sin \gamma + \sin \alpha \sin \beta \cos \gamma & -\cos \alpha \sin \gamma - \cos \alpha \sin \beta \cos \gamma & \cos \beta \cos \gamma \end{pmatrix} \quad (7)$$

One way to solve the rotational angle is using the traditional method by eliminating one angle. However, this may result in some deviations. A novelty method was proposed in [7]. The method utilizes imaginary variables which conclude the formula for the value β and γ in (8). The problem with the proposed formula is that it always results in 0-degree rotation angle. For instance, the spine's initial coordinate in BVH Hierarchy setup is (0, 20, 0) and it was moved to (10, 15, 8.66) as illustrated in Figure 10 (9) shows the solution to find $R(\gamma)$ using the proposed formula in (8). The formula only utilizes X_1, Y_1 coordinates which consists of value 0 and the length of the bone between the hips and spine joint. In this case, the proposed formula cannot be used to calculate the rotation angle.

$$\cos \beta = \frac{z_2}{\sqrt{x_2^2 + z_2^2}}; \sin \beta = \frac{x_2}{\sqrt{x_2^2 + z_2^2}}; \cos \gamma = \frac{y_1}{\sqrt{x_1^2 + y_1^2}}; \sin \gamma = \frac{x_1}{\sqrt{x_1^2 + y_1^2}} \quad (8)$$

$$R(\gamma) = \cos^{-1}\left(\frac{20}{\sqrt{0^2 + 20^2}}\right) = \cos^{-1}(1) = 0 \quad (9)$$

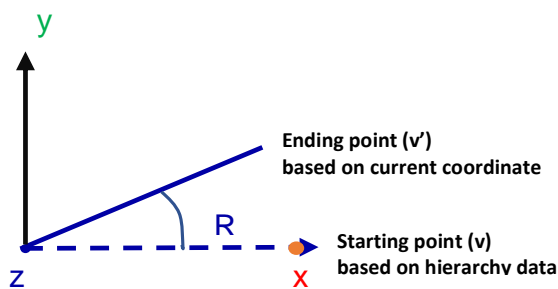


Figure 9. Illustration of joint rotation

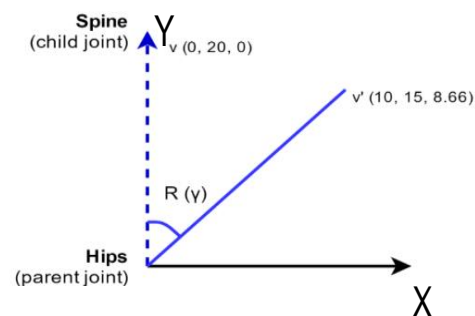


Figure 10. Child joints coordinate

2.1.2. Solving BVH Motion Data by Processing the Quaternion Data

Another solution to produce the motion data in BVH file that may be found in the quaternion data [16] is by assessing it through Kinect SDK. It represents rotation information in any axis in the form of a 1x4 vector consisting of $W, X_1, Y_j,$ and Z_k values. Using quaternion data directly from the SDK can actually improve the quality of the movements captured especially when there is a specific body part linear rotation on a certain axis, i.e. saying "no" head rotation. Producing the motion data using only positional data will fail to acknowledge the rotation of the head along the y axis for the aforementioned movement. These quaternion values are used in JointOrientationBasics application [17] in Unity to represent the rotation of each bone mesh from

an upright position as illustrated in Figure 11 to the current pose of the performer as illustrated in Figure 12. The quaternion data provided by the Kinect SDK differs from what is required for the BVH motion data. In BVH motion data, the rotation angle is based on the parent joint and the initial pose specified in the hierarchy part. When the quaternion data was used directly, it leads to an unwanted posture as illustrated in Figure 13.



Figure 11. Bone renders in unity without quaternion data



Figure 12. Joint orientation basics unity application [5]

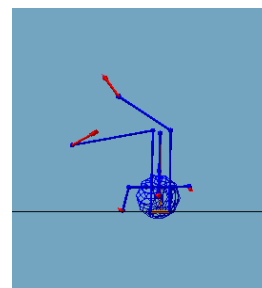


Figure 13. BVH file representation from quaternion data

2.1.3. Kinect Animation Studio

Eventually, Kinect Animation Studio was used in this research for the motion capture animation experiment. It is developed by Marco Furtado with MIT license [18]. It is used to retrieve body joints data and process it to produce fbx file that contains motion data. This fbx file is essential for the motion capture animation experiment to animate the 3D human model in Autodesk Motion Builder. The main drawback of Kinect Animation Studio software is it still uses positional data to produce the motion data stored in the bvh file. Thus, some animations are not perfectly depicted. Moreover, there is a jittering in the produced animation that significantly reduces the animation quality.

2.2. Summary of Motion Capture Applications Research

The development of motion capture application was halted during the phase of producing rotation angles for the motion data in bvh file as previously explained. During the attempts, several methods were examined and explored. These methods are summarized in Table 1.

Table 1. Methods to Produce BVH Motion Data

No.	Method	Problem	Drawbacks
1	Processing the Positional Data	The proposed formula from the related work cannot be applied	Some movements cannot be depicted perfectly
2	Processing the Quaternion Data	The algorithm to process further the Quaternion data must be further explored	(-)

3. Result and Analysis

3.1. Experiment Result

Figure 14 and Figure 15 show the hardware setup of motion capture animation experiment and the video recording of the live performance based on the narrated movements done by the performer. Figure 16 and Figure 17 show the screen recording of the motion capture animation experiment while the live performance is being recorded in the computer to produce the FBX file then the application of FBX file will drive the 3D human model in Motion Builder respectively. After applying the FBX file, the animation was rendered in Motion Builder and produced an animation video. Figure 18 shows the process of animating 3D human model using keyframe based technique done by the 3D animator, while Figure 19 shows the animation video result for keyframe based technique.



Figure 14. Motion capture animation experiment hardware setup



Figure 15. Video recording of performer

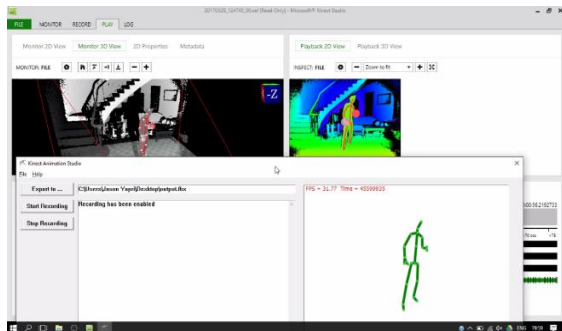


Figure 16. Screen recording for motion capture animation experiment

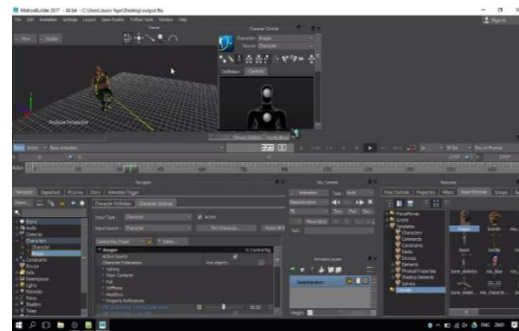


Figure 17. Screen recording for motion capture animation experiment

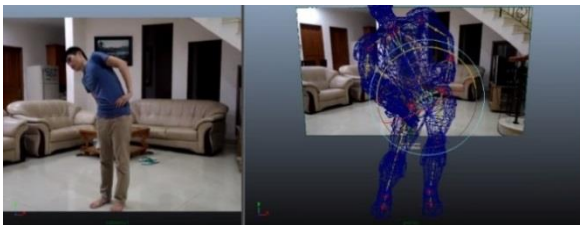


Figure 18. Animating 3D human model using keyframe based technique

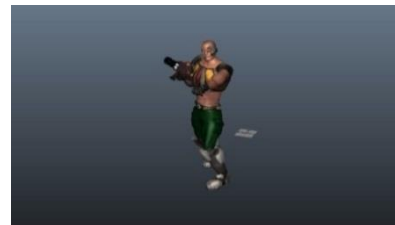


Figure 19. Keyframe based animation video

3.2. Result Analysis

An interview is done to evaluate the quality, provide the feedback and retrieve estimation cost of video production. The interviewee is a 3D animation expert who is also a lecturer in 3D animation. Animation principles are used to measure the quality. Out of 12 animation principles (Squash and Stretch, Timing and Motion, Anticipation, Staging, Follow Through and Overlapping Action, Straight Ahead Action and Pose-to-Pose Action, Slow in and out, Arcs, Exaggeration, Secondary Action, Appeal, and Personality), the principle Staging cannot be evaluated. Based on the expert evaluation, the quality score of motion capture is 26 pts while keyframe based is 50 pts. Keyframe based animation technique indeed produces higher quality of animation. The total score that can be achieved is 110 pts (from 11 animation principles). The quality of keyframe based animation result may be further increased by investing in a more skilled 3D animator or investing more time in animation process.

On the other hand, the motion capture animation result may also be further increased by using a more developed motion capture software up to certain extend, but due to the Kinect

v2 sensor limitation itself, the sensor cannot detect body joints that is obstructed. Moreover, the sensor always assumed that the performer's body is facing towards the sensor. These two factors reduce the quality of the animation significantly and they also limit the movements that can be captured. This can be seen in the animation video result from motion capture animation experiment where the movement "Front Kick", "Side Kick", and "Soccer - Kick ball" suffer deeply from the obstruction limitation. Figure 20 and Figure 21 display the performer's head towards the camera, even when it should be facing away the camera when performing the movement "Walking backwards".



Figure 20. Motion capture animation video snapshot (from left to right-front kick, side kick, kick soccer ball)



Figure 21. Motion capture animation video snapshot (walking backwards)

An alternative solution to the problem faced by Kinect sensor as suggested by the 3D animation expert is using multiple Kinect sensors to get better motion data or using more advanced motion tracking system such as marker based motion capture system with cameras "Optitrack" (name of a brand) or marker based motion capture system with gyroscope sensors [19] without any camera for a more affordable alternative. This motion capture system with gyroscope is also equipped by accelerometer and magnetometer. Together they are called IMU (Inertial Measurement Unit) [20]. The screen recordings from the previous two experiments show the process to animate 3D model using two different techniques based on a reference of 59 seconds life movements performed by real performer. As shown in Table 2, the motion capture animation technique resulted in 7 minutes and 48 seconds, while the keyframe based animation [21] technique resulted in 3 hours 19 minutes and 33 seconds. It shows that within 10 minutes animation duration, the time to create animation using motion capture only needs 2.6-3.9% out of time for keyframe based animation.

Table 2. Time Comparison

Animation Duration	Motion Capture	Keyframe based	Percentage Motion Capture vs Keyframe-based
59 seconds	7 minutes and 48 seconds	3 hours 19 minutes and 33 seconds	$468/11973 = 3.9\%$
2 minutes	+/. 13 minutes	+/. 6 hours	$13/360 = 3.6\%$
10 minutes	+/. 52 minutes	+/. 33 hours	$52/1980 = 2.6\%$

Cost breakdown for motion capture animation process is shown in Table 3. This includes a laptop to run the motion capture application, the Kinect v2 sensor with tripod to be attached together and the adaptor to connect the sensor with the computer. The cost needed for keyframe based animation is IDR 60,000/second of animation produced. This data was given by the 3D animation expert who filled in the questionnaire. To produce a 59 seconds animation, the cost would be IDR 3,540,000 (IDR 60,000x59 seconds) for keyframe based animation. However, a longer duration of animation would cost more, and motion capture has fixed cost. This is illustrated in Table 4.

Table 3. Cost Breakdown for Motion Capture Animation Technique

#	Item Name	Price
1	Asus Laptop A456UR – i5 [22] Intel Core i5 7200 U Processor, Windows 10, 14" HD Screen (1366 x 768), GTX 930MX – 2GB Graphics Card, 1TB HDD – 4GB DDR4 Memory, USB 3.1 Type C – BT 4.0 – Wi-Fi	IDR 8,299,000
2	Microsoft Kinect v2 sensor [23]	IDR 1,995,000
3	Microsoft Kinect Adaptor [24]	IDR 1,200,000
4	Tripod [25]	IDR 225,000
	Total	IDR 11,719,000

Table 4. Cost Comparison of Motion Capture and Keyframe Based Animation Technique

Animation Duration	Motion Capture	Keyframe based	Percentage Motion Capture vs Keyframe-based
59 seconds	IDR 11,719,000	IDR 3,540,000	331 %
2 minutes	IDR 11,719,000	IDR 7,200,000	163 %
10 minutes	IDR 11,719,000	IDR 36,000,000	33 %

*motion capture application license not included (when available)

4. Conclusion

Although a single Microsoft Kinect v2 sensor can be used as a quick and cheap solution for motion capture device, it has some drawbacks that made it unreliable to be used for wide variety of movements. These drawbacks include the lack of body detection accuracy when there is any obstruction and the sensor's consistency to assume that the performer's body is facing towards the sensor. Movements such as "Front Kick", "Side Kick", "Kick soccer ball", and "Walking front and back" resulted in unfathomable animation. Overall, keyframe based animation technique is more preferable in this case even if the time needed is far more than motion capture. In terms of quality, the keyframe based animation is superior to the motion capture animation, scoring 50 points while the motion capture animation only scores 26 points. However, both animations still have many rooms for improvement as the total score that can be achieved is only 110 points, judging by the 11 animation principles with a scale of 10 points each. In terms of time, the motion capture technique only requires 7 minutes and 48 seconds to complete the animation. On the other hand, Keyframe based animation technique requires 3 hours 19 minutes and 33 seconds and it is directly proportional to 59 seconds of animation video produced. So, when producing a lengthier animation video, it requires far more time for keyframe based animation technique rather than motion capture technique. In terms of money invested, the motion capture animation technique costs IDR 11,719,000 while the keyframe based animation technique costs IDR 3,540,000. Even if the keyframe based animation technique is cheaper, the cost surpassed that of motion capture when producing an animation video of 4 minutes.

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