Feasibility Study of Markerless Gait Tracking Using Kinect

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Abstract: Gait analysis is a complex process since it involves tracking motion with high degrees of freedom. It has seen a lot of development in recent years with approaches changing from Markerbased to Markerless systems. This paper presents a new approach for gait analysis that is based on Markerless human motion capture using Microsoft's popular gaming console Kinect XBOX. For this study, the RGB camera mode output of the Kinect system was used as Markerbased system. The skeleton mode output of the Kinect system was used as Markerless system. The system introduced in this paper tracked the human motion in a real time environment using foreground segmentation and computer vision algorithms developed for this purpose. The study shows that Kinect can be used both as Markerbased and Markerless systems for tracking human motion. The degree angles formed from the motion of 5 joints namely shoulder, elbow, hip, knee and ankle were calculated. The RGB camera of Kinect was used to track marks placed over specified joints. The image resulting from the Kinect skeleton mode was considered as the images resulting from markerless system and used to calculate the angle for the same joints. The developed software application tracked the motion successfully. The study showed a correlation coefficient of 90.16% between the Kinect camera's Markerbased and Markerless systems.
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1. INTRODUCTION

Augmented reality has a huge potential for a wide variety of applications in healthcare and rehabilitation than just being limited to the gaming industry. Rehabilitations are costly and limited to clinical settings. There is a need to develop technology that can measure and help in rehabilitation using gait and motion analysis.

Motion tracking comes with challenges that are complex due to the degree of freedom involved with human motion. A Markerless method for motion tracking and background changes of color and light add to the complexity.

Gait analysis usually needs various tools which are expensive in nature and, except for specialized labs, they are commonly inaccessible to common people [1]. Cost being of major importance, this paper introduces a cheaper method for gait analysis.

Computerized environments for motion analysis are largely separated into marker based motion capture and marker less motion capture. Marker less motion capture and analysis are undergoing numerous researches using the local features, color, shape, texture, and depth map from stereo vision, but are still a challenging issue in the area of computer vision and graphics due to dependency of camera viewpoints, partial occlusion, clutter, high-dimensional state space and pose ambiguity within the target object [2].

Motion analysis had been used by animators for over 100 years by tracing light tables to produce animations. Latest techniques usinginterface are similar to 3D key-frame animation (like Autodesk Maya and other tools). The user had the liberty to play the video back and forth selecting key frames location over video by just using a click. The frames are tracked with general pattern trackers or are interpolated (Adobe 1995, Vicon 2009) to name a few [3].

Accurate Markerless system is complex to develop and technically challenging, Corazza [4, 5] provides an insight into the computational framework enabling Markerless human motion capture accurately, even for the most demanding applications such as biomechanical and clinical analysis.

Despite their precision and popularity, Markerbased technique poses various limitations:

(i) Markers placed on a subject may influence their movement;
(ii) Controlled environment is needed to acquire quality data;
(iii) Marker placement is time consuming;
(iv)Markers placed may cause skin artifacts [6, 7, 8].

Marker based systems are commercially very expensive ($10k-$100k), they also require large to install. Kinect system has a depth sensor with a valid field of operation between 1.2 and 3.5 meters and depth camera resolution of 640x480 pixels operating at 30fps. Alnowami et al have assessed quantitatively the Kinect X box 360 with a Markerbased system and found out that there is small deviation in motion analysis between the two systems and that the Kinect Xbox could be used as a potent tool for motion analysis [9].

Gait analysis requires knowledge of spatio-temporal parameters such as hip and knee angles, ankle angles, length and width of stride, support while walking and walking speed. In order to capture 3D human motion, reflective markers were placed at various key points on the subject's body and later captured using fixed infrared cameras.

Feeds captured from multiple cameras provide inaccurate results. As result, the 3D information formed from these images is inaccurate in making the motion tracking of markers, almost impossible. Using conventional cameras without special hardware implementation for Markerless motion tracking is not feasible. Haritaoglu et al [10] defined an efficient system capable of tracking 2D body motion using a single camera based on articulated models approach. The inability to extract the 3D data is using the articulated models approach which is compensated by Microsoft Kinect in this study. The frame to frame region search method was based on matching and applied using on short multi camera sequences [11]. This method was neither easily portable nor fast and resulted in cluttered background. Learning methods used by combining 3D configuration models and 2D trackers were possible to produce 3D data from single camera feeds.

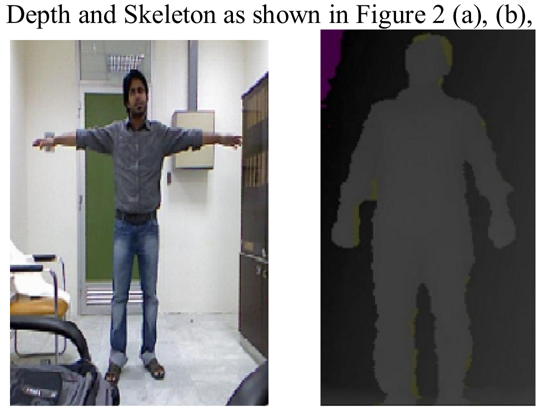
Explicit hierarchical search techniques were used to locate the body parts sequentially in kinematic chain thusconsiderably reducing the search algorithm complexity [12]. Real world situation is hard to define and it's much difficult to specify each body part as independent identity without using colors or labels. To overcome this difficulty, condensation algorithm [13, 14] was used with stochastic models and generative model to generate full image of the body. The large number of data used as particles in condensation algorithm makes it slow to process and expensive. To overcome demerits, support vector machines were used to train the body to reduce the number of particles. Dynamic models restricted the approach of motion tracking in general making it difficult to track the gait abnormalities [15]. Dynamic modeling techniques with particle filtering approach, a complex form of condensation algorithm was used to produce the 3D tracking motion of body using multiple cameras at 60 frames per second[16].

Kinect is a system that was developed by Microsoft for its gaming console XBOX. Kinect is a motion sensing device that provides its user unique experience of controlling and interacting with the game by using gestures and eliminating the need of any game controller [17].

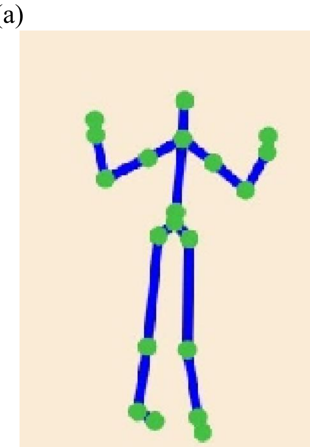
Kinect is based on range camera technology developed by PrimeSense. The range camera technology can recognize specific motion gestures by using an infrared projector, a camera, and a special microchip to track the movement of individuals in three dimensions [18].

Figure 1. Kinect

The Kinect system consists of RGB camera, depth sensor and microphone, and using proprietary software to facilitate 3D motion capture capabilities. The system can provide three different outputs RGB, Depth and Skeleton as shown in Figure 2 (a), (b), (c).



(a) (b)



(c)

Figure 2. Kinect Outputs, (a)RGB, (b)Depth, (c) Skeleton

Kinect RGB camera has an 8 bit VGA resolution (640 x 480) and capable of handling higher resolutions up to 1024 x 1024, but at a lower frame rate [19]. A sample RGB image is shown in Figure 2 (a).

The Kinect depth sensor consists of an infrared laser projector with monochrome CMOS sensor, which enable Kinect camera to capture the 3D depth information in any ambient light condition. The depth output indicates how far an object is from the system [20, 21]. A sample image for the depth output is shown in Figure 2 (b).

Kinect skeleton tracks human motion with 20 joints defined by Microsoft proprietary software. The software processes the depth information of body in view to generate 20 joints defined by Microsoft. The infrared emitter of a Kinect sensor projects a pattern of infrared light. This pattern of light is used to calculate the depth of the people in the field of view allowing the recognition of different people and different body parts [22]. A sample image for the skeleton output is shown in Figure 2 (c).

The objectives of this work are:

1. Study the utility of Kinect cameras in tracking joint movements from sitting to standing positions to analyze the space temporal dynamic movement using sagittal (side) and coronal (back) planes;
2. Compare the motion characterization using the Kinect system as both markerless and markerbased systems.

2. MATERIAL AND METHODS

2.1 Methodology

On recommendation of physiotherapist, the motion of 5 selected joints was tracked using the Kinect system as both markerbased and markerless system. Markers were placed on the following joints of a subject, the right shoulder, right elbow, right hip, right knee and right ankle. The subject was asked to perform a gross motor skill from sitting to standing which is an important skill for physiotherapists since it's one of the most commonly performed task every day. In addition, in this skill, most of the above tracked joints are under movement.

Markerbased system tracked the markers by software that was developed using MATLAB. The software subtracted successive frames from each other pixel by pixel and applied a threshold to obtain the markers. The centroids for each marker were determined by calculating a ROI (region of interest) that was selected based on the boundary of images in each frame. The developed software tracked centroids of each marker werederived from each frame and implemented foreground segmentation, vector transformation and SE (structural elements) to generate the degree angle of markers. Once the centroids for each marker were identified in each frame, the angle formed by the joints during the motor task was calculated.

In case of the Markerless motion analysis, the angles for joint positions were computed using the skeletal image generated by the Kinect system. The skeletal image was processed to obtain the angles by an algorithm developed using Kinect SDK (Software Development Kit), C# programming language and coding4fun toolkit [23]. Kinect SDK is available from Kinect website, C# programming language is widely available over internet, Coding4fun website provides toolkit to develop code for Kinect. Markerless motion tracking used computer vision algorithm at its core. The developed application for skeleton tracking tracked the specified joints over skeleton with their X, Y, and Z coordinates in space. The coordinates were used to calculate the vector transformation and calculate the degree angle.

2.2 Experiment Setup

2.2.1. The following steps show how the Kinect system was used as both Markerbased and Markerless system for the purpose of this study

1. Kinect camera was placed in a room at a distance of 2 meters on the right side of a chair used by the subject. The room had ambient light conditions;
2. Circular Markers were placed over the joints right shoulder, right elbow, right hip, right knee and right ankle;
3. Subjects were asked to perform the motor skill of sitting to standing without any hand support.

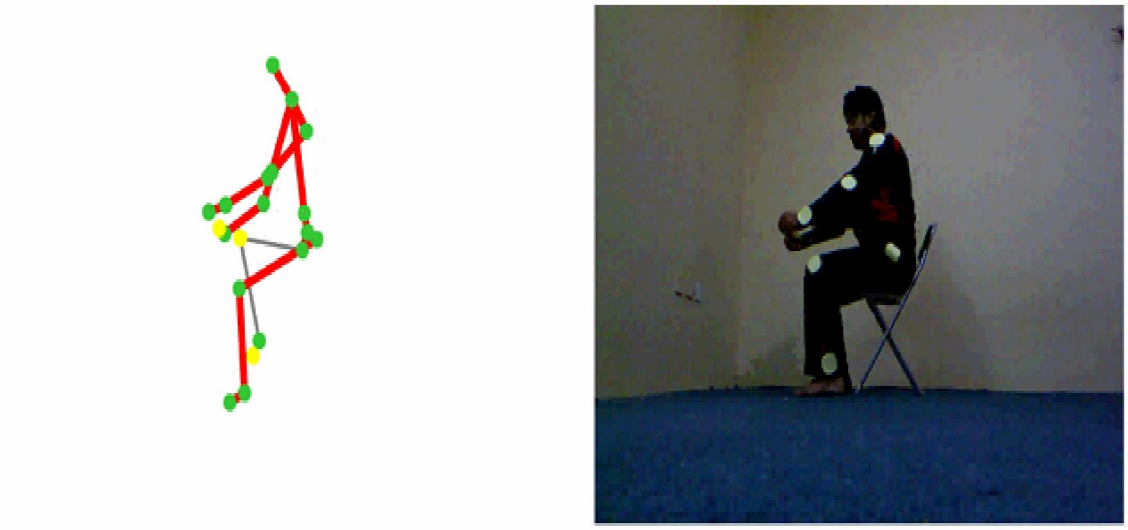
2.2.2. Markerbased Analysis

1. Kinect RGB camera output mode was used to record the motion of the subject;
2. Centroid of each markers was calculated for each frame and its X, Y coordinates were determined;
3. X, Y coordinates were later used in the developed application for calculating the angles formed by the motion of the joints.

2.2.3. Markerless Analysis

1. Kinect skeleton mode output was used to record the data for skeleton camera;
2. An application was developed to calculate the joint angles using the vector transformation during the task.All the angles were computed real-time while the task was being performed.

The Kinect captured skeleton feed is shown in Figure3 (a) and the RGB camera feed is shown in Figure3 (b).



(a) (b)

Figure3 Kinect capturing (a) Skelton Feed (b) RGB Feed data

The poses for which the angles were calculated are shown in Figure 4.

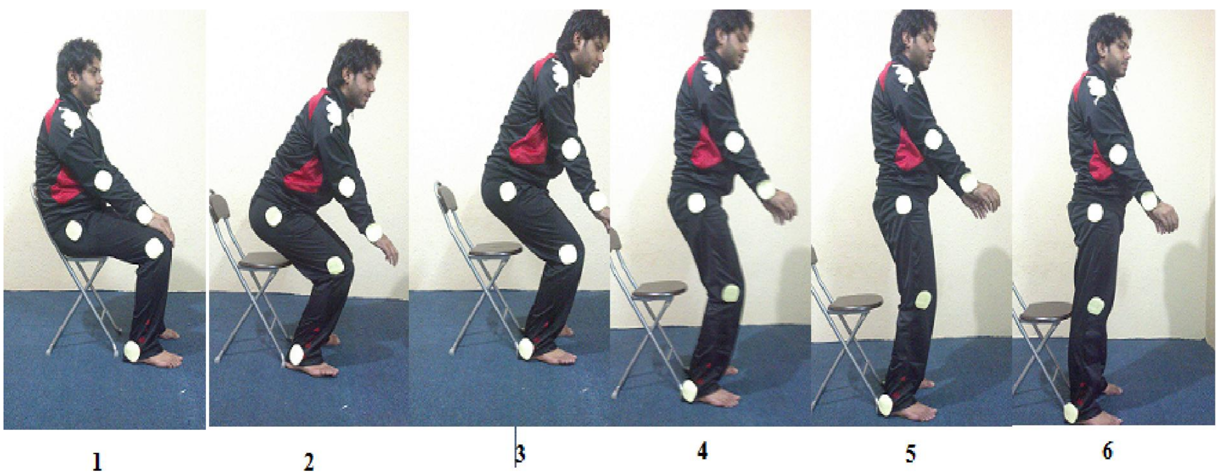


Figure4 Poses for which angles were calculated

Figure 5 shows the workflow of this study. It is noted that each of the application was developed separately and independently for Markerless Kinect camera and Markerbased Kinect skeleton features.

For Kinect RGB camera (Markerbased system), angles were calculated based on markers placed over joints as shown in Figure6. Below is the code developed for calculating the angles in MATLAB:

```
for i=1:r-2
 x10 = C(i,1)-C(i+1,1);
 y10 = C(i,2)-C(i+1,2);
 x20 = C(i+2,1)-C(i+1,1);
 y20 = C(i+2,2)-C(i+1,2);
ang(i)=atan2(abs(x10*y20x20*y10),x10*y10+x20*y20)*180/pi;
figure, imshow(img);
end
```

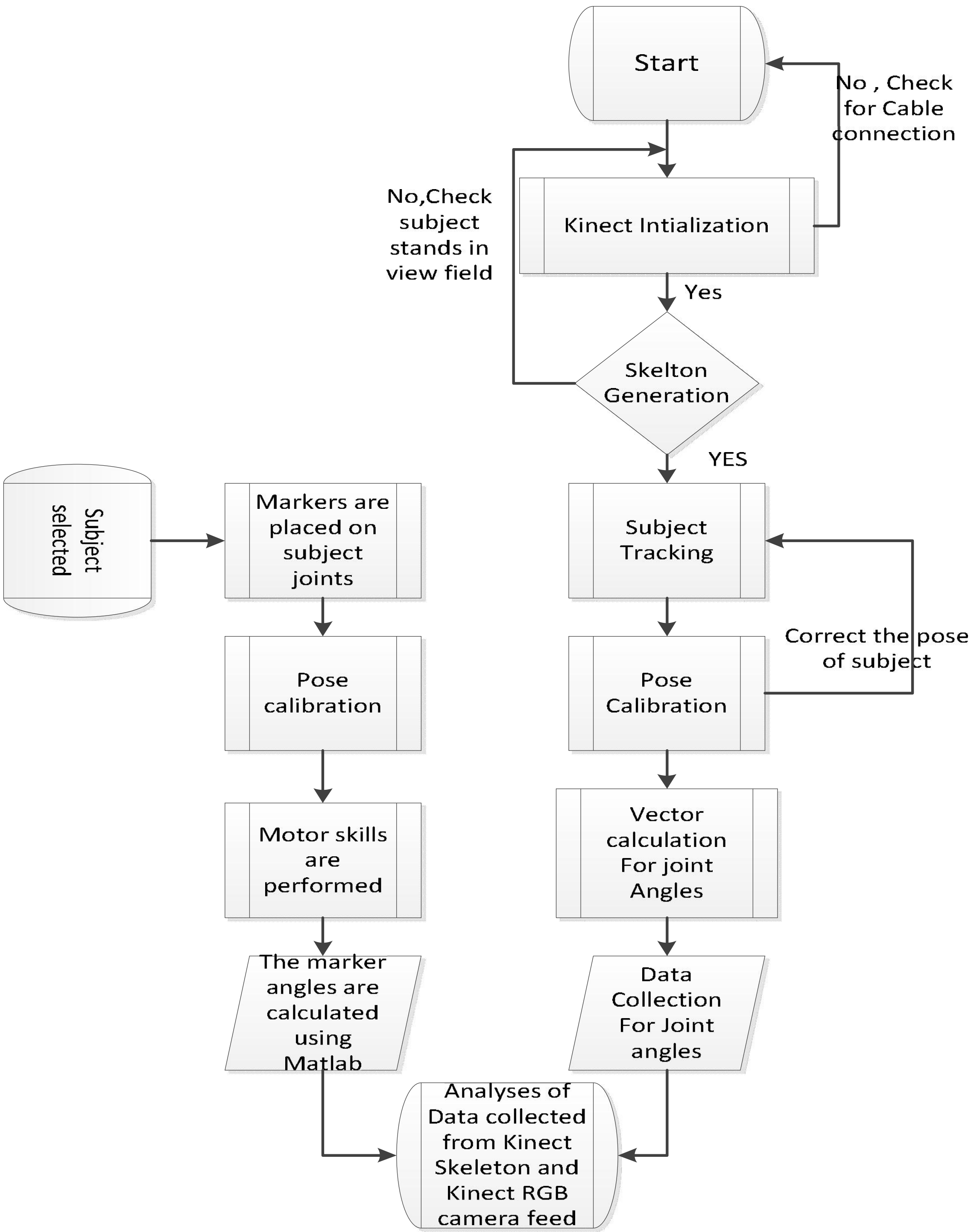


Figure 5. Workflow of the study

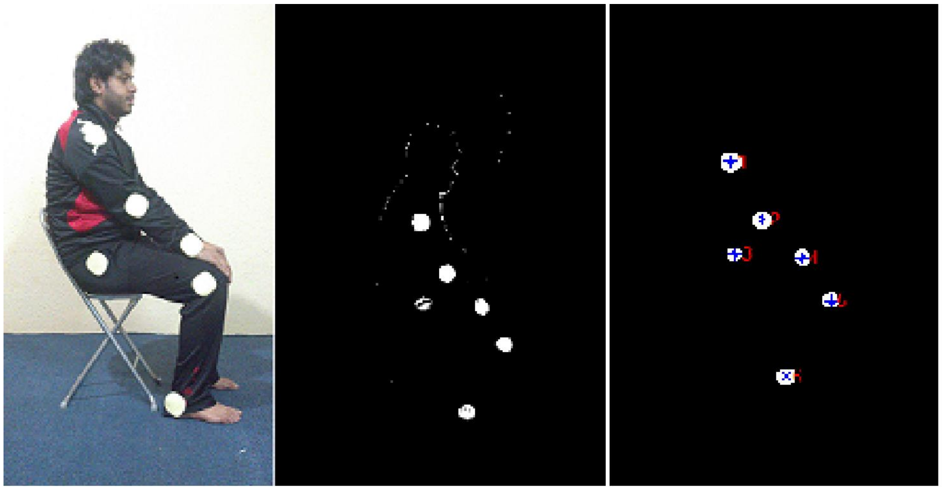

(a) (b) (c)

Figure 6. (a) RGB feed; (b) ROI and Markers; (c) Centroids of Markers and angle calculation.

Figure 6 shows the steps involved in calculating the angles for markers. Figure6 (a) shows the RGB feed captured by Kinect along with marker. It shows the initial position taken by subject for the task. Figure 6 (b) shows the method of obtaining the ROI and the markers by using the foreground segmentation and using threshold over the structural elements. Figure 6 (c) provides the information of centroid of markers. The centroids provide the X, Y coordinates for the markers. Vector transformation method was used to calculate the angles formed by the motion of the joints

3. RESULTS

All doses were normalized with the dose at 40 cm scan length as the maximum scan length during the experiment.

Kinect captures feed at 30 FPS (frame per second) but this capture rate varies based on the mode in which the Kinect camera is used. Usually RGB feed is captured at 30 FPS but when depth and skeleton mode are used at the same time, this rate differs due to heavy processing which is required for these modes. In order to have a synchronous nature with the feed, Kinect brings down the FPS capture rate to a level in which all three modes can coexist [24].

In this study, the capture rate is less than the defined 30 FPS due to the fact that Kinect RGB camera and Kinect skeleton mode were used at the same time. The capture rate in this study varied between 25 and 30 FPS. Figure6 shows an image for an experiment conducted by Microsoft. The Kinect feed consisting of RGB, depth and Kinect skeleton were used simultaneously resulting in less than that 30 FPS as shown in Figure 7 [24]. In order to keep the same frame for this study, each frame was time stamped which provided an alternative for maintaining the concurrency of data and only the frames with same timestamp were taken into the study.

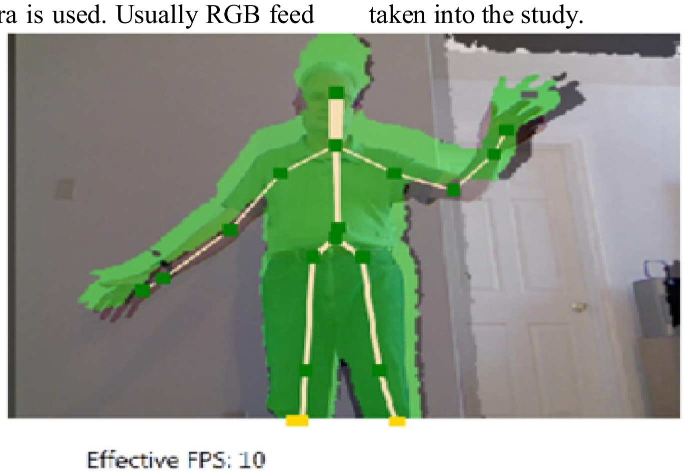


Figure7 Kinect capturing RGB, depth and skeleton at the same time resulting in a lower frame rate.

For this study, 6 poses were used as described in Figure4 and the data for Markerbased as wells as Markerless system were calculated for the poses. The results from video captures of different poses of subject are shown below in Figure8, which performing sitting to standing gross motor skill in lab with ambient lights and under supervision of physiotherapist. The feeds were captured at 25-30 frames using a single Kinect camera. Image processing was done offline, using i5, 2.40 GHz PC.

Figure 8 (a), (b), (c), (d), (e), (f) show the subject's poses for Kinect skeleton and Kinect RGB camera for task sitting to standing. The change in angles for the markers and joints was calculated for these poses.

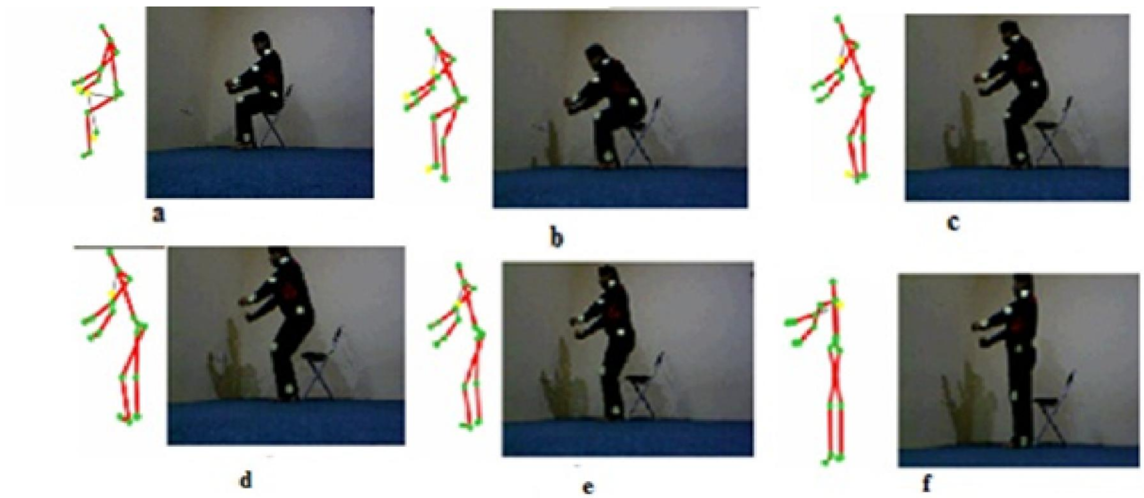


Figure8 (a) Sitting pose (b)Standing up pose1 (c) Standing up pose2 (d) standing up pose3 (e) Standing up pose4 (f) Standing pose

In this study, the change in angles was calculated to correlate the joints positions in Markerless and Markerbased systems. Figure 9 through 14 shows the analysis of change in angles for the various joints for both Markerbased system and Markerless systems.

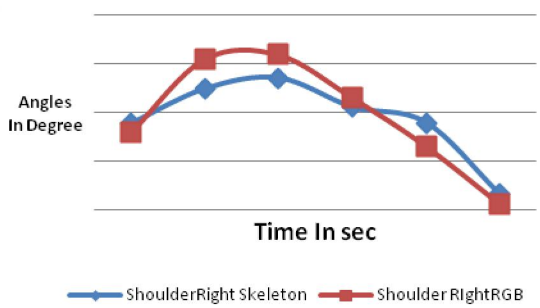


Figure 9 Shoulder angle movement for skeleton and RGB

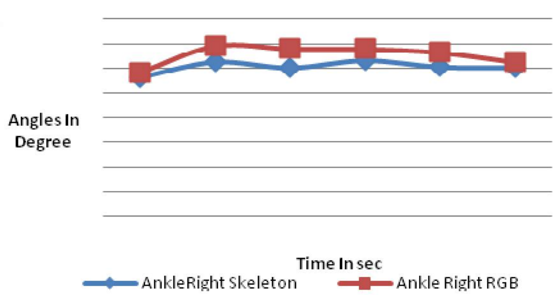


Figure 10 Elbow angle movement for skeleton and RGB

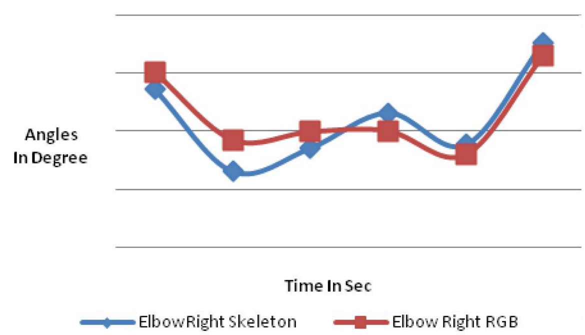


Figure 11 Hip angle movement for skeleton and RGB

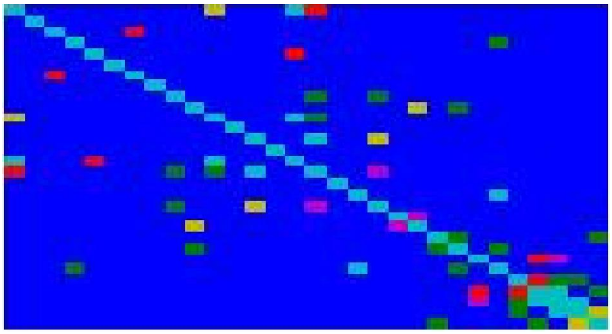


Figure12 Knee angle movement for skeleton and RGB

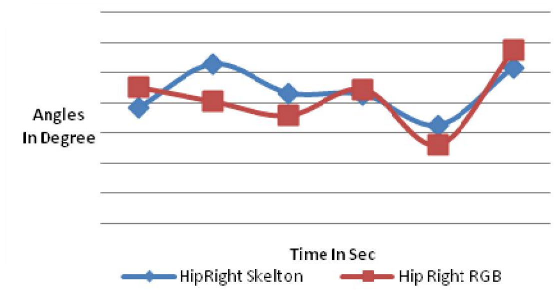


Figure 13 Ankle angle movement for skeleton and RGB

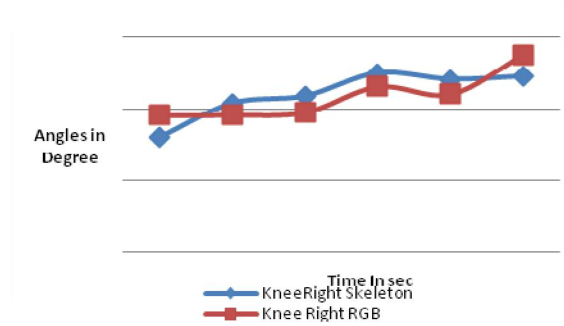


Figure14 Results of similarity matrix for RGB and skeleton

Figure 9 shows the change in angle for shoulder which varies for Kinect RGB data and Kinect skeleton data. The minimum and maximum range of difference in change of angle for Kinect RGB and Kinect skeleton data are 80° to 250° . Minimum change in angle occurs for the pose shown in Figure8 (a) and maximum for pose shown in Figure8 (b).

Figure10 shows the change in angle for the elbow joint, the minimum and maximum difference in change in angle for Kinect RGB and skeleton data is 90° to 270° . Minimum change in angle occurs for the pose shown in Figure8 (e) and maximum for pose Figure8 (b).

Figure11 shows the change in angle for hip joint. The minimum and maximum difference for the change in angles for Kinect RGB and Kinect skeleton varies from 40° to 250° . The minimum change in angle occurs for the pose in Figure8 (d) and maximum being for pose in Figure8 (b).

Figure12 shows the calculated angle of knee movement. The minimum and maximum difference for the change in angle for Kinect RGB and Kinect skeleton is 90° to 150° . The minimum change in angle is visible for Figure8 (d) and maximum change for Figure8 (b). The minimum angle for Kinect RGB data is 950° and maximum is 1370° . For Kinect skeleton minimum angle is 800° and maximum is 1220° .

Figure13 shows the ankle movement in degrees. The minimum and maximum difference for the change in angle for Kinect RGB and Kinect skeleton is 40° to 150° . The minimum change in angle is visible for Figure8 (d) and maximum change for Figure8 (b).

The data collected from both Markerbased and Markerless systems were used to calculate the similarity matrix in MATLAB. Similarity matrix is used to represent the similarity, between the data points between two data points [25]. Similarity matrix was developed by computing the degree of matrix and applying the normalized Laplacian method. NL is the normalized Lapacian, D is the Degree of matrix and L is Lapacian matrix in equation (1).

$$NL_1 = D^{-1/2} * L * D^{-1/2} \quad (1)$$

The correlation coefficient achieved with the Kinect RGB data and Kinect skeleton for the discussed joints by the developed application on Markerless and Markerbased system was found to be 90.16%. Shoulder joint had the maximum correlation coefficient with 96%, elbow joint 90%, ankle joint 88%, knee joint 70%, and hip joint 66%. Shoulder joint correlation estimation was much accurate between Kinect skeleton and Kinect RGB markers as compared to hip. Hip provided the least accurate result as it was difficult to actually locate the hip joint being derived by Kinect skeleton with Kinect RGB marker placed byphysiotherapist.

4. DISCUSSION

Kinect provides a unique opportunity for capturing two forms of data at the same time though it created limitations which brought some restriction during study.

- Kinect has a view range of 43° vertical by 57° horizontal field which restricted the movement and subject had to be presented within the viewing frame, the subject also had to be in the range of 6 to 8 feet to perform the task which ruled out the usage of Kinect in small room [26]. The precision level of Kinect also depended on the subject's distance from Kinect and its calibration [27].
- Another limitation during this study was the usage of specific version of commercial software made available from Kinect website to derive the results, new release would bring further improvements [28].

The marker placement and tracking was a tedious task as it had to be placed as per instructions and had to be tracked using Kinect RGB camera. The joints defined by Kinect are a good start for a

Markerless system but the joint prediction accuracy is not 100% as discussed by Shotton [29]. Looking at Figure 3, although markers placed over the subject seem to match the joints with Kinect skeleton joints but the perceived joint by physiotherapist and Kinect are not related to each other. Further studies are needed to compare the performance of both systems if the markers were placed on the body at locations that are different from the 20 predefined points in the skeletal image.

The Kinect provides the benefits in term of depth data, skeleton data, and portability. Easy to handle and cost effectiveness makes it a potent tool for generic use by physiotherapist. Markerless skeleton and Markerbased RGB systems showed a slight deviation while calculation for the angles of joints was expected. The system developed will be further tested to analyze the motion for more subjects before it can be approved completely.

5. CONCLUSIONS

In this paper, a new approach was presented for Markerless human motion capture from a single Kinect camera. An algorithm for analysis of RGB was developed. The aim of this study was to extract gait parameters from the feeds, and the results obtained were compared to those of markerbased system, which were encouraging. The developed algorithm was easy to implement and it was compatible with the latest OS for Windows 7 and 8. As restrictive dynamic model is not used, the approach used in this study can be considered as generic.

Further development of the Kinect hardware and good quality of RGB camera will be needed for better results. Low quality RGB images were difficult to handle and brought complexity to the algorithm which had to be modified frequently. Good quality camera may resolve the issue of poor RGB images. The developed system needs further trials and experiments which will be held under medical supervision at physiotherapy.

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