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Hidden Marker Position Estimation during Sit-to-Stand with Walker

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Abstract— **Motion capture analysis of sit-to-stand task with assistive device is hard to achieve due to obstruction on reflective makers. Previously developed robotic system, Smart Mobile Walker, is used as an assistive device to perform motion capture analysis in sit-to-stand task. All lower limb markers except hip markers are invisible through whole session. The link-segment and regression method is applied to estimate the marker position during sit-to-stand. Applying a new method, the lost marker positions are restored and the biomechanical evaluation of the sit-to-stand movement with a Smart Mobile Walker could be carried out. The accuracy of the marker position estimation is verified with normal sit-to-stand data from more than 30 clinical trials. Moreover, further research on improving the link segment and regression method is addressed.**

I. Introduction

Motion capture has been widely used as an evaluation tool for human movement. Recent technology in 3D camera enables motion capture with real-time results. For clinical purpose, the biomechanical evaluation of the human movement is an essential step. With set of markers attached to the specified location of the body segments, 3D cameras can acknowledge human joint positions based on the previously defined human body model. This model is defined by body segmentation with anthropometric parameters data from past studies. [1]-[3]

Upon preceding a motion capture using 3D cameras, there exist few restrictions on testing environment. In order to be captured, both edges from one reflective marker should be scanned by multiple 3D cameras. If any object obstructs the sight of 3D cameras, marker could not be captured. Recently, the markerless motion capture technology emerges as a new solution to the hidden marker issues. [4] However, current markerless motion capture technology is less accurate than the motion capture with markers. [5] To be employed in an evaluation of biomechanics of human movement, accurate marker positions should be acquired.

Previously, sit-to-stand without supporting equipment is commonly evaluated by many researchers. [6] Various determinants of sit-to-stand movement such as speed, chair heights and foot position are also studied. However, the motion capture analysis was not commonly applied to the sit-to-stand with supporting equipment. Most studies apply force plate data with kinematic solution instead of full body motion capture analysis due to hidden marker problems. [7]

In this study, the hidden marker positions on lower limbs (Thigh, Knee and Tibia) during sit-to-stand task are restored. The link-segment and regression method with constraints is applied to estimate the position of lost markers. This method is verified with normal sit-to-stand sessions (More than 30 trials from 3 normal subjects) for accuracy and reproducibility. Restored marker positions are used in the biomechanical evaluation of the sit-to-stand movement with Smart Mobile Walker. [8] The joint forces and moments could be evaluated.

II. Methods

A. Experimental Apparatus and Protocol

VICON Motion system is used to perform motion capture sessions. The reflective markers are attached to the designated positions to define human body model. Using BodyLanguage and BodyBuilder, the full body human model for biomechanical evaluation could be implemented. Fig. 1 demonstrates the full body model used in this study.

Motion captures on three different subjects are conducted. Each subject performed five normal sit-to-stand tasks and fifteen sit-to-stand tasks with Smart Mobile Walker. One session of sit-to-stand motion capture consists of following phases: 1) standing from chair 2) standing still for few seconds 3) sitting down. Normal sit-to-stand motion captures data are kept as reference data for verification on the accuracy of marker estimation method.

As shown in Fig. 2, the lower limb markers are completely invisible during sit-to-stand with Smart Mobile Walker. Since a robotic walker obstructs lower limb markers from 3D cameras, no markers could be recognized by VICON Motion system. Following method will be used to find the estimated position of lost markers.

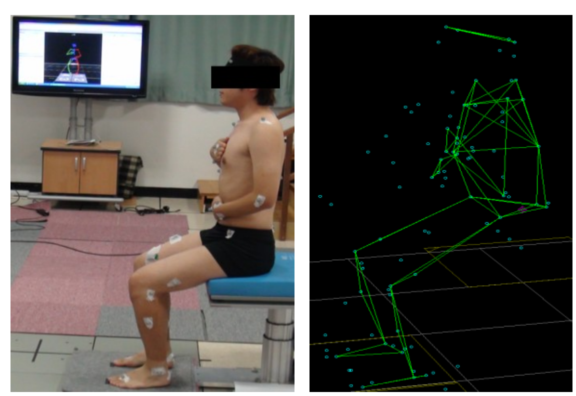

Figure 1. Experimental setting in trial (Left) and Full body model implemented by BodyLanguage script (Right)

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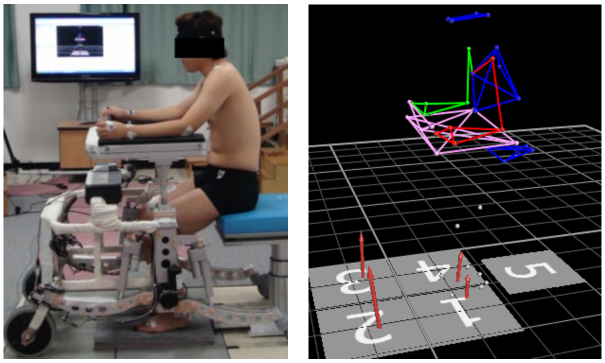

Figure 2. Sit-to-stand with a robotic walker (Left) and VICON Motion capture result with hidden markers in lower limbs (Right)

B. Link-segment & Regression Method

The overview of the link-segment method is described in Fig. 2. The link-segment model estimates the position of lower limb markers including thigh, knee and tibia. By acquiring position of these markers, the link-segment model is defined and traditional kinematics and kinetics method could be applied.

There are several constraints on applying the method. First, the hip related markers including left anterior superior iliac spine, left posterior superior iliac spine, right anterior superior iliac spine, and right posterior superior iliac spine should be visible through whole session. The ankle related markers are assumed to be fixed during sit-to-stand since these markers change positions relatively small comparing with other markers.

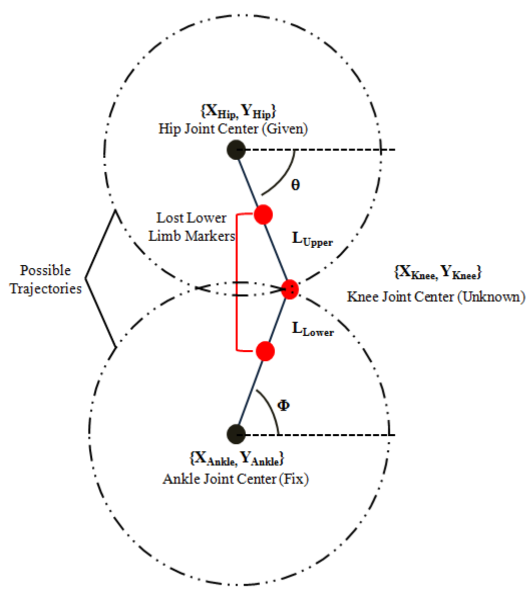

Figure 3. Basic concept of link-segment method

$$X_{Knee} = X_{Hip} + L_{Upper}\cos\theta \quad (1)$$

$$X'_{Knee} = X'_{Ankle} + L_{Lower}\cos\Phi \quad (2)$$

$$Y_{Knee} = Y_{Hip} - L_{Upper}\sin\theta \quad (3)$$

$$Y'_{Knee} = Y'_{Ankle} + L_{Lower}\sin\Phi \quad (4)$$

$$\sqrt{(X_{Knee} - X'_{Knee})^2 + (Y_{Knee} - Y'_{Knee})^2} \quad (5)$$

Based on given data from hip markers, fixed ankle position and (1)-(4), X_{Knee}, Y_{Knee}, X'_{Knee} and Y'_{Knee} could be calculated. When (5) becomes the smallest (close to 0), the contact points between upper and lower link are determined. The problem arises in that there always exist two possible contact points for intersecting two circles. However, it is easily removed by restricting joint angles in a reasonable range ($0 \leq \theta,\Phi \leq 180°$ & $\theta + \Phi < 200°$) that human can achieve. Tibia and thigh marker positions are attainable using calculated θ and Φ. Since distances from knee to thigh and tibia markers are known, trigonometry computation brings out the positions of thigh and tibia markers.

It is also called regression method because the marker position estimation is not only done with theoretical computation. The real data from motion capture system such as hip related markers are used as independent variables in computing hidden markers. In addition, various data from normal sit-to-stand task such as initial ankle positions, relationships between each marker are employed. Savitzky-Golay smoothing filters are applied to reduce signal noises by adopting a local polynomial regression. Using filters, tremendous noise from link-segment method could be removed.

In biomechanics, the spatial coordinate system is usually defined as follows: vertical direction as Y-axis, the direction of progression (anterior-posterior) as X-axis, and the transverse direction (medial-lateral) as Z-axis. Since 2D version of link-segment method is introduced, only X-axis and Y-axis marker positions could be estimated. Nevertheless, Z-axis marker positions are determined via specific patterns observed during normal sit-to-stand task. Illustrated in Fig. 4, transverse position of thigh, knee and tibia markers are closely related to each other as well as vertical position of knee marker. There are four critical points (Start Point1, Start Point2, End Point1, and End Point2) which can describe an overall pattern in transverse direction. At 'Start Point1',

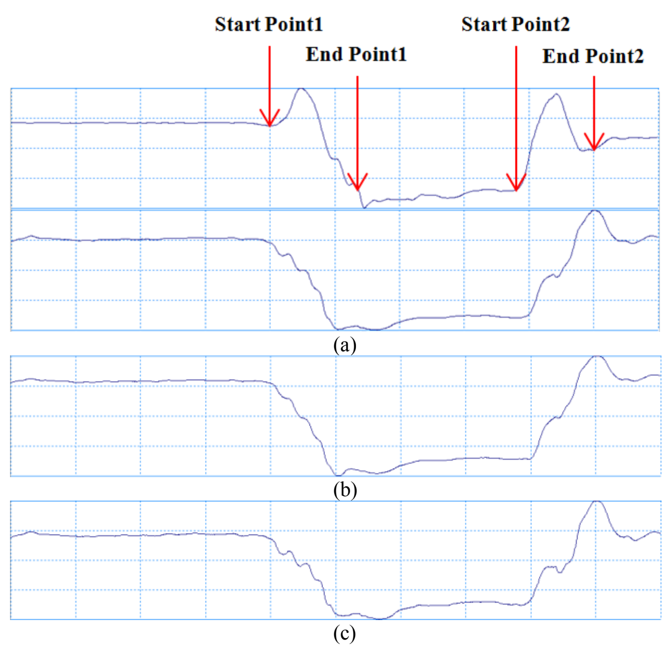

Figure 4. Marker position during normal sit-to-stand (a) Knee -X & Z direction (b) Thigh-Z direction (c) Tibia-Z direction

the transverse position of the marker starts to climb downward (narrowing lower limbs) until it reaches the 'End Point1'. From 'End Point1' to 'End Point2', the position would be steady since these are the regions when the subject stands still. Starting from 'Start Point2', marker position starts to climb upward (spreading lower limbs) until 'End Point2'. Applying these patterns directly, Z-axis positions of lower limb markers are attained.

III. Results

A. Verification

Normal sit-to-stand task results are used as reference data for validation of the introduced method. The verification is processed under a circumstance where the lower limb markers are completely lost during the sit-to-stand task. Firstly, thigh, knee and tibia marker position data of normal sit-to-stand task are deleted for whole frames. Link-segment and regression method is applied to compute the estimated position of removed markers. Fig. 5 illustrates the difference between the estimated marker positions with reference data. From graphs (a)-(i), it is shown that all differences between reference and estimation are within 10% range. The average percentage difference was less than 1%. Under verifications on more than 30 clinical trials, the average and maximum percentage differences do not exceed 3.5% and 12%. Thus, the accuracy of estimated marker positions is approved.

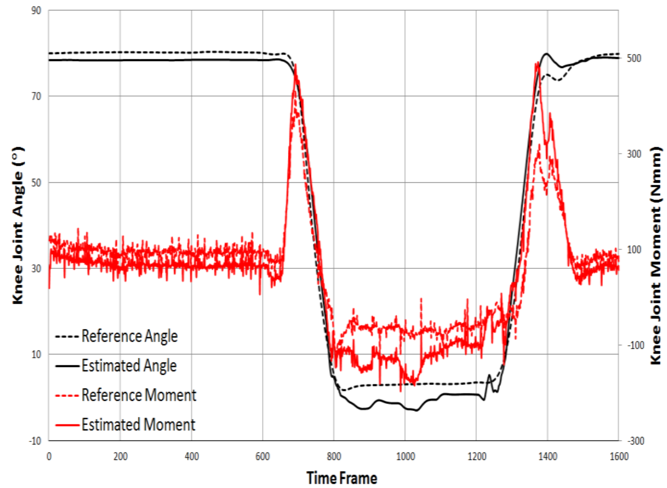

Figure 6. Comparison of joint angle and moment

Next step in verification process is applying estimated positions to compute the biomechanical evaluation results such as joint angle and moment. Fig. 6 indicates that the joint angle and moment from estimated positions are within a reasonable range comparing with reference. These verifications assure that introduced method could be employed in the biomechanical evaluation of the sit-to-stand movement with a supporting device where most of lower limb markers are hidden during the task.

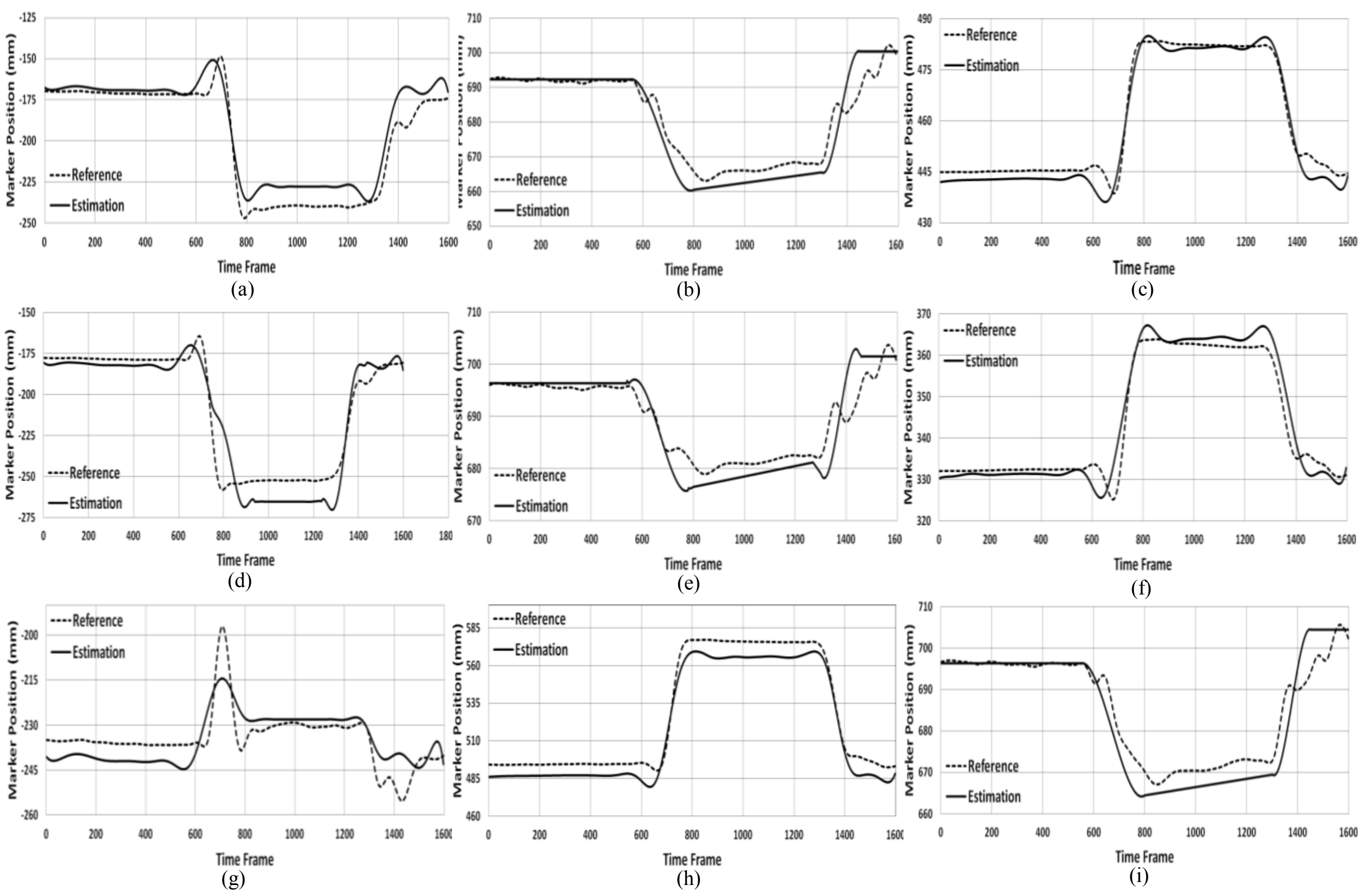

Figure 5. Comparison between referenced vs. estimated marker positions (a) knee: x-direction (b) knee: z-direction (c) knee: y-direction (d) tibia: x-direction (e) tibia: x-direction: z-direction (f) tibia: y-direction (g) thigh: x-direction (h) thigh: x-direction (i) thigh: x-direction

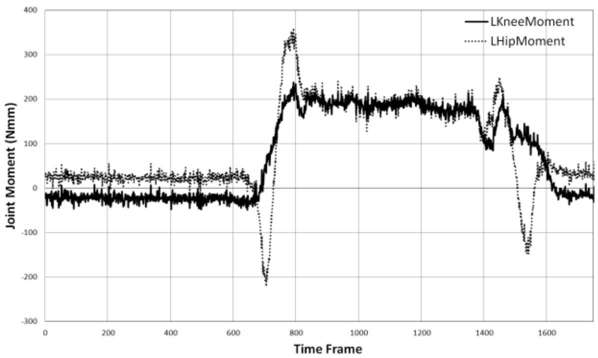

Figure 7. Joint moments during sit-to-stand with a robotic walker

B. Biomechanical evaluation during sit-to-stand with a robotic walker

Using introduced method, lost lower limb marker positions during sit-to-stand with 'Smart Mobile Walker' are restored. Based on these estimated positions, the joint angles, forces and moments could be computed. Fig. 7 shows results from sit-to-stand with a robotic walker. As the method is verified with reference data, the results show no awkward pattern as well as reasonable joint moments and forces. From these results, it could be inferred that 'Smart Mobile Walker' helps reducing required joint moments for sit-to-stand movement. However, deeper studies with numerous clinical trials should be proceeded in order to guarantee the performance of the supporting system. More clinical trials would also enhance the accuracy of the marker position estimation method by accumulating regression data.

IV. Discussion

The estimation method is only applicable to the sit-to-stand movement since all assumptions and constraints are based on this specific case only. For other human movements such as gait, running and jumping, different methods should be established to track the hidden marker positions. It is possible that the upgrade version of link-method and regression method could apply to these applications for marker position estimation.

The verifications with more than 30 clinical trials with three different subjects ensure that the introduced method has high accuracy and precision. Applying the method to find out the joint related information during the sit-to-stand with a robotic walker is more effective than traditional methods.

The traditional methods on lost marker including 'Spline Fill' and 'Pattern Fill' require most of marker positions during the task. However, the markers are usually invisible through whole task. Since new method only requires hip markers instead of most of lower limb markers, it will have more applications to resolve the hidden marker issues.

There is a problem in using link-segment method. It assumes that center of rotation for knee is fixed. Actually, it is not fixed and it might cause the change in thigh and tibia lengths. This might causes errors in estimating positions since thigh and tibia lengths are crucial part in calculating thigh and tibia marker positions. Although errors in estimated position are within 12%, the motion pattern of knee joint center and center of rotation during sit-to-stand should be carefully examined in order to minimize errors in marker position estimation.

The next research topic would be improving the link segment and regression method on all age and functional groups. In this paper, only young and normal subjects' clinical trials are used as reference data. There could be difference between normal and impaired subjects as well as young and old subjects. It might arise that unique constraints might be required for different age and functional groups.

Based on the improved method, it can be applied to clinical trials of sit-to-stand movement with a robotic walker of overall age and functional groups. The marker estimation method will be mostly used in the verification process where the performance of sit-to-stand supporting system should be examined in respect of biomechanics.

V. Conclusion

The link-segment and regression method is proposed as a solution to hidden marker issues. The method is verified by real data set for its accuracy and reproducibility. With normal and young subjects, this method works quite effectively in estimating the lower limb marker positions during sit-to-stand with or without supporting system. Thus, it could be employed in a situation where hidden marker issues are unavoidable.

Acknowledgment

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