Markerless Motion Capture Methods for the Estimation of Human Body Kinematics

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***Abstract*— The most common methods for the study of human movement use markers placed on the skin. While marker-based methods have demonstrated the value of quantitatively methods assessing human movement there are some drawbacks to marker -based including the impediment to the motion by the presence of skin markers and relative movement between the skin where the markers are placed and the underlying bone. Markerless motion capture represents a novel approach allowing the unencumbered capture of human motion. Human motion is captured as video data from multiple cameras subjects' kinematics is extracted in three dimensions using specific algorithms. A few alternative markerless systems developed by the authors are described. Results of different algorithms for the identification of the full body kinematics are presented, demonstrating the effectiveness and potential of markerless motion capture for human movement analysis in biomechanical applications.**

Keywords-human motion capture; full body kinematics; kinematic model; movement analysis;

I. INTRODUCTION

Motion capture is an important method for studies in biomechanics and has traditionally been used for the diagnosis of the patho-mechanics related to musculoskeletal diseases [1, 2]. Recently it has also been used in the development and evaluation of rehabilitative treatments and preventive interventions for musculoskeletal diseases [3]. Although motion analysis has been recognized as clinically useful, the routine clinical use of gait analysis has seen very limited growth. The issue of its clinical value is related to many factors, including the applicability of existing technology to address clinical problems and the time and costs required for data collection, processing and interpretation [4].

At present, the most common methods for accurate capture of three-dimensional human movement require a laboratory environment and the attachment of markers, fixtures or sensors to the body segments. These laboratory conditions can affect the natural movement of the subject and require a lot of time for subject's preparation. Moreover the obtained kinematics is affected by intra-operator and inter-operator variability as well as by skin artifacts due to the movement of the markers relative to the underlying bone, which is a primary factor limiting the accuracy of marker-based systems [5-7]. Skeletal movement can be measured directly using alternative approaches to a skin marker-based system. These approaches include stereoradiography [8], bone pins [9, 10], external fixation devices [11] or single plane fluoroscopic techniques [12, 13]. While these methods provide direct measurement of skeletal movement with adequate accuracy, they are invasive or expose the test subject to radiation.

Therefore, a non-invasive technique for human body kinematics estimation that does not require markers or fixtures placed on the body would greatly expand the applicability of human motion capture and enhance our understanding of normal and pathological human movement. Eliminating the need for markers would also considerably reduce patient preparatory time and enable simple, time-efficient, and potentially more meaningful assessments of human movement in research and clinical practice. Moreover such a system could allow capturing human motion in natural environment.

The feasibility of accurately measuring 3D human body kinematics using markerless method on the basis of visual hulls is presented. A comprehensive review of markerless motion capture methods can be found in [14, 15].

II. METHODS

Movement was determined by first capturing video streams of the subject's movement, then constructing 3D representations of the subject in the form of visual hulls and subsequently labeling individual body segments for extracting human body kinematics. To critically analyze the effectiveness of markerless motion capture in the biomechanical/clinical environment, we quantitatively compared data obtained from the markerless systems with data obtained from marker-based motion capture system

A. Data Acquisition

The data acquisition process consisted of the recording of a video stream from calibrated and synchronized color cameras. The accuracy of markerless methods based on visual hulls is dependent on the number of cameras. Configurations with fewer than 8 cameras resulted in volume estimations greatly

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deviating from original values and fluctuating enormously for different poses and positions across the viewing volume [16].

B. *Reconstruction of the 3D representation*

The visual hull of an object [17] can be defined as the locally convex (over) approximation of the volume occupied by an object. The 3D representation of the motion of the subject across the motion capture volume consists of one visual hull for each instant in time. The visual hull construction process (diagrammed in Figure 1) consisted of the projection of the subject's silhouette from each of the camera planes back to the 3D volume. The 2D silhouettes in the camera planes were obtained by foreground/background separation for every captured frame. The intersection of the resulting cones in 3D space generated the subject's visual hull.

C. *Model matching and kinematics extraction*

Several algorithms have been published in the past trying to estimate human body kinematics from visual hull [18-20] generally lacking in providing a clear quantitative validation. These authors recently published and validated several approaches involving both model-based [15, 21] and model-free approaches [22].

The idea behind the model-based methods for the identification of human body kinematics though 3D representation is:

- To use subject specific information about the subject's morphology and joint location,
- To define a cost function describing how well the model approximates the posture described by the 3D representation,
- To solve the cost function minimization problem, providing the relative "optimal" kinematics for every captured frame.

The subject specific information can be achieved in many different ways, using combinations of methods involving laser scanning, adjustable templates, anthropometric data or possibly a database of human shape and postures [23].

The formulation of the cost function is the crucial point in the entire model matching process. Two examples of cost functions are given in [15] and [21] implemented over articulated ICP or simulated annealing algorithm, respectively.

Model-free approaches try to bypass the most tedious step in model-based methods, i.e. the setting up of a subject specific model, comprehending morphological and kinematics information. Model-free approaches rather use intrinsic general anatomical information such as number of human body limbs, their relative size in terms of volume, and the way they are connected to each other. The 3D representation is mapped to a pose invariant space with focus either on preserving the local structure (Laplacian Eigenmaps [24], Local Linear Embedding [25]) or the global structure (Isomaps [26]). The intrinsic anatomical information is then used to identify the different anatomical segments.

The extraction of the kinematics can be done by identifying an approximation of the underlying skeleton directly in the mapped space [20] or in the original Euclidean space as described in [24].

D. *Validation*

To critically analyze the effectiveness of markerless motion capture in the biomechanical/clinical environment, the authors performed two levels of validation.

The first level of validation test was in a virtual environment. A realistic human 3D model walked through a defined viewing volume using a most favorable camera arrangement [16]. The virtual environment permitted the evaluation of the quality of visual hulls on extracting kinematics while excluding errors due to camera calibration and foreground/background separation. The model represents an absolute gold standard for both the kinematics and the location of joint centers. The accuracy obtained in the virtual environment validation test represents the upper bound of what we can expect in an experimental scenario.

The validation test in experimental environment is usually performed against methods marker-based in terms of joint angles [15], even though these methods can have significant errors that have been extensively described in recent publications [6, 27]. In some cases, as for example during *on the field* outdoor analysis, a comparison with marker-based data is not feasible.

III. RESULTS

Results of a walking sequence and a running sequence are shown, and quantitative results are reported. Accuracy of human body kinematics was calculated in the virtual and experimental scenario as the average of the joint angles deviation obtained from the markerless system with respect to the virtual character actual joint angles or marker-based results, respectively. The high accuracy obtained in the virtual scenario is confirmed by the small deviations that were found in the experimental environment between markerless and marker-based methods, being on the order of 1-2° for the knee joint in both sagittal and frontal plane.

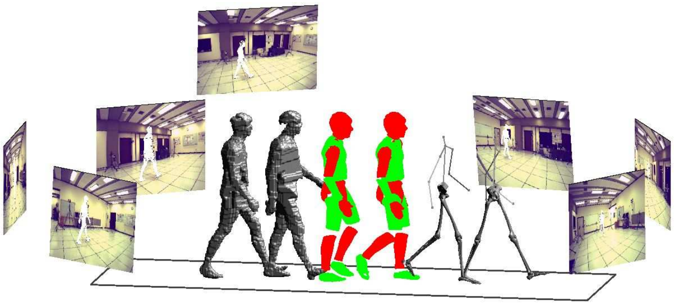

Figure 1. Walking sequence: from the left, 3D representation, body segments model and skeleton model, with image data of cameras configuration; from articulated ICP tracker.

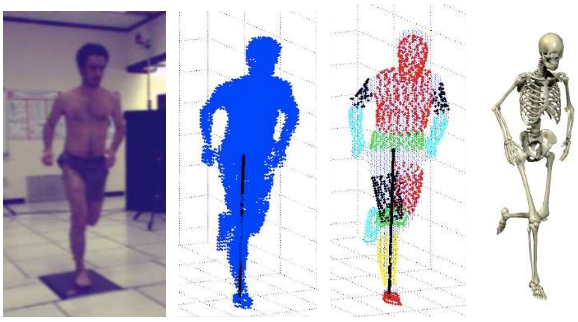

Figure 2. Running sequence, from the left to right: selected video frame, 3D representation, body segments model, skeleton model; from Simulated Annealing tracker.

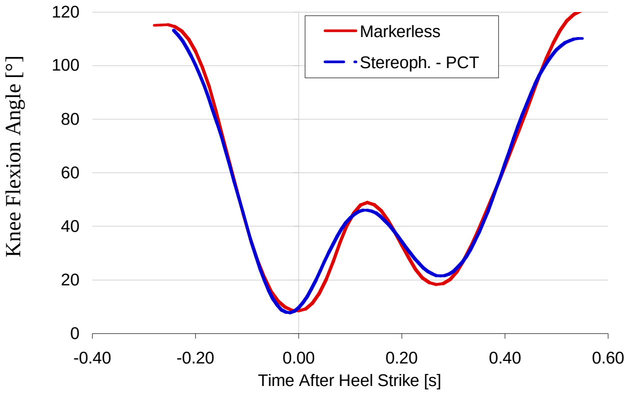

Figure 3. Motion graph of knee flexion graph for a running sequence: Markerless results (red) vs marker-based technique (blue).

IV. Conclusions

The development of markerless motion capture methods is motivated by the need to understand normal and pathological human movement without the encumbrance of markers or fixtures placed on the subject, while achieving at least the same accuracy of marker-based systems.

The studies summarized here demonstrate that markerless motion capture has the potential to achieve a level of accuracy that facilitates the study of the biomechanics of normal and pathological human movement. While additional evaluation of the method is needed, the results demonstrate the feasibility of calculating meaningful joint kinematics from subjects without any markers attached. For example, the model-based markerless system was recently used to investigate the role of trunk movement in reducing medial compartment load [28].

Model-free methods are a promising option for the future, being able to simplify the whole motion capture process. These methods have been under investigation and some preliminary results seem promising even though they have not reached the accuracy and robustness of model-based methods.

It is easy to foresee further improvements and development in the following years in the field of markerless motion capture that will lead to even more accurate and robust systems that will facilitate potentially more meaningful assessments of human motion in clinical practice and research.

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