Augmented Reality Visualization of Joint Movements for Physical Examination and Rehabilitation

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Abstract

We present a visualization tool for human motion analysis in augmented reality. Our tool builds upon our previous work on joint biomechanical modelling for kinematic analysis, based on optical motion capture and personalized anatomical reconstruction of joint structures from medical imaging. It provides healthcare professionals with the *in situ* visualization of joint movements, where bones are accurately rendered as a holographic overlay on the subject – like if the user has an "X-ray vision" – and in real-time as the subject performs the movement. Currently, hip and knee joints are supported.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology

1 Introduction

Healthcare professionals are interested in knowing how the range of motion (ROM) of the patient's joint changes over time. This is true in a physical rehabilitation scenario, where the patient participates in periodic physical activities to recover movement, as well as in a post surgery scenario, where the physician wants to assess the effect of the intervention on the joint [7]. Patient's physical examination usually includes palpation and evaluation of the passive ROM of the joint under investigation using standard goniometers or inclinometers. Unfortunately, this process may lack precision because the clinician has no direct access to the joint (i.e, external measurement).

We designed an augmented reality (AR) application for the personalized visualization and analysis of joint movements targeting several orthopedic activities, such as clinical examination and rehabilitation. Our application builds upon our previous work [2, 4, 5] on joint biomechanical modelling for kinematic analysis, based on optical motion capture and personalized anatomical reconstruction of joint structures from medical imaging. In the application, the user can observe the movement of the bones, the ROM of the joint, and mark points on the surface of the bone to track their trajectory in space. All of this is accurately rendered as a holographic overlay on the subject – like if the user has an "X-ray vision" – and in real-time as the subject performs the movement (Fig. 1).

In a related work, Baillot et al. [1] proposed a knee kinematic simulation and posterior retrieval of pre-computed poses for AR visualization through a look-up table. The landscape of AR and computing have significantly changed since [1], and new kinematic models can be now computed and used to present joint poses in real-time [2, 4, 5]. To our knowledge, our system is the only to use

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(a) (b)

Figure 1: Overview of our visualization application. In (a) and (b), we show the examination of the joint range of motion during passive and active movements, respectively. Note: markers were put on a suit for convenience of these pictures, but they are usually placed directly on the skin during medical capture.

AR for medical visualization and examination of patient-specific joint model and kinematics to date. Such development is challenging as it requires expertise in different fields: motion capture, 3D reconstruction, biomechanical modeling, human computer interaction, and AR visualization.

The application was developed for the Microsoft HoloLens[1] Optical See-through Head-mounted Display (OST-HMD), which required the development of a calibration method to align the physical center of projection and optical axis of the OST-HMD to an arbitrary coordinate system defined by the external tracking system. The correctness of this alignment is critical as in an AR context a small error can result in major visual mismatch of the graphical overlay. The calibration procedure is described in [6].

2 Materials and Methods

2.1 Equipment and System Architecture

The application hardware consists of a VICON MXT40S motion capture system[2], a computer, and a Microsoft HoloLens OST-HMD. The VICON tracking system consists of 24 infrared cameras sampling at 240 Hz and is used to track retro-reflective markers stuck on the subject's skin (⌀ 14 mm) and other auxiliary objects (⌀ 19 mm).

A schematic representation of the system architecture is shown in Fig. 2. The VICON Blade software[3] is used to process the cameras data and to stream the marker positions to Arthro3D, an in-house application for biomechanical simulation running on the same

[1] www.microsoft.com/en-us/HoloLens
[2] www.VICON.com
[3] www.VICON.com/products/software/blade

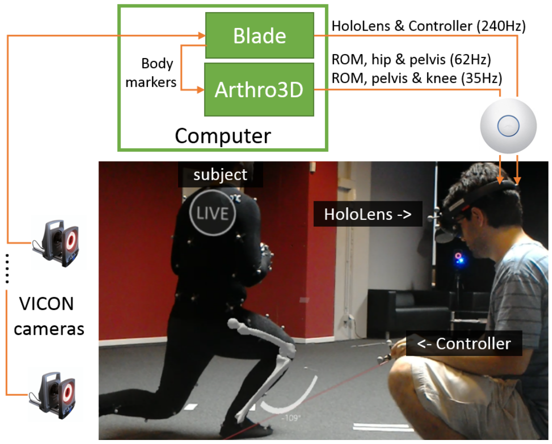

Figure 2: Overview of the system architecture.

computer. Arthro3D receives the marker information and processes it with validated joint biomechanical models to reconstruct the poses of the body segments. Finally, Arthro3D streams the bone poses information and the joint ROM to the HoloLens through a wireless infrastructure. Two other auxiliary objects are tracked by the motion capture system, a controller used for interaction, and the HoloLens itself. These are directly streamed from Blade to the HoloLens. HoloLens receives the poses of the tracked objects and is used for the virtual cameras rendering and visualization of that information as an overlay on the patient.

2.2 Biomechanical Simulation

The Arthro3D software integrates validated biomechanical joint models for the hip [2, 5] and knee [4] to compute accurate joint poses accounting for soft tissue artifact [8]. The models are based on a subject-specific kinematic chain of two rigid bodies (for the hip, the pelvis and femur; for the knee, the femur and tibia) using personalized joint 3D models reconstructed from medical images. The accuracy of the models developed range from 0.24 to 3.7 mm in translations and from 0.55° and 6° in rotations, which is acceptable for clinical use in the study of joint pathology.

From the computed bone poses, the ROM of the hip and knee joints can be evaluated at each point of the movement. This is achieved by calculating the relative orientation between the pelvis and femur (or femur and tibia) using two local coordinates systems [5], which were established based on the definitions suggested by the International Society of Biomechanics [9].

2.3 AR Application Design

The system allows clinicians to perform online *in situ* visualization and analysis of the joint movements, and to record movement clips as the subject performs the desired actions (Fig. 1ab). That is, with the subject-specific bone models reconstructed from medical imaging and simulated by our biomechanical simulation software, the user can visualize in real-time the movement of the hip or knee joint as an overlay on the subject.

A 6 DOFs (position and rotation) controller is used for input. The controller is coupled with a HoloLens clicker, which connects directly to the headset and is used as a confirmation button only. A raycasting metaphor – where the pose of the controller controls the origin and direction of a laser pointer-like ray – is used to point and interact with the scene.

The clinician can visualize the current amount of flexion/extension, abduction/adduction and internal/external rotation of the joint under investigation, and add trajectory points to the surface of the bones. Fig. 1ab shows the visualization of the angles in a live scene. Rendering opacity is proportional to the rotation angle, which prevents the angle from being visible when it is small and avoid a cluttered virtual layer. Opacity has a linear relation with the rotation angle when it is smaller than 40° and becomes saturated for angles equal or above 40°.

Movement trajectories are drawn as line strips in 3D space, and the rendering color of their segments is defined by the speed of movement, thus the optimal mapping is dependent on the task. To add a trajectory point, the controller button should be clicked while the ray intersects with one of the bone models.

3 Discussion and Conclusion

We presented an AR application for visualization of joint movements. The development of this application was accompanied by an experienced orthopedic surgeon, and it could assist in different medical scenarios, such as: (i) physical examination, with evaluation of the passive and active joint ROM during standard clinical movements, which can help the clinician to visualize abnormal functional joint behaviors; and (ii) physical rehabilitation, with periodical sessions for the observation and documentation of the joint ROM during the execution of typical rehabilitation exercises.

Future work will consider the extension of this system in different directions. Two short-term developments will be prioritized: first, we will support the visualization of the shoulder, another joint commonly affected by musculoskeletal disorders. This will require the adaptation of our biomechanical model for patient-specific shoulder kinematics [3] for use in real-time applications. Second, we will perform a comprehensive validation study with patients comparing our system with conventional methods of joint ROM examination.

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