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Coordinate System Transformations for Imitation of Goal-Directed Trajectories in Virtual Humans

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Abstract

The goal of this work is to record human hand trajectories during goal-oriented reaching behaviors in immersive VR for later imitation by a virtual human. It is desirable that the used trajectory representation generalizes over different positions and orientations of the target object. To this end, this work investigates trajectory representations in two neurophysiologically inspired coordinate systems. Results show that natural looking movement can be preserved as real motion capture data is used as a basis for these calculations.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Animation I.3.7 [Computer Graphics]: Virtual Reality

1. Introduction

In recent years, Motion Capture has become a standard in computer graphics. Movements performed by a real human are recorded and played back with a virtual character to result in naturally looking animations. Unfortunately, this approach has some drawbacks, such as retargetting problems when a scene changes. To circumvent this problem, Jung et al. [JBHW06] introduced the Action Capture (AC) method. This method uses immersive virtual environments to record user interactions like "grasping a ball" as generalized action representations. Instead of simply replaying captured motions, the actions can then be imitated by virtual humans in modified scenes where e.g. the target object is displaced. At the current state of AC, however, some motion detail, such as style or timing of the arm movements, is lost. This work describes a first, neurophysiologically inspired approach to imitate the hand motion trajectories performed during AC, while both preserving the natural looking style of the motions and achieving flexibility with respect to new situations.

2. Related Work

To achieve adaptability of goal-directed reaching behaviors to changing environments, often elaborate motion planning algorithms are used, see e.g. [KAAT03]. An alternative approach, so far more commonly pursued in the field of robotics, involves the adaptation of reach motions demonstrated by a human instructor based on certain internal models of the trajectory. E.g. [INS02] use control policies and an attractor landscape to encode observed motion trajectories. However, such approaches often fall short w.r.t. the naturalness of the generated motion as compared to animations generated by motion capture. Additionally, some of them have limitations in the degree of body articulation, making it difficult to judge the naturalness of motions, or are not able to cope with different start and end positions of the desired trajectory. As a consequence, the problem of generating adaptive, yet life-like reach motions for virtual humans is still a challenging task.

3. Coordinate System Transformations of Hand Trajectories

Recent behavioral and neurophysiolgical findings suggest that humans make use of different coordinate systems (CS) for planning and executing goal-directed behaviors such as reaching for an object [HS98]. Although the nature of such CS transformations is not yet fully understood, there is empirical support for the critical role of eye-centered, shoulder-centered and hand-centered CS. These are used for transforming a sensory stimulus into motor commands (visuomotor transformations). The fact that humans can perform goal-directed movements in varying situations (e.g. different object positions and orientations) indicates that such transformations play a vital role in motor planning.

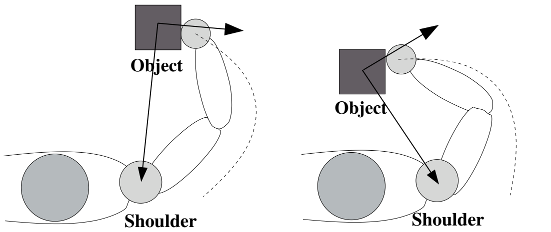

Figure 1: *Trajectory adaptation through CS transformation. Left: the trajectory is recorded w.r.t. an object-shoulder CS. Right: for playback, an updated object-shoulder CS is constructed, yielding a rotated and scaled trajectory.*

Motivated by these neurophysiological findings, we propose the representation and later adaptation of hand trajectories to varying target positions and orientations w.r.t. (a) object-shoulder CS and (b) object-hand CS. The object-shoulder CS is spanned between the center of the goal-object and the shoulder of the (virtual) human. Let $\vec{s}$ and $\vec{o}$ be the position of the shoulder and the object respectively. Let also $\vec{up}$ be a vector indicating the up direction. Then the coordinate-axes for the object-shoulder CS can be computed as follows:

$$\vec{z} = \frac{\vec{s}-\vec{o}}{|\vec{s}-\vec{o}|}, \qquad \vec{x} = \vec{z}\times\vec{up}, \qquad \vec{y} = \vec{x}\times\vec{z} \qquad (1)$$

Alternatively, the y-axis can be chosen such that it corresponds to the orientation of the target-object. In contrast, the object-hand CS is spanned between the center of the target-object $\vec{o}$ and the initial hand position $\vec{h}$ at the beginning of the movement: $\vec{z} = \frac{\vec{h}-\vec{o}}{|\vec{h}-\vec{o}|}$ and $\vec{x}, \vec{y}$ as in equation (1). The construction of the object-shoulder CS is shown in Fig. 1. While recording a new goal-directed trajectory, the positions of the hand are transformed into the object-shoulder CS (Fig. 1 left). To apply the trajectory to a new situation (Fig. 1 right), a new object-shoulder CS is constructed while subsequently transforming the trajectory points from this space into the global CS. The resulting positions are used as a parameter for an inverse kinematics solver, to drive the end-effector of the virtual human to the trajectory point.

4. Experiment & Results

We applied both types of CS transformation to the Action Capture method. A human demonstrator had to reach and grasp an object in Virtual Reality. The actions (reaching, grasping) were extracted and the hand trajectory was recorded and transformed into (1) object-shoulder CS and (2) object-hand CS. Afterwards, the grasped object was moved to four new positions and the action was reproduced by a virtual human. Fig. 2 shows the resulting hand trajectories of the virtual human. The object-shoulder space, as shown on the left side plot, results in faithful (similarly-shaped) goal-directed trajectories which adapt to the situation, i.e. changing object positions. However, the start-position of the hand critically depends on the position of the target object and on the start-position encoded in the trajectory. As a result, when recording a trajectory for reaching an object this trajectory cannot be used for reaching objects starting from another object. This leads to large gaps between subsequent trajectories. In the case of the object-hand CS, shown on the right side plot of Fig. 2, this problem does not occur as any new trajectory will start from the current hand position. This guarantees, that any arbitrary set of trajectories can be played in sequence without any jumps or gaps.

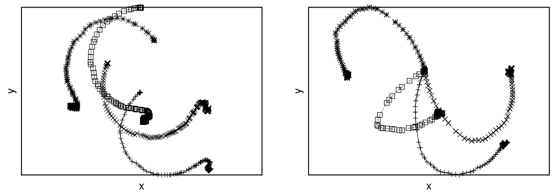

Figure 2: *The same recorded trajectory reproduced for different goal-positions. Left: object-shoulder CS; right: object-hand CS.*

5. Conclusion

We presented two neurophysiologically inspired CS transformations for recording and planning of lifelike hand trajectories. Reaching and grasping movements of real humans were recorded. These actions were replayed with new object positions and with different objects by virtual characters. While both proposed CS adapt the trajectory to the new situations, only the object-hand CS was able to generate trajectories starting at the current hand position, and thus produce sequences of trajectories without gaps.

References

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