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Poster

Evaluation of Optimization Strategies for Synchronization of Fine Motor Movements in Distributed Real-Time Systems

A. S. Pavlov[1], J. H. Israel[1] and S. Keppler[1]

[1]University of Applied Sciences for Engineering and Economics, Berlin, Germany

Abstract

With the growing demand for real-time collaboration in distributed immersive environments, e.g. in mechanical engineering or health care, a need for synchronisation of user's fine motor movements is gaining significance. This paper presents the evaluation of several popular optimization strategies for synchronization of fine motor movements. The evaluation was performed using a dedicated simulation software which recorded several network metrics and transformation errors. Fine motorics included hand and finger movements, which were recorded using the finger tracking system Leap Motion. It was shown that a combination of Cubic Hermite Spline Interpolation for spatial positions and Squad Interpolation for spatial rotations with Local Lag for time synchronization provided the smallest average position error among all clients at a 10 Hz tick rate.

CCS Concepts
• ***Human-centered computing*** → *Collaborative and social computing;*

1. Introduction

Collaborative VR applications are systems in which many people can perceive each other and work on tasks together either in the same location or remotely [ELLF18]. They are used, for example, in engineering [ESO*17], education [PL19], and health care [DWW*19]. Especially when joint manual interaction plays an important role in application scenarios, it is necessary to display the position of the hands and fingers quickly, precisely, and consistently. This requires the use of optimization strategies, which we analyze in the following. To our best knowledge, there were no yet specific realizations of the collaborative work under the technical requirements as presented in this work.

2. Simulation Software for Movement Replication

The simulation software (Fig. 1) was developed in Unity and implemented a client-authoritative client-server architecture using the Photon network framework. It offers network transmission of state updates and motion replication.

- Deterministic mode (m:n replication): pre-recorded sequence of fine motor movements is replicated among all clients in a time synchronous manner (using local processor time for synchronization).
- Nondeterministic mode (1:n replication): movements are directly controlled by user input from Leap Motion with one client and replicated to all other clients in real-time.

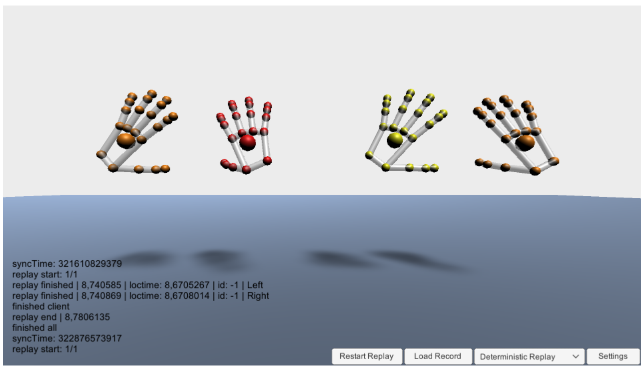

Figure 1: *Screenshot of movement replication of the hands with 2 clients in deterministic mode of the client application. From left to right per pair of hands: original hands client 1, replicated hands client 2.*

Spatial position and rotation algorithms are used to simulate continuous movement from transmitted discrete transformation data. Time synchronization algorithms are then applied to synchronize the replicated and original movement in time. We tested several algorithms. Position algorithms: Linear Interpolation, Cubic Hermite Spline Interpolation, Linear Extrapolation with Constant Speed, Extrapolation using a Linear Approximated End Position, Projective Velocity Blending, Discrete Kalman Filter. Rotation al-

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gorithms: Spherical Linear Interpolation (Slerp), Spherical Cubic Spline Quadrangle Interpolation (Squad). Time synchronization algorithms: Local Lag, Lag Compensation using Linear Extrapolation.

Further, the software implements two motion simulation modes:

- Point-to-point: each node performs a direct movement between a start and end position using movement replication algorithms.
- Hand model: built from fixed-length direction vectors of the palm and finger joints, which are rotated during the simulation.

3. Results and Discussion

Optimal combinations of motion synchronization algorithms for each model of the movement simulation were determined using a deterministic test series (100 runs at 100 FPS, 40 measurements per second), which recorded network metrics and position errors. The approaches *IntrHermite* for point-to-point model and *IntrHermiteSquad* for hand model, each in combination with Local Lag using interpolation time and RTT, showed the smallest average position errors of all approaches at a tick rate of 10 Hz (Fig. 2, 3). This is possibly due to the simulated curvilinear motions that correspond to the continuous spherical movements of an anatomical hand. The hand model showed the smallest position error among all simulation types due to the implemented hand and finger constraints. Interpolations showed overall smaller position errors than extrapolations due to the difficult-to-predict fine motor movements. The optimal approaches were evaluated on a remote server to determine the behavior and performance of the motion replication and load limits of the Photon framework in distributed systems. For this, the server was connected using VPN to an university network. In the deterministic mode with a remote server, delays in processing and visualization of the movements were observed up from 5 clients due to an overload of the clients computer's CPU and RAM. However, in the nondeterministic mode, the remote Photon server was able to perform a very satisfactory real-time network transmission for 20 distributed clients without any stalling of the simulation. The evaluation showed that position errors alone do not represent a sufficient measure for determining the quality of a movement synchronization. The subjective impression of the fluidity of the replicated movement is also of great importance.

4. Conclusions

In this work, several algorithms for fine motor movement synchronization were implemented in a simulation software and evaluated. The simulation software fulfilled the real-time requirement of establishing a client-to-client transmission with a maximum total latency of under 200 ms. The approaches *IntrHermite* for the point-to-point model and *IntrHermiteSquad* for the hand model, each in combination with Local Lag, delivered the smallest average position error of all algorithms at a tick rate of 10 Hz in Photon. In the future, the following approaches could be implemented to possibly improve the movement synchronization: extension of the Cubic Hermite splines to Kochanek-Bartels splines for extended curve tuning, limitation of the maximum extrapolation path after an interpolation for reduction of corrective movements, combination of several algorithms, use of data compression methods for bandwidth reduction.

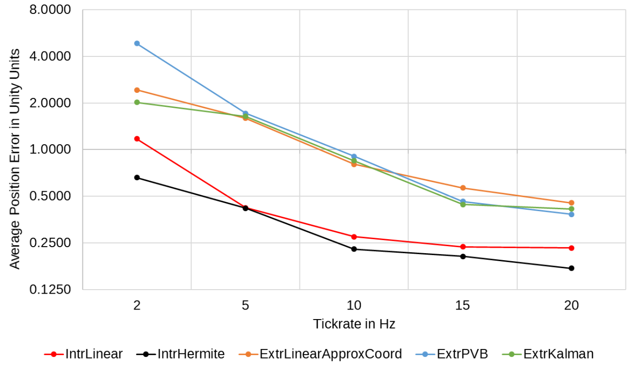

Figure 2: *Average position error of client movements depending on tick rate and position algorithm in the point-to-point model with Local Lag. Performed in a local network with 2 clients, a server and a simulated RTT of ≈50 ms.*

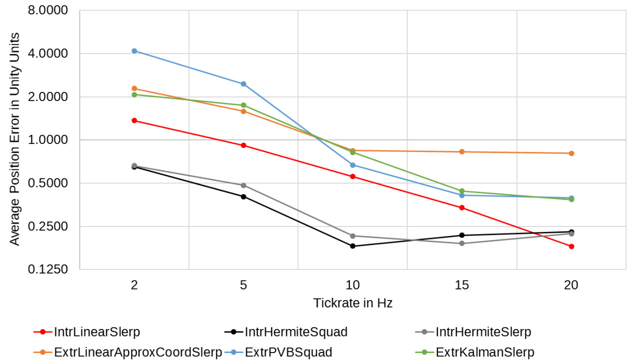

Figure 3: *Average position error of client movements depending on tick rate, position and rotation algorithm in the hand model with Local Lag. Performed in a local network with 2 clients, a server and a simulated RTT of ≈50 ms.*

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