Swarm Sim2Real:
Novel Indoor Experiments with Multiple Swarm-bots to Study Human-Swarm Interaction and Translation from Simulation to Reality

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Abstract

Motivation

In the research on human-swarm interaction (HSI), it is important to focus on designing the behavior of swarm robots and examine how human supervisors can interact with these robot groups, especially when dealing with emergencies like search and rescue missions.

Objective

Studies on human-swarm interactions are essential to involve a human user commanding a swarm of robotic systems. To perform the HSI experiment, we integrated a computer simulation environment and an indoor physical setting. The innovative framework was able to physically implement swarm robots controlled in a computer simulator and determine what factors to be considered in the physical environment.

Approach

To achieve a real-time experiment, swarm robots were utilized in a motion capture lab in the physical environment, and their movements were reflected back to the virtual environment to analyze the delay or latency between the two environments. Understanding the results and analyzing the limitations of merging virtual and physical environments in HSI research can lead to the development of an advanced framework.

Methods

Experimental Environment Designed

We created a new environment named "SPLASH (Simulation and Physical environment for Live Adaptable Swarm Human interaction)" by combining the simulation environment and an indoor physical environment to perform HIS experiment, as shown in Figures 1 and 2 [1].

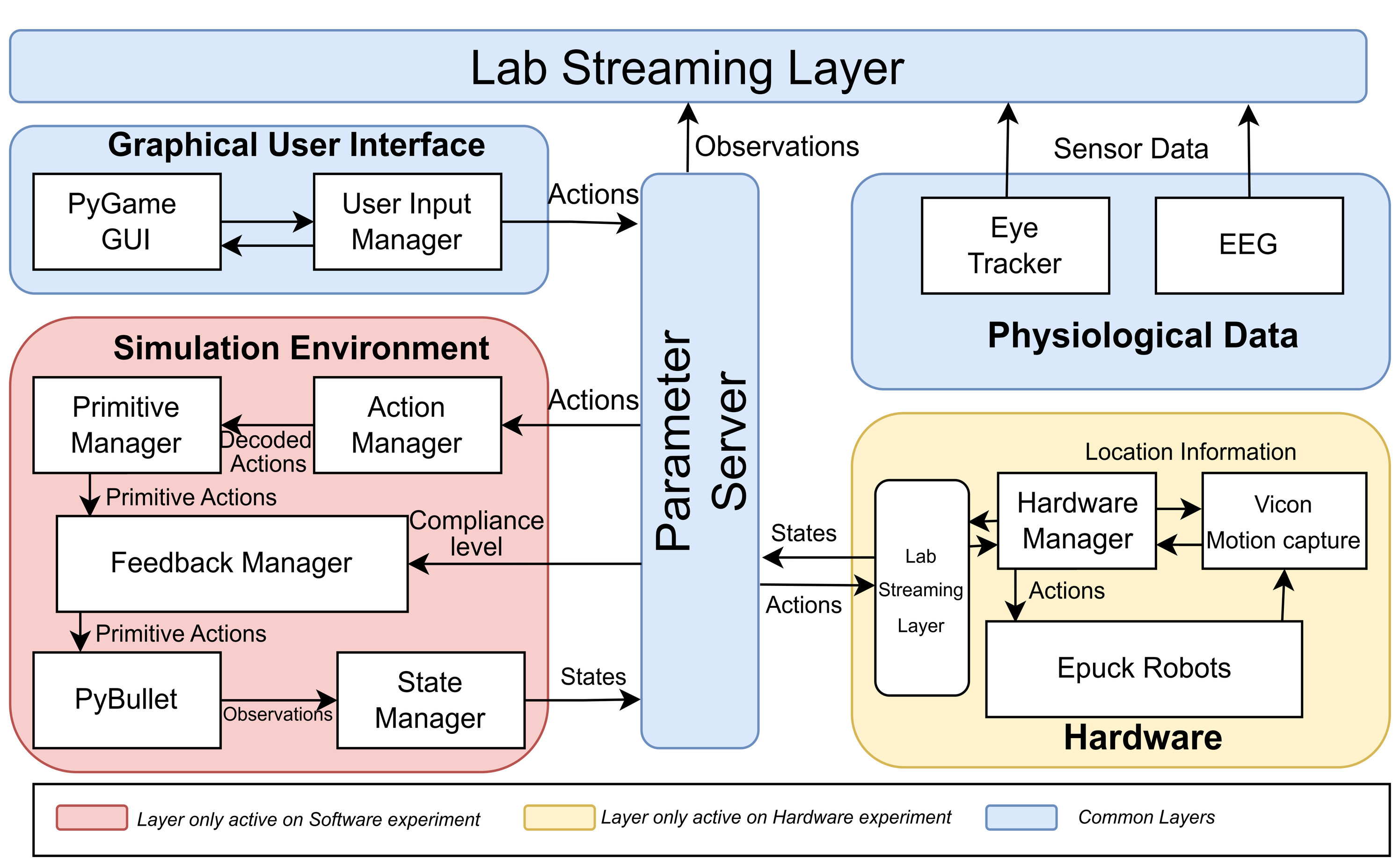

Figure 1. The new framework "SPLASH". All the physical experimental data was saved in the Lab Streaming Layer.

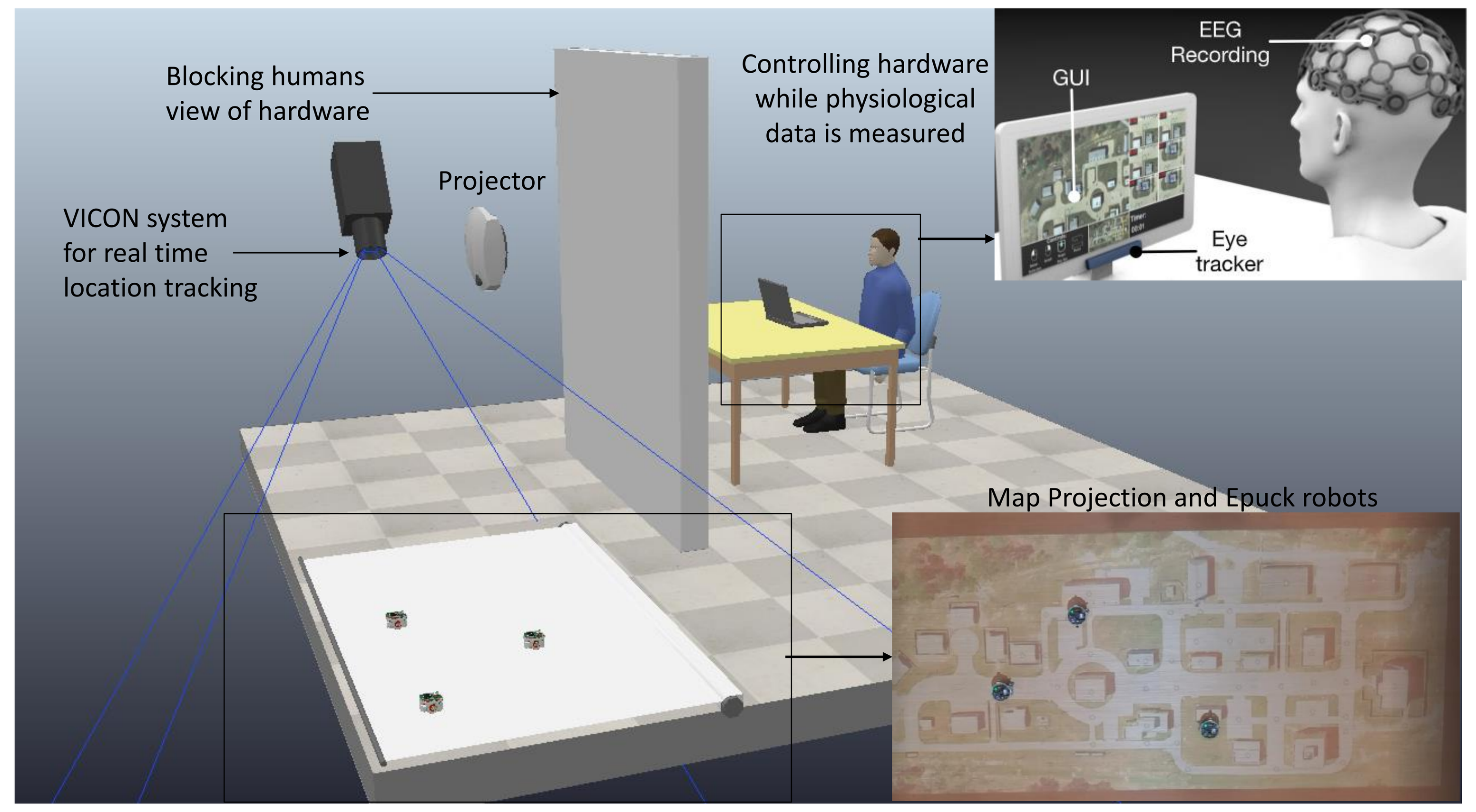

Figure 2. The physical setup used for recording the data. The subject was blocked from the physical environment with a screen, and E-Puck2 was used to physically represent the swarm robots that were moving in the simulator.

Figure 3. E-Puck 2, a small ground vehicle utilized for the experiments. In order to localize each robot to the desired position, we utilized VICON Tracker in the motion capture lab, as the robots themselves did not possess a sufficiently accurate IMU.

Experiments That Were Conducted

- Calibration between the map projected on the floor and displayed on the simulator is needed to adjust the two different coordinate systems.
- When the subject moves UAVs in the simulator environment, E-Pucks in the physical environment move according to them.
- The positions of each E-Puck are reflected back to the simulator, and data is collected on how the subjects react to the delay that occurs during this process.

Data Analysis

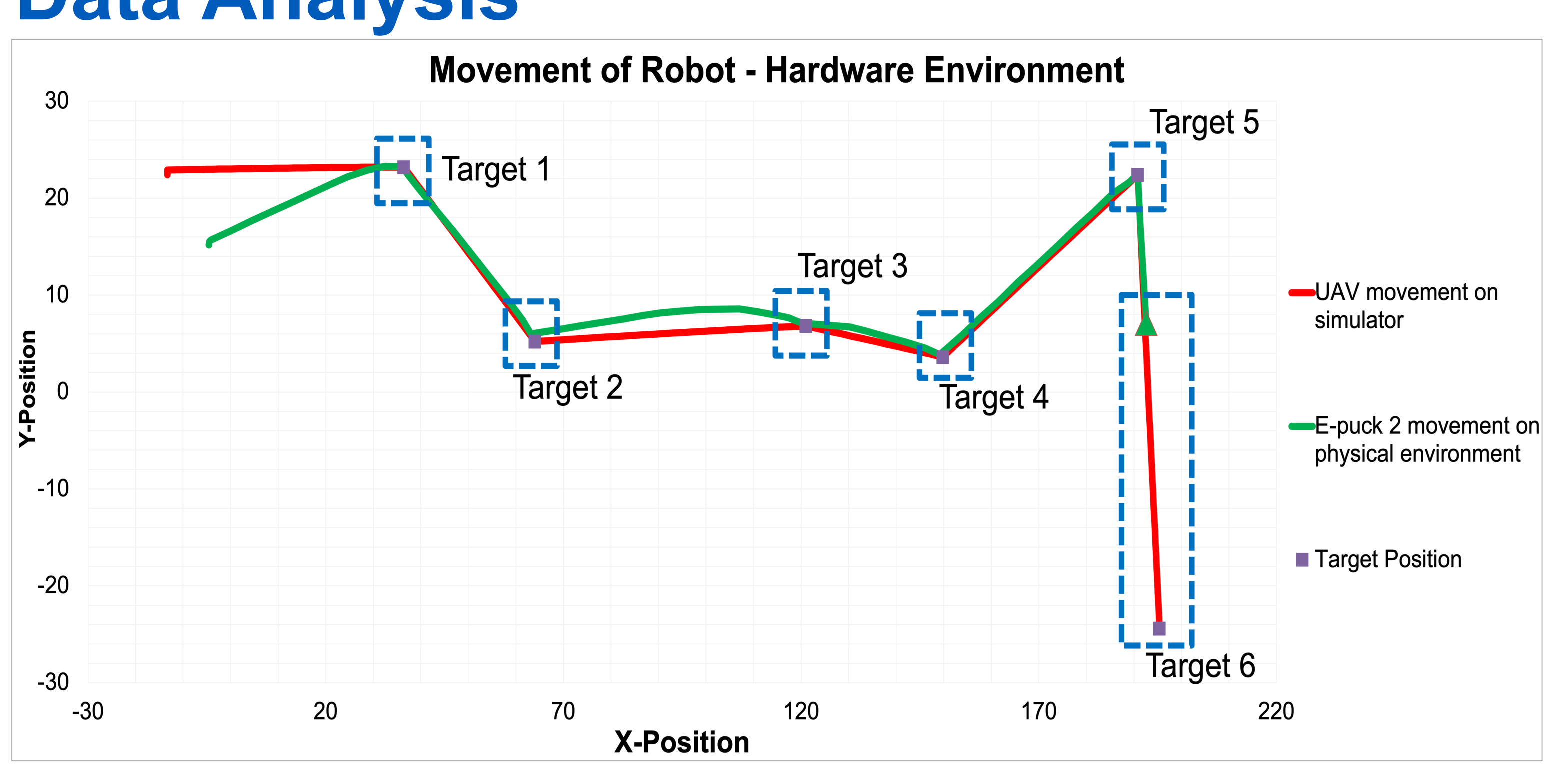

Figure 4. Comparison of the robot target tracking in physical hardware and simulation. The subject assigned target locations through the GUI, and both the simulation and the hardware strived to reach that location. It was possible to observe what differences the hardware can make from the desired movement.

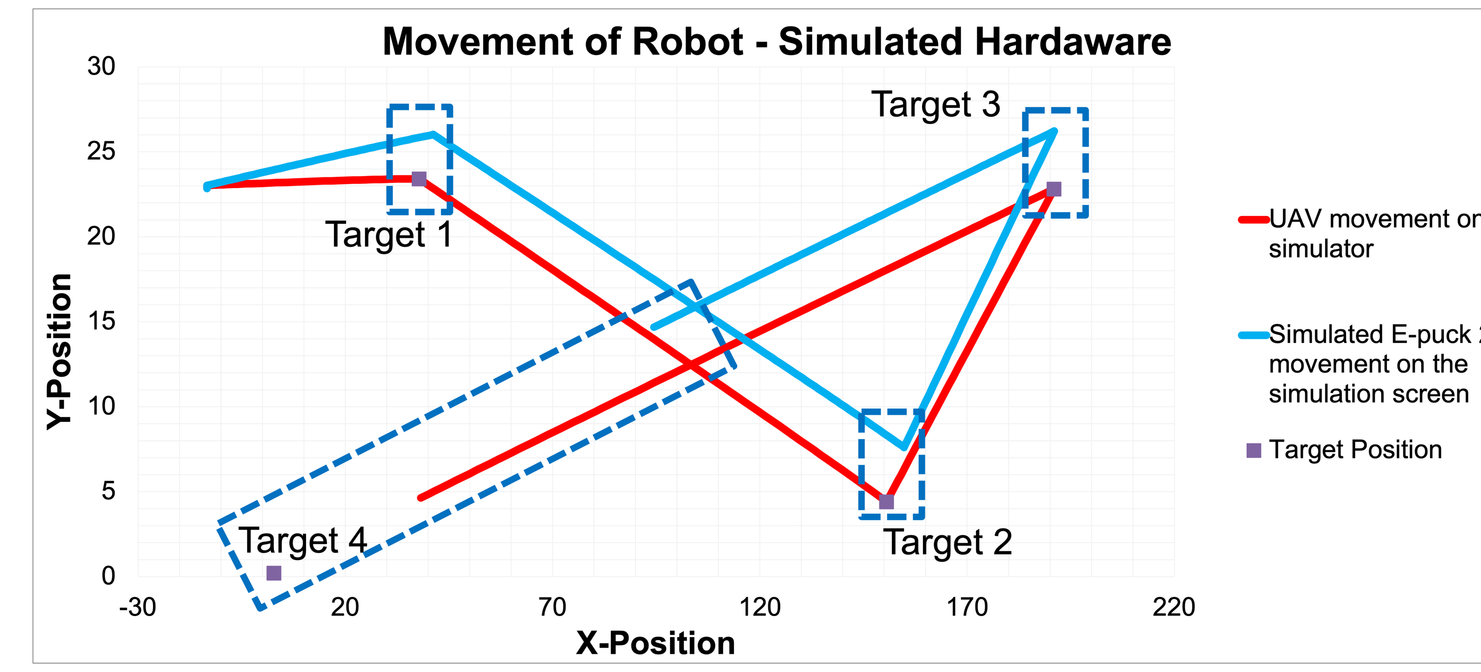

Figure 5. Comparison of the robot target tracking in simulated hardware and simulation. The experiment of simulated hardware is a representation of the physical hardware delays and travel speed. By comparing how humans respond to simulated hardware and physical hardware, HSI research can be conducted.

Traveling Time in Both Scenarios

Target	Input Time	Arrival Time (Simulation)	Arrival Time (Alternative)	Alternative
1	11.3	14.6 (3.3 sec)	26.8 (15.5 sec)	Pyshical Hardware
2	24.9	30.2 (5.3 sec)	33.0 (8.1 sec)	
3	34.3	38.5 (3.3 sec)	44.8 (10.5 sec)	
4	52.4	57.2 (4.8 sec)	58.8 (6.4 sec)	
5	60.5	65.0 (4.5 sec)	68.0 (7.5 sec)	
6	79.6	85.0 (5.4 sec)	DNF	
Average Travel Time		4.43 sec	9.60 sec	
1	5.9	14.7 (8.8 sec)	15.4 (9.5 sec)	Simulated Hardware
2	19.4	34.1 (14.7 sec)	36.9 (17.5 sec)	
3	40.4	43.7 (3.3 sec)	49.9 (9.5 sec)	
4	53.7	DNF	DNF	
Average Travel Time		8.93 sec	12.16 sec	

Table 1. Comparison of the traveling time between physical and simulated hardware from Figures 4 and 5. The physical hardware takes an average of 5.2 seconds longer to reach the target position, while the simulation hardware takes an average of 3.23 seconds longer than the simulation.

Note: At the beginning of the experiment, the physical hardware takes approximately 5 seconds to align itself.

Conclusion

By comparing the Arrival Time in Table 1, it was possible to check how much delay and latency there was in the hardware experiment, and the delay and latency can be controlled by the following factors:

- **The number of swarm robots:** Since the robots were controlled via Bluetooth on a laptop, unintended latency occurred in controlling each robot as the number of robots increased.
- **The processing rate of the Motion Capture System:** It was required to find the appropriate frequency of the VICON System to prevent data loss.
- **Overall framework structure:** While transmitting data to other frameworks, there is a risk of losing connection with the robots during the process, which can lead to experimental failure.

References

[1] Distefano, J., Cho, H., KrisshnaKumar, P., Esfahani, E., Chowdhury, S. (Under Review). Framework for Analysing Human Cognition in Operationally-Relevant Human Swarm Interaction. ASME International Design Engineering Technical Conferences and Computer and Information in Engineering Conference (IDETC-CIE2023), August 20 - 23, 2023, Boston, MA.