Technische Universität Wien

Master Thesis Proposal

Mixed reality simulation environment for the f1tenth racing car

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1 Motivation and Problem Statement

According to the international federation of robotics, the number of robots used in production and warehouses more than doubled in the last decade [1]. With interconnection of components emphasised by industry 4.0, the need of flexible, and decentralized solutions are needed to keep up with the increased connectivity between different devices within evolving cyber physical systems (CPS)s [2].

One example of CPSs are autonomous vehicles used in warehouses or driving public roads. To test and verify such systems, flexible and extensible solutions are needed. A Digital Twin can be used from early developing onwards to mimic the actual behaviour of the car within a simulation environment while the actual hardware is also executing the application [3]. This enables to verify properties of the observed robot with minimal computational overhead for the real robotic system.

To extend the testing capabilities to the real system, mixed reality enables one to combine simulated scenarios with the real autonomous vehicle without expensive real world setups [4].

In our work on Smart farming [5] we explored the capabilities of Docker in a CPS with heterogeneous hardware and decentralized architecture. Now the question arises, whether it is viable to extend a simulation environment for mobile robotics, to cope with mixed reality use-cases such that it is integrable into an existing CPS/IoT setup and if it can bring benefits to the validation and verification scenario for autonomous vehicles.

2 Aim of this Work

The goal of this master thesis is to create a simulation environment wherein the f1tenth mobile robot [1] is digitally mirrored and coupled to the real robot. The f1tenth mobile robot is a RC-racing car with the scaling of 1 : 10 to a Ford Fiesta. The Digital Twin within a simulation environment and sensor data of the virtual and real reality are shared between each other, enabling a mixed reality use-case verification framework.

Furthermore the capabilities and soundness of this framework shall be evaluated, regarding computational overhead, real-time capability and functional system validation.

[1] `https://f1tenth.org/index.html`

3 Methods

Literature research: A thorough search of the current state of the art of mixed reality simulation environments. Especially for autonomous mobile robots for the purpose of verification and validation using the robotic operating system (ROS) or Gazebo.

Digital Twin: The first practical part is to create a Digital Twin of the f1-tenth racing car platform within the 3D simulation environment Gazebo [6].

Merging the virtual and real world: The second step consists of the integration of the real car with the Digital Twin. Using ROS and Gazebo to merge the perception of the two entities. ROS is a flexible middleware for programming robotic software with a vast amount of community created libraries, such as localization and navigation [7].

Integrating into a IoT infrastructure Once the mixed reality simulation is properly running, the next task is to integrate it into an IoT infrastructure, as shown as Mixed Reality Simulator into the fog layer in fig. 1. Where green boxes mark sensor/actuators, blue the (virtual) machine or embedded system a software runs on, and orange generalized ROS applications.

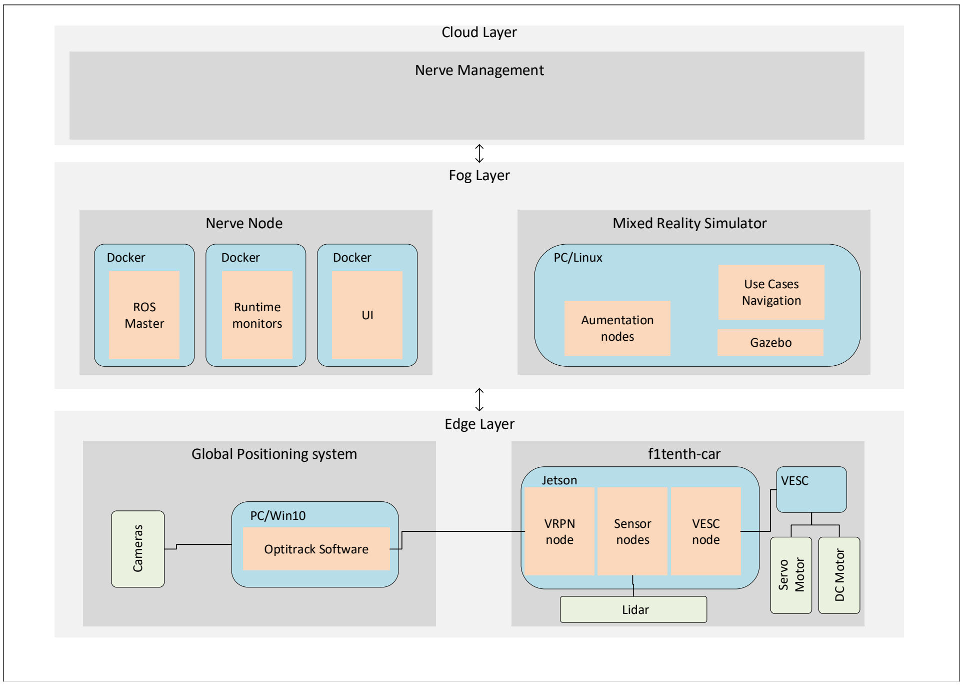

Figure 1: IoT infrastructure for the complete setup

Evaluation: The mixed reality simulation environment will be firstly analysed whether the interaction between simulation and real world can be done without them drifting apart and maintain a close coupling. I.e.: can the simulation be run with a timing factor close to 1 between real time and simulated time. Secondly, is it a viable tool to verify or test scenarios in a mixed reality environment for this robot. I.e.: is the drift of wheels and surface properly accounted for, is the Digital Twin a proper model of the car without being too simplistic or complex.

4 State of the Art

Providing a valuable testing environment for autonomous vehicles is an ongoing topic in today's research. There are plenty of mixed reality test systems for autonomous vehicle but only few using ROS.

In the paper "A Flexible Mixed Reality Simulation Framework for Software Development in Robotics" by Chen [4], the basic concept of mixed reality simulation framework and its potential use for robotic development is explained. Fig. 2 shows the architecture of their generic mixed reality framework using Gazebo 3D. Covered use cases are cow following with an autonomous drone and a stationary screw removal robot.

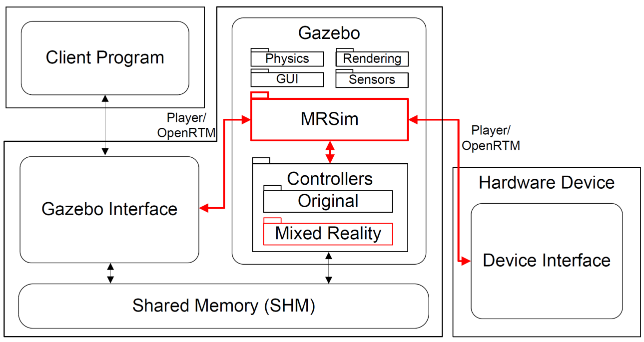

Figure 2: Architecture of the flexible MRSim integrated into Gazebo [4]
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Zofka et al. [8] created a test system for non-holonomic robots, i.e. carlike robots, with mixed reality lidar (fig. 3). Using three different laser scan merge strategies: Replacement, minimal distance and object of interest, with their self defined lidar sensor model using a raycasting algorithm. the Sleepwalker framework uses Gazebo for the vehicle and environment model of the virtual part.

Liu et al. [9] used the context of mixed reality simulation for holonomic mobile delivery robots. Using ROS and Unity, a cross-platform 3D game engine [10], to create a multi robot testing system. The lidar scan data

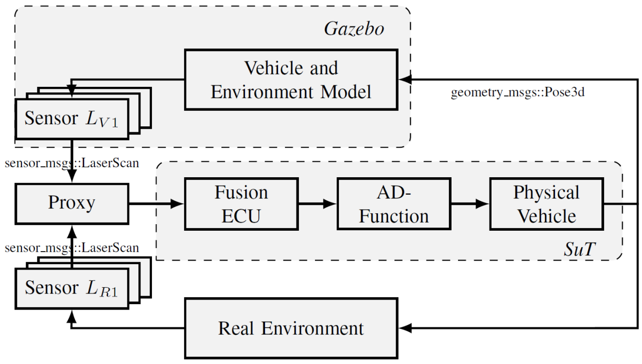

Figure 3: Architecture of the sleepwalker framework [8]
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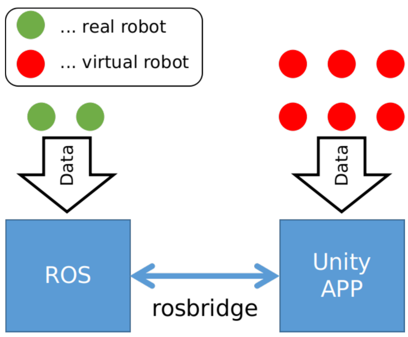

Figure 4: Communication scheme of the multi robot mixed reality test system [9]

was augmented by the virtual doppelganger within unity for mixed realty data exchange. Fig. 4 shows the communication scheme between virtual doppelgangener and real car. ROS bridge is a JSON interface between ROS nodes and non-ROS applications [11].

Baruffa et al. [12] extends the Hardware in the loop (HIL) paradigm, where real hardware executes simulated sensor data and feeds its actuator output back into the simulation. They create a follow the car scenario, where the real miniature car follows a simulated bus and vice versa. By augmenting the camera stream and using a QR-code like tag on the back of the bus to retrieve the position of it, where the distance and angle between bus and car are controlled by two separate PID controllers. For the sofware architecture, Unity 3D is used for the visualization and physics engine, using generic 3D models of the vehicles. All the simulation layer is processed on a workstation, communicating via ROS to the embedded system on the car, which also uses ROS for its sensors and actuators.

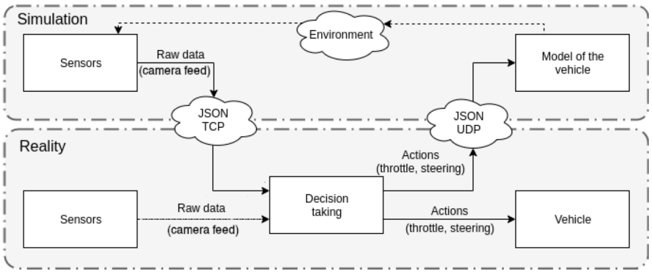

Figure 5: Architecture of the extended HIL scheme [12]

5 Relevance to the Curriculum of Computer Engineering

The thesis focuses on the integration of heterogeneous systems, with the virtual counterparts. These interactions and combination of various virtual and physical domain is handled by the Cyber-Physical-Systems (CPS) pillar in the curriculum of 066 938 computer engineering at TU-Vienna.

The most notable courses are as follows.

- 191.119 VU Autonomous Racing Cars
- 183.660 VU Mobile Robotics
- 182.753 VU Internet of Things
- 191.106 VU Runtime Verification

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