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Development of a multi-protocol interface to a Hardware-in-the-Loop setup

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Introduction

In-orbit failures of CubeSats are often caused by **electrical interface issues** [1]. **Hardware-in-the-Loop (HIL) simulations** are fundamental for addressing these challenges. Limited interoperability of simulations hinders flexibility and exchangeability, impacting CubeSat's reliability. Figure 1 from [2] shows an example of a **basic setup of a HIL simulation**, where hardware and software work together to test and validate systems in a controlled environment.

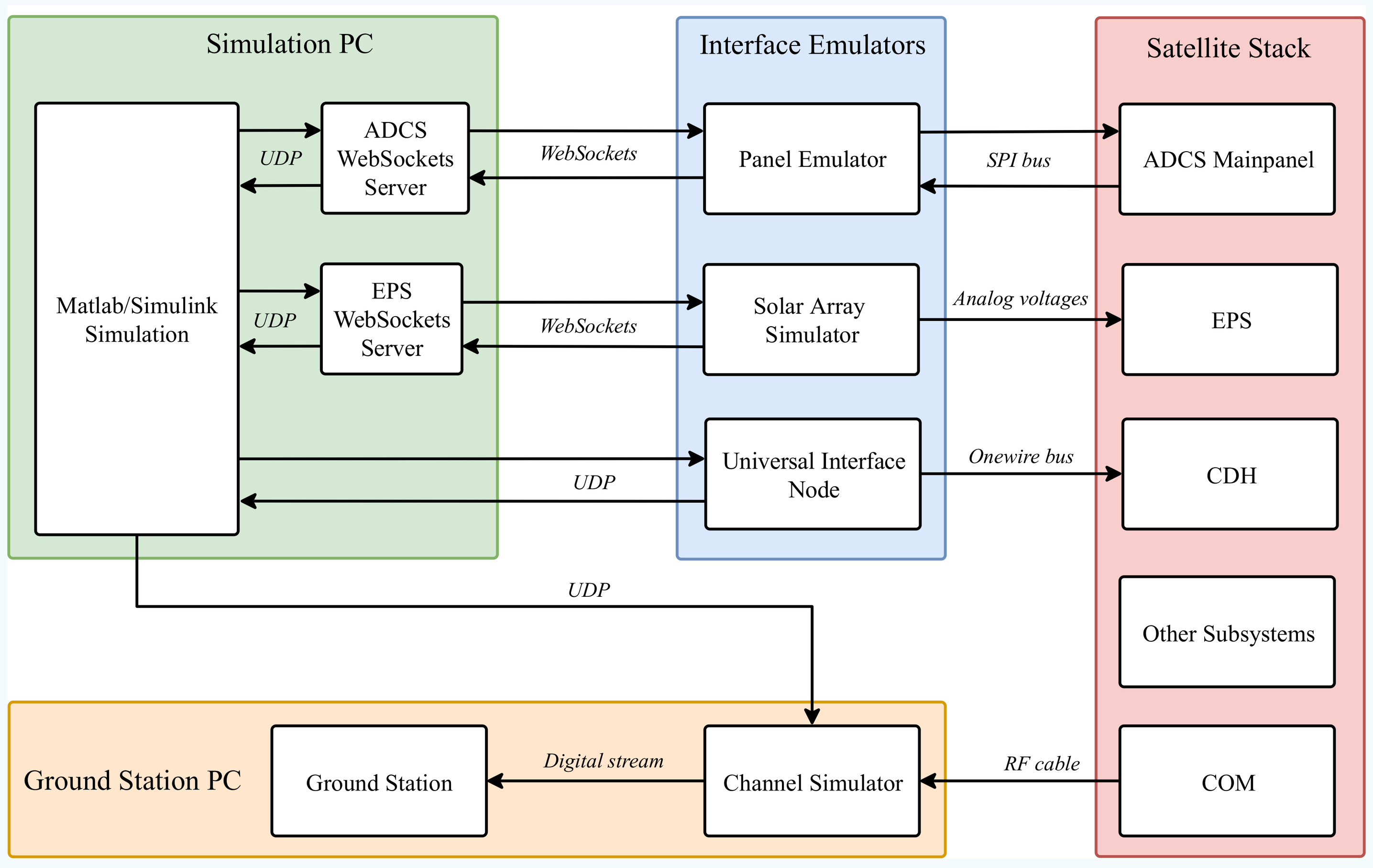

Fig. 1: Architecture and interfaces of the Hardware-in-the-Loop (HIL) environment of the MOVE-II CubeSat [2].

The **High-Level Architecture (HLA)** framework offers a promising solution to **overcome** the **disadvantages of single-core HIL simulations**, such as limited hardware reusability and increased setup effort. HLA enables compliant and interoperable simulations **independent of software and hardware platforms**. However, existing HLA simulations often require different integration of hardware interfaces, limiting scalability and adaptability.

This project develops a generic interface adapter that enhances **connectivity, synchronization,** and **interoperability** between the HLA-based simulation and CubeSat flight hardware to improve HIL simulations' overall performance.

High-Level Architecture

Overview

The High-Level Architecture (HLA) is a **framework** and **rules** providing an architecture for distributed simulations, standardized in **IEEE 1516-2010**. The **Run-Time Infrastructure (RTI)** facilitates communication and synchronization between simulation components represented as **federates** in the simulation, called federation. To establish a connection between the HLA simulation and the sensor, a **new federate** called the **InterfaceModule** is introduced, as illustrated in Figure 2 [3].

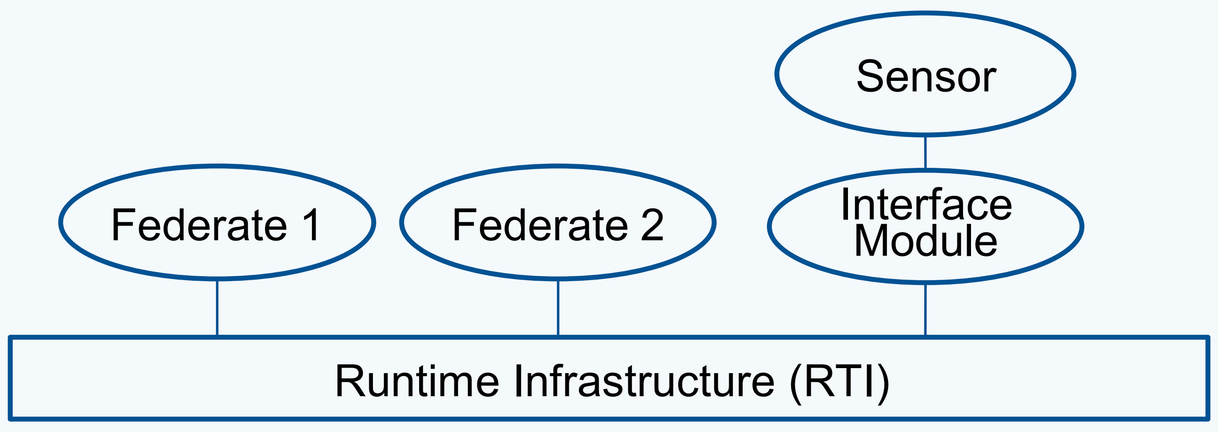

Fig. 2: Structure of the High-Level Architecture with Hardware Interface Connection.

Run-Time Infrastructure Implementation Comparison [4]

Pitch pRTI:
- **Commercial** solution developed by Pitch Technologies.
- User-friendly graphical interface for easy setup and high-speed capabilities.
- Research sustainability may be limited due to licensing constraints.

Portico:
- **Open-source** project developed by Calytrix Technologies.
- Decentralized approach for flexible and scalable simulations
- Limited documentation, and it has the lowest speed capabilities.

CERTI:
- **Open-source** project developed by ONERA.
- Centralized approach suitable for handling large payloads with high speeds.
- Minimalistic documentation.

Hardware Implementation

A **Raspberry Pi 4B** is chosen as the hardware interface and computational platform for running the simulations. It is selected due to its strong processing capabilities, extensive community support, and **built-in interfaces**. These interfaces and the available expansion modules enable connectivity with most CubeSat electrical bus interfaces mentioned in [1], making it an ideal choice for HIL simulations.

The chosen example sensor is the **Bosch BMP180**, which can measure pressure and temperature and communicates via the **I2C** interface. Setting up a **breadboard configuration** enables data acquisition and evaluation. This setup is essential for developing the simulation and allows the seamless incorporation of sensor measurements to verify the functionality of the HLA simulation environment.

The combination of the Raspberry Pi 4B and integrated sensors offers a powerful platform for conducting hardware-in-the-loop simulations and evaluating the performance of sensors in real-time scenarios.

Software Implementation

CERTI is selected as the HLA middleware solution because of its open-source nature, robustness in handling large payloads, and availability of essential documentation. It offers a platform for integrating HLA-based simulations, enabling efficient **communication** and **coordination** among federates.

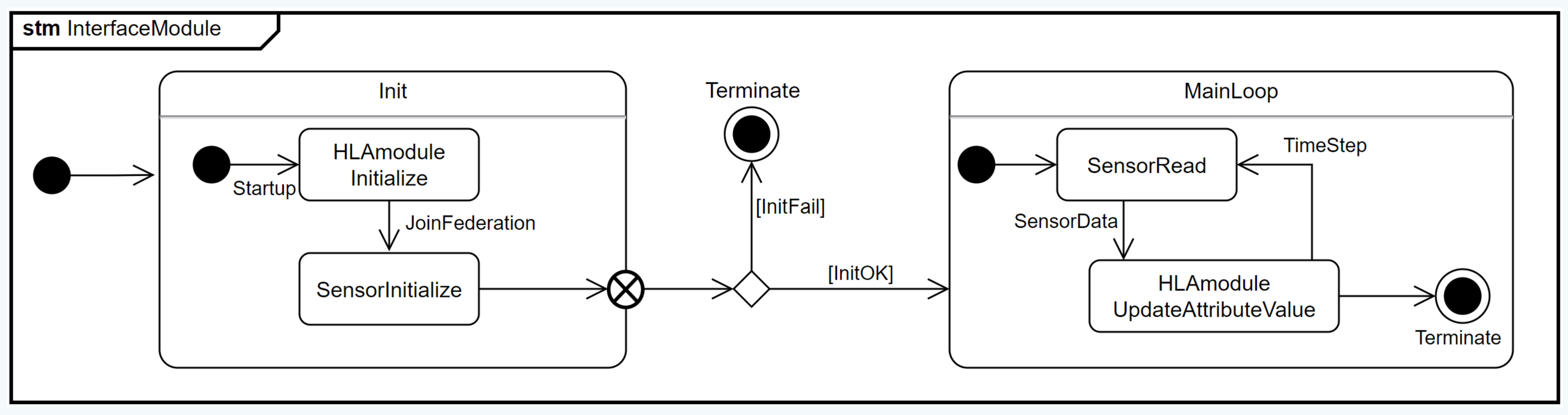

Fig. 3: Internal Procedure State Machine Diagram of the InterfaceModule Federate.

The **InterfaceModule** is implemented using **C++** and follows a generalized approach. It includes its own **XML-based Federation Object Model (FOM)** incorporating the universal **SensorAttributes**. Acting as a bridge, the InterfaceModule facilitates the **initialization** of both the HLA simulation and the sensor. Subsequently, the InterfaceModule continuously **collects sensor values** and **updates attributes** within the simulation through a dedicated **loop**. To visually depict this process, refer to Figure 3.

Outcome

The project successfully implemented an **HLA simulation on a Raspberry Pi 4B**, allowing the simulation to **read sensor values**. The simulation is connected to a temperature and pressure sensor using the I2C interface in this setup. It covers a gap in the existing literature, addressing a previously unexplored aspect of the research field. Adding more sensors to the system **requires minimal code modifications**.

Future Work

Future work involves practical experimentation **adapting multiple input/output devices** to broaden the module's application. It aims to develop a generalized approach for integrating sensors and handling the values effortlessly in the HLA simulation. Strategies will **optimize data transfer efficiency** and establish **synchronization points** for accurate alignment between simulation and real-time sensor data.

Sources

[1] J. Bouwmeester, M. Langer, and E. Gill, “Survey on the implementation and reliability of CubeSat electrical bus interfaces,” CEAS Space J, vol. 9, no. 2, pp. 163–173, 2017, doi: 10.1007/s12567-016-0138-0.

[2] J. Kiesbye et al., “Hardware-In-The-Loop and Software-In-The-Loop Testing of the MOVE-II CubeSat,” Aerospace, vol. 6, no. 12, p. 130, 2019, doi: 10.3390/aerospace6120130.

[3] Simulation Interoperability Standards Organization/Standards Activities Committee (SISO/SAC) of the IEEE Computer Society, “IEEE Std 1516'-2010, IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) „Framework and Rules”.

[4] M. Gutlein, W. Baron, C. Renner, and A. Djanatliev, “Performance Evaluation of HLA RTI Implementations,” in 2020 IEEE/ACM 24th International Symposium on Distributed Simulation and Real Time Applications (DS-RT), Prague, Czech Republic, 2020, pp. 1–8.