Digital-twin Prototype Design and Validation for Connected and Automated Driving Simulation

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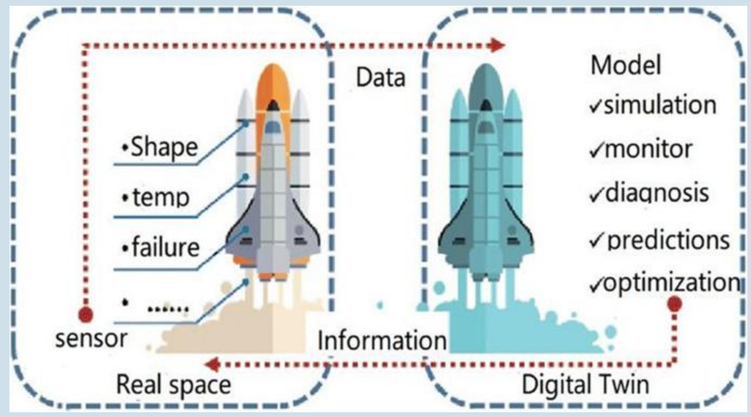
Abstract

A digital-twin is a real-time digital replica of a physical system, regarded as a promising methodology to bridge the virtual and real world and facilitate the design and optimization of different models.

This project aims to develop a digital twin prototype especially for connected and automated driving simulation, which is expected to serve as an ideal testbed to validate and demonstrate the advanced connected and automated driving applications.

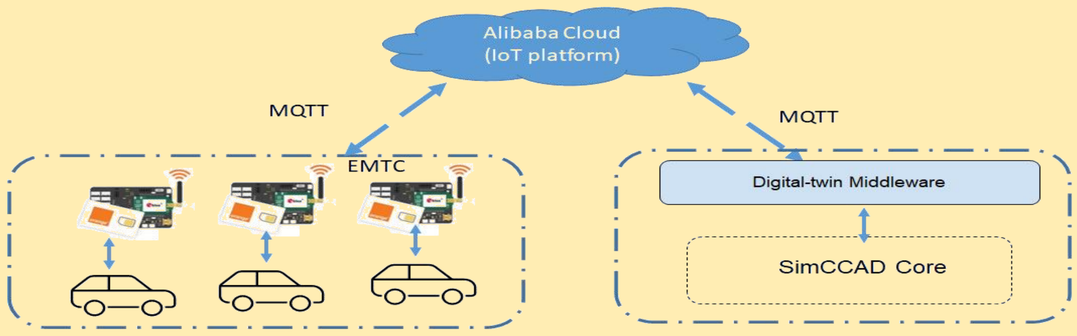


System Framework

Overall, the proposed digital twin prototype system is composed of three components: local field sensor system, network deployment, and virtual simulation platform, as shown in the following diagram.

- **Local field sensor system**

  Local field sensors are deployed in the real world to obtain the real-time traffic information, which then will be uploaded to the IoT cloud platform via MQTT protocol for message storage and exchange. This project focuses on vehicle position and speed, which are collected by GPS modules interfacing with Arduino.



Architecture of Digital-twin prototype

- **Network deployment**

  Network deployment includes configuration of an IoT cloud platform and a network middleware. Alibaba Cloud is selected as the IoT cloud platform, where a MQTT broker is integrated to coordinate data format and guarantee cloud communication between sensors system and the middleware.

  The middleware is independently designed in this project to fetch and forward messages from one network terminal to the other one.

- **Virtual simulation platform**

  This component is based on the integrated Simulation platform for Conventional, Connected, and Automated Driving(SimCCAD), which tightly combines the core components of V2X (vehicle to everything) communication, traffic networks, and autonomous/conventional vehicle model. In this project, the open-source simulator Webots is applied to construct digital replica of real-world traffic environment.

Component Design and Implementation

Field Information Collections

The main purpose is to collect real-time vehicle kinetic information via an open-source hardware platform Arduino integrated with a LTE CAT4 module SIM7600CE.

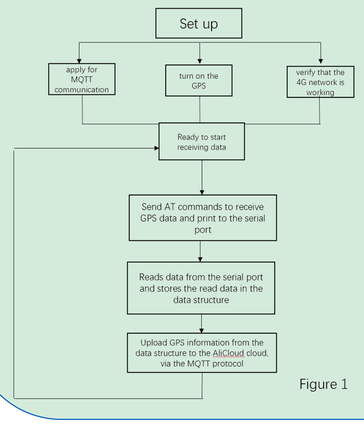


Figure 1

- **Hardware modules integration and debug**

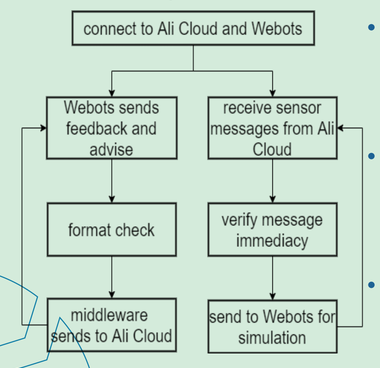
  UART communication links SIM7600CE to Arduino, in which GPS submodule and 4G submodule of SIM7600 are used to collect and upload the data.

- **Embedded software development**

  The main function is to collect GPS data and upload it to the AliCloud platform. As shown in the left flow diagram, Sim7600 GPS module first sets up and collects location data, which are then uploaded to Alibaba cloud via the standard MQTT protocol. In order to complete the full function automatically, Arduino sends sequential commands to the Sim7600CE through UART communication.

Network Middleware

The middleware designed in this project is an independent executable file, which establishes duplex communication between the IoT platform and the Webots simulator.



- **Flexible Network Connection**

  The middleware connects to Ali Cloud with MQTT and the simulator via local socket, which can create multiple connections with multiple simulators.

- **Multi-thread design**

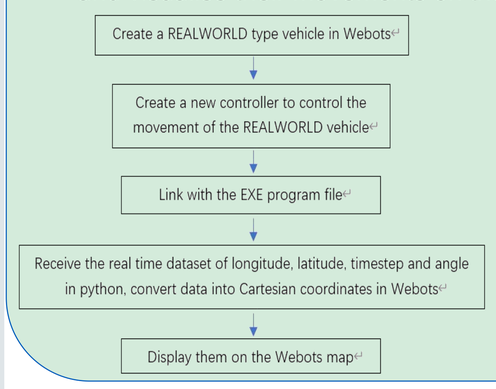
  Two tasks transmitting messages in the opposite directions in parallel are created to ensure duplex communication and the immediacy of messages.

- **Data Inspection**

  Data from Ali Cloud are checked with its timestamp, only real-time data in correct format are sent to simulator.

Visualisation in Vehicle Driving Simulator

The main purpose is to model multiple types of vehicles from the mixed virtual-reality world and visualise their movements on the Webots simulator in a real-time way.



- **Establishment of vehicle model**

  A new real-world vehicle is modelled and introduced in the Webots.

- **Virtual-reality information synchronisation**

  Real-time data are received from the middleware and accordingly synchronized in Webots: vehicle position is tracked, transformed, and updated in the simulation.

- **Mixed traffic simulation**

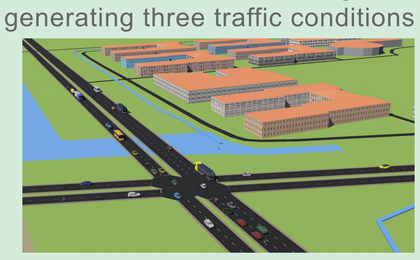
  Three types of vehicles, real-world vehicle, SUMO vehicles, and Webots vehicle (controlled by external driving simulator) can interact with each other.

Digital Replica of Real-world Traffic Environment

Real-world environment will be digitalised into the simulation scenario including road networks, simple surrounding buildings, as well as generating three traffic conditions under different traffic demand levels.

- **Location in Reality**

  The actual location is chosen to create the virtual world in Webots. Two real roads Wenjing Road and Songtao Street nearby the XJTLU were extracted from OpenStreetMap to construct the digital-twin world.



- **Virtual World**

  This is a screenshot of the simulation world, where background traffic are created by a microscopic traffic simulator called SUMO.

Experiment and verification

- The hardware prototype wrapped in the box, with the 4G antennas and the GPS antennas exposed outside for reliable and effective data collection.

- Virtual vehicle is manipulated by external driving simulator and interact with other vehicles in the same simulation platform.

- The GPS device is equipped on the car for real data collection. With the car moving, the data will be refreshed..

- Simulation screenshot on the right: The movement of real-world vehicle is mapped into Webot simulator and updated in real time.

Conclusion

- The project has successfully verified the proposed digital twin model: bridge virtual-reality world via the real data transmission to a virtual platform.
- The detailed system design has been implemented: hardware field data collection, middleware for data transfer, virtual simulation world build up, as well as field trials.
- Future work will focus on system optimisation, e.g. reducing transmission packet loss, improving GPS data sampling, smoothing simulation jerk, etc.

Project webpage:https://github.com/AAAAAkki/surf2022044

Reference

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