Connected Solar Boat for C-ITS Applications

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Abstract

This paper describes the development of a reference Cooperative Intelligent Transportation Systems (C-ITS) architecture for connected solar boats, whose purpose is to collect and disseminate relevant information concerning marine navigation. The proposed system is able to measure depth and water temperature by means of a sonar, monitor photovoltaic generation and battery storage levels and observe weather and environmental conditions. All these parameters are transmitted in real-time over cellular networks (LTE/5G), by using a newly proposed message type - Vehicle Sensor Messages (VSMs). The architecture also encompasses the transmission of standard short-range vehicular communications (V2X) messages, enabling C-ITS applications among waterborne vehicles. The system is currently being installed and tested on a 7-meter long tourist boat that operates in the Aveiro lagoon, a coastal region of Portugal.

1 Introduction

Cooperative Intelligent Transportation Systems (C-ITS) have been evolving in the recent years, mainly due to the integration of mobile communications into the existing transportation systems. This covers different means of transportation, from road to rail and from personal to public transportation. Recently, developments in maritime and waterborne systems have also been proposed, including for instance the tele-operation of ship vessels using 5G networks [1]. There is a need to increase the safety and efficiency of these waterborne vehicles, which can be achieved by including more sensing and communications capabilities both in the vehicles as well as on the surrounding environment. In the specific context of this work, the analysis of both tidal and water depth data is essential for navigation in a coastal lagoon, since it enables the skipper with information regarding which canals and waterways the boat is able to cruise at each time of the day.

This paper provides an overview of the development and implementation of the systems required to enable a solar boat with V2X communications and C-ITS applications, exploring the key components, design considerations and potential benefits of this solution.

2 Architecture

The architecture of the on-board system was inspired on the framework proposed by Rocha et al. [2]. Figure 1 shows a representation of the devices installed on the boat.

The On-Board Unit (OBU) is the central unit that is responsible for collecting sensor data and transmitting it to nearby vehicles and to the Traffic Management System (TMS). It includes a cellular transceiver (LTE/5G) and a GNSS receiver. The cellular antennas are connected to its housing and the GNSS antenna is placed next to the boat driving controls, where there is a clear view to the sky. A sonar is installed on the underside of the boat and is used to measure the water depth and temperature. The boat is fully electric and is equipped with a photovoltaic system, comprised of solar panels, a charge controller, batteries and electric motors. The OBU is placed next to this system in order to get power supply. It is also possible to monitor the production and consumption of solar energy of the boat, connecting the data output port of the charge controller to the OBU. Additionally, there is a weather station that collects environmental data and sends it to the local OBU. Finally, there is a smartphone application that connects to the OBU via WiFi and can present to the passengers the collected data

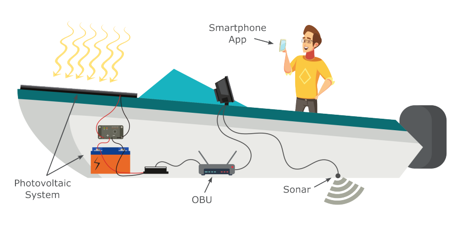

Figure 1: On-board device installation.

during the trip, such as the boat position, as well as nearby vehicles, and the collected sensor data.

The data collected by the on-board system is transmitted to the TMS, where a Message Queuing Telemetry Transport (MQTT) broker is deployed and used for real-time message distribution. Other OBUs can connect to this broker and publish/subscribe to different topics, sharing live data among them. The TMS also features other cloud services, such as logging, storage and data visualization.

2.1 OBU Internal Architecture

The internal organization of the OBU is represented in figure 2. It consists of different services, each with its own purpose, that communicate with each other using an internal message broker, sharing custom messages. This provides a modular software architecture that is easily extendable.

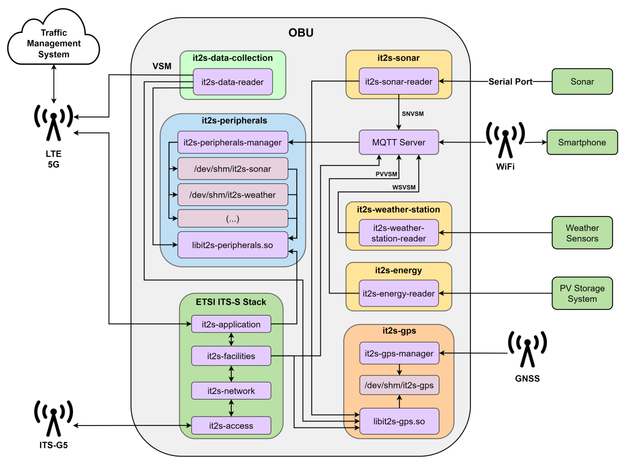

Figure 2: OBU's internal architecture and interfaces.

The central element of the architecture is the MQTT broker. It acts as a message distributor that allows all modules to publish and subscribe to topics, therefore exchanging data with each other. Each data source has a service associated with it, that has the purpose of establishing a communication channel with the data source, performing any necessary configurations, and fetching data from it. This way, if there are different types of sensors that do not share a common interface (e.g. WiFi, serial), each service takes care of the specific operations required for its data source. There are three different data sources, and respective services:

- **it2s-sonar**: Fetches data from a marine sonar. This data is compiled into a custom internal message, the **SNVSM**, and is published to the MQTT Broker.
- **it2s-weather-station**: Manages the weather station data collection and publishes **WSVSM** messages to the MQTT Broker.
- **it2s-energy**: Similar to the previous services, collects data from the boat's PV storage system and publishes **PVVSM** messages to the MQTT Broker.

There are other services related to the data collection process. The **it2s-gps** reads data from a GNSS receiver and stores it in a shared memory file. The **it2s-peripherals** collects and stores the internal messages from all the data sources. It subscribes to the topics of the data sources and stores the messages in shared memory files. The **it2s-data-collection** is responsible for compiling the different sensor data, made available by it2s-peripherals, into a single **VSM**. These messages are transmitted to the TMS via cellular networks at a fixed period, that can be adjusted taking into consideration different aspects, such as how fast the transmitted data changes over time, and cellular data usage and cost.

Lastly, the **ETSI ITS-S Stack** is an implementation of the ITS-Station architecture defined by ETSI [3]. Its application layer makes use of the data available on it2s-peripherals and includes it on standard ITS messages.

2.2 Vehicle Sensor Message

This paper proposes the definition of a new type of message, the Vehicle Sensor Message (**VSM**). It includes relevant information concerning marine navigation that can be disseminated to connected solar boats and to the TMS. The structure of a **VSM** is presented in figure 3.

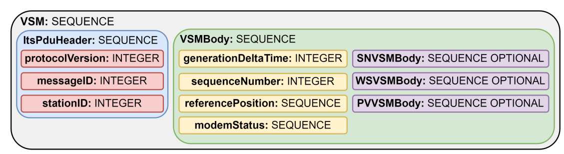

Figure 3: VSM message architecture.

It includes an ETSI ITS standard header with static information relevant to other ITS stations, such as the type of message and the ID of the station. The body of the message contains dynamic information that include the timestamp and the position of the station, information on the status of the cellular modem, as well as optional fields regarding the data collected from the sensors.

These fields come in form of the internal messages mentioned on section 2.1 and are described as follows:

- **SNVSM**: Sonar's Vehicle Sensor Message - includes an ETSI ITS standard header and a message body, populated with a timestamp, the position, speed and heading of the boat, and the water depth and temperature.
- **WSVSM**: Weather Station's Vehicle Sensor Message - similar to the previous message, with the body containing environmental data gathered by the weather station, namely air temperature, humidity and pressure, air quality, and solar exposure.
- **PVVSM**: Photovoltaic System's Vehicle Sensor Message - once more, similar to the previous messages, providing information regarding the on-board's PV Storage System. The message body contains the amount of energy produced by the solar system and consumed by the boat, as well as the batteries' status.

3 Implementation

In this section brief implementation details are described regarding the different modules that comprise the system, at both software and hardware level.

3.1 Hardware

The OBU is based on a Raspberry Pi 3B+, a single board computer (SBC) with a compact size featuring a 64-bit quad-core ARM Cortex-A53 processor clocked at 1.4GHz and 1GB of RAM. It features other modules connected to the SBC, described below, and all of the electronics are conveniently housed on a waterproof enclosure to avoid water damage. It features multiple connectors for interface with the outside devices, such as a power connector, a sonar data plug, as well as SMA connectors for the cellular and GNSS antennas. Its assembly is visible on figure 4, where the important modules are highlighted and labeled. It is installed on the boat underneath one of the floor panels, inside the hull, to avoid direct solar exposure.

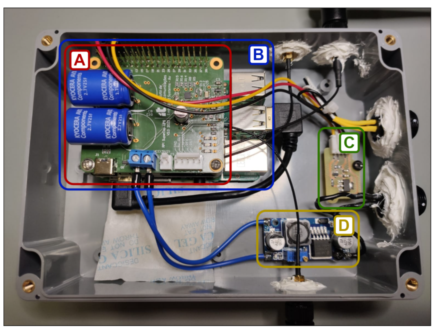

Figure 4: OBU Assembly. A: UPS, B: SBC, C: Sonar Interface, D: DC-DC Converter

3.1.1 Power Supply

The power supply of the OBU is an important topic that should be taken into consideration. The OBU is powered directly from the 12V DC supply available on the boat. This poses an issue, as when the boat is powered-off the power to the OBU is interrupted without the SBC being able to properly shutdown. If done multiple times, this can cause the file system of the SBC to become corrupted.

To overcome this problem, a custom UPS was designed. It is based on a pair of supercapacitors and a charger IC to provide a backup power supply to the SBC. In case of a power failure (i.e. powering off the boat), the UPS sends a signal to the SBC and provides a backup power supply to allow it to safely shutdown. This can last for about 30 seconds, depending on the power consumption of the load connected to the UPS, which gives enough time to stop the running processes and data transmission, and to power-off.

The SBC and remaining modules inside the OBU run on 5V DC. To allow the OBU to be powered by higher voltages, which are commonly available on vehicles, a DC-DC converter was used. It receives an input voltage between 6-32V DC and outputs a power supply of 5V DC @ 3A, that is used to power the OBU hardware.

3.1.2 LTE Module

To provide cellular connectivity to the OBU, an LTE module was used. This way, the OBU can access the internet and connect to the TMS. The module used is the Quectel EC25, a mini PCIe mounted on a SixFab LTE Base HAT to interface with the SBC.

3.1.3 Sonar Serial Port Level Shifter

The used sonar provides a serial port that outputs data in a form of NMEA0183 sentences. This serial port uses the UART protocol, however the physical interface does not use the typical levels. After observing the signals on the oscilloscope and logic analyzer, it was found that the voltage levels are between 0 and 5V, and that the signal is inverted. This means that, for example, the start and stop bits are inverted and the data frame cannot be successfully interpreted by a UART receiver. To solve this, a simple circuit was designed, consisting of a MOSFET used as a logical inverter and a level shifter, to be compatible with the voltage levels of the SBC UART.

3.1.4 Sonar

The installed sonar is the Humminbird Helix 5 Chirp GPS G2. It is a compact marine navigation and fishfinding device that combines sonar technology with GPS functionality. It provides underwater topography, fish detection, navigation assistance and water temperature measurements. Offering a depth capability of up to 450 meters, multiple sonar modes, and a data output port, it makes it suitable for our application, allowing the sonar to be used not only as a data source for the system but also as a navigation tool to assist the boat crew.

3.2 Software

The software modules inside the OBU are implemented as systemd services running programs written in C and bash scripts. The communication and data-exchange between services is implemented using an MQTT broker and shared-memory files, as stated before.

3.2.1 Sonar Reader

The sonar outputs NMEA0183 sentences containing several information, such as timestamp, position, speed, heading, and water depth and temperature. These fields are all standard to the NMEA0183 specification and there are already several linux utilities used for reading and parsing this data, with the most common one being GPSD.

Unfortunately, the latest stable version of GPSD available at the time of writing this paper does not support the water depth and temperature fields. They are available on the internal data structures, but are not being parsed from the NMEA0183 sentences. A custom version of GPSD is being used, with the code being modified to include these fields.

3.2.2 Auto Power-OFF

A service was implemented, that senses the GPIO associated with the power-failure signal generated by the UPS. When this signal is detected, an event is generated and issues a shutdown command to the SBC.

3.2.3 Cellular Reconnection

During testing it was discovered that, when the cellular connection is unstable, it is sometimes dropped. This way it is necessary to have a way to reconnect in case this happens.

A simple bash script was implemented to test the connection periodically and reconnect when necessary.

3.3 Installation

The system was installed in a 7 meters long tourist boat that operates in the Aveiro lagoon (Portugal). Figure 5 shows the vehicle used for testing the proposed system.

Figure 5: Solar boat used for system deployment.

While this section described the modules that are already implemented, as this is a work-in-progress, some other are yet to be included, such as the smartphone and weather station integration, the PV system monitoring, and the ETSI ITS-S stack and V2X hardware.

4 Preliminary Tests

At the moment of writing this paper, the sensors are not yet installed on the boat. The OBU is the only hardware installed, thus only the communications part was tested. The boat did multiple trips while VSM messages received on the TMS were being recorded. Then, multiple parameters regarding the cellular communications were analyzed, such as the RSSI, SINR, RSRP and RSRQ. Figure 6 shows a comparison of the recorded RSSI and SNR values (LTE RAT mode), as well as the trip trajectory. Each vertical black line represents a change in the associated serving Physical Cell ID and the horizontal colored zones represent the quality of the measurement, ranging from good (green) to bad (red).

Looking at the obtained results, one can see that when the signal has a negative SINR, with high noise and interference, the PCI changes multiple times in order to try to obtain better signal strength, until the SINR reaches positive values. The results show a poor connection, that sometimes is lost. We believe that this can come from two factors: on the one hand, the network coverage in this area is not ideal, since the quay is located in the outskirts of the city; on the other hand, the placement of the cellular antennas on the boat is not the best. They are next to the power cables that connect the batteries to the electric motors, being prone to electromagnetic interference generated by the high currents flowing in these cables. We noticed that when the boat performed abrupt accelerations, the connection was sometimes lost. To overcome these problems and get better results, tests will be performed with SIM cards from different operators (seeking better network coverage) and the antennas will be placed on a more suitable location, away from interference sources.

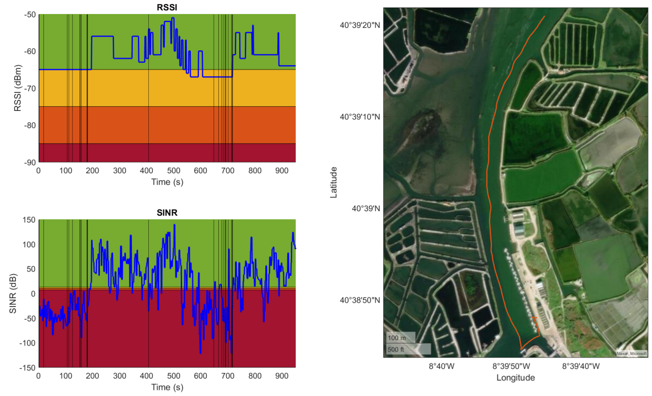

Figure 6: Preliminary field trial results.

5 Conclusion

This paper overviews the design, development, and testing of a C-ITS implementation for connected solar boats, with the purpose of collecting and disseminating sensor data relevant to marine navigation. The proposed architecture of the system was presented, with focus on the OBU's internal architecture and its installation on the boat, as well as the proposed Vehicle Sensor Messages. The implementation of the different modules that comprise the system was then described, both at hardware and software levels. An OBU was deployed on a solar boat, and preliminary tests were performed to validate the operation of the system. Results demonstrate that there are some problems regarding cellular communications of the OBU that need to be addressed.

6 Acknowledgments

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7 References

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