Low Cost Hardware In The Loop (HIL)

Test Tool

Luis E. Castaneda-Trejo  
The Electrical and Computer Engineering Department  
The University of MichiganDearborn, Michigan USA  
luisct@umich.edu

*Abstract*—Test and Validation teams across several automotive companies use COTS (Commercial Off-the-Shelf) technology for the design and development of Automated Test Equipment (ATE). During System Validation and Verification (V&V) phases, automotive R&D programs budget high costs for professional development tool licenses like Vector CANoe/CANalyzer, Vehicle Spy from Intrepid Control Systems or similar to execute test cases to a vehicle Electronic Control Unit (ECU) under test. While these tools are excellent to design and develop large simulations and tests scenarios, once the design is finished, sometimes they are no longer needed. This project uses a low-cost microcontroller platform that can execute specific test cases to an ECU using CAN protocol commanded by an instruction received by a TCP client.

Keywords—Hardware-in-the-loop, Automated Test, Ethernet, CAN.

# Introduction

Commercial of the Shelf Technology (COTS) offer several solutions out of the box for automotive communications. Companies like Vector Informatik or Intrepid Control Systems have specialized hardware and software tools to simulate complete Electronic Control Units (ECUs). Some of these commercial tools have become a standard in the automotive industry.

In R&D disciplines, most of System Validation and Verification teams rely on these types of tools to design and develop Automated Test Equipment (ATE) to communicate and execute test cases. Some of the benefits they offer are tool standardization, database homogenization, system model reuse from software development teams among others.

These tools are excellent to design and develop large vehicle simulations and tests scenarios but once the test modes have been designed, users of these tools still need to have expensive Runtime licenses to execute their developed models. Sometimes these models are for Proof of Concepts purposes, test demos or small implementations that make it difficult to justify the purchase of a high-cost development or Runtime tool license.

The purpose of this Hardware-in-the-loop (HIL) test tool is to allow test developers to implement and execute their already developed test scripts without the need of Runtime licenses.

This project uses a development platform from ST Microelectronics which has a low cost but highly capable MCU. This MCU can communicate with any ECU via CAN and execute user defined test scenarios. The user communication to the HIL Test Tool is via Ethernet, the HIL Test Tool acts as TCP server so any TCP client can communicate with it and send command instructions to the Device Under Test (DUT).

This project was designed and built using the waterfall process methodology. The overall design of the system suits this deign well because the requirements are known and for demonstration purposes they will not change. A requirements phase, design phase, implementation phase and test phase were implemented and will be discussed in the following sections

The test modes in the other hand, were developed in sprints using Test Driven Development. Section XYZ describes the system development progress in the 3 main sections: Hardware, Software and Testing.

# Concept

The general purpose of this project is to emulate the functionality of an Automated Test Equipment (ATE) capable of running pre-defined test scenarios via CAN communication to any type of ECU that has CAN communication available. For this project, a basic vehicle CAN network consisting of 3 ECUs is simulated using Vector CANoe to demonstrate the functions of the HIL Test Tool.

The HIL Test Tool uses FreeRTOS as operative system to handle the different tasks (application code) to interact with the DUTs implemented in the simulated vehicle network in CANoe. The application code consists of 3 different tasks. Each task will execute a predefined Test Mode. The software architecture is modular so in case there is a need to add more test cases, the design pattern supports the addition of new tasks just by adding new tasks within freertos.c

The yellow box in *Figure 1* represents the CAN interface to allow physical devices to interact with the simulated network. Any TCP client can interact with the HIL Test Tool but for this project a custom TCP client was developed using NI LabVIEW to have a better interaction with the Test Tool.

*Figure 1* shows the overall concept of the project and the main project elements. The next section will describe the different requirements for the main project components.

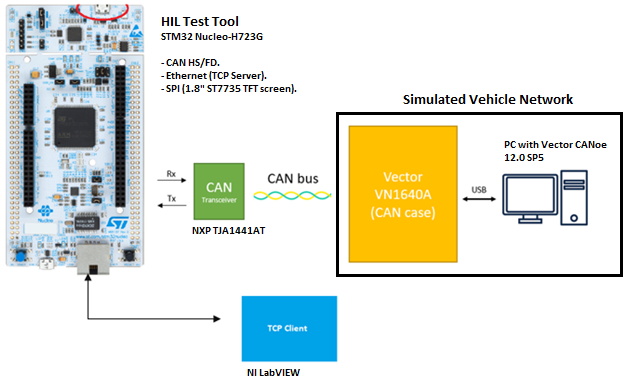
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Figure 1. Project Elements: HIL Test Tool, Simulated CAN network and TCP client.

# REQUIREMENTS

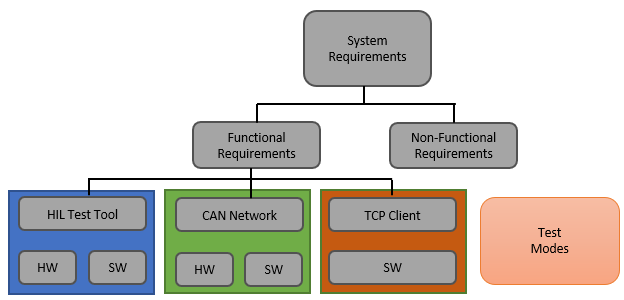
In this section, the system requirements for this project are shown and divided in 3 groups: HIL Test Tool, CAN Network and TCP client.

Figure 2. Overall System Requirements

## HIL Test Tool Hardware Requirements

| ID | HIL Test Tool Hardware Requirements | | |
| --- | --- | --- | --- |
| Name | Type | Description |
| HW-001 | Dev. Board | Functional | Board has 3 CAN HS/FD controllers. |
| HW-002 | CAN Transceiver | Functional | NXP TJA1441AT is used as Tx. |
| HW-003 | Ethernet Comm. | Functional | Board has Ethernet connection. |
| HW-004 | CAN termination | Functional | 120Ohm resistor used as termination. |
| HW-005 | Ethernet cable | Functional | CAT6 cable is used. |
| HW-006 | CAN Connector | Functional | A DB9 connector is used for PINs 2 & 7. |
| HW-007 | CAN cable | Functional | A twisted pair cable is used for comm. |
| HW-008 | LCD screen | Functional | Adafruit ST7735 1.8” display. |

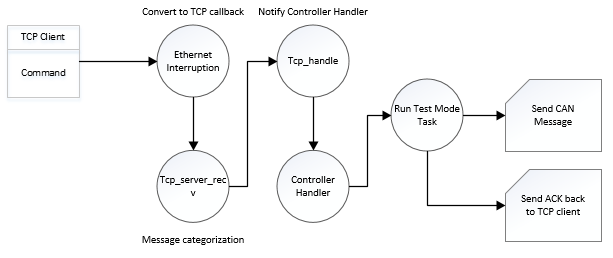
Table 1. HIL Test Tool Hardware Requirements.

| ID | HIL Test Tool Software Requirements | | |
| --- | --- | --- | --- |
| Name | Type | Description |
| SW-001 | RTOS | Functional | FreeRTOS is used |
| SW-002 | CAN bus speed | Functional | 500kbaud is configured |
| SW-003 | Serial COM | Functional | UART1 enabled |
| SW-004 | RT response | Functional |  |
| SW-005 | TCP Comm. | Functional | Board has a TCP server. |
| SW-006 | Software Arch. | Functional | Modular & scalable. |
| SW-007 | Test Scripts | Functional | Modular & scalable. |

Table 2. HIL Test Tool Software Requirements.

Figure 3 shows the path that data follows when a command is received by the HIL Test Tool, how is it processed by the TCP handle process and how the CAN message is sent to the network.

Similarly, figure 7 shows the Data Flow Diagram for the inverse process when the ECU responds back with the information via CAN needed to evaluate and apply PASS/FAIL criteria.



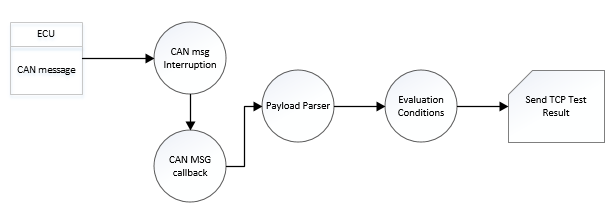
Figure 3. Data Flow Diagram for TCP message

Figure 4. Data Flow Diagram for ECU message response

## Simulated CAN Network Requirements

| ID | Simulated CAN Network Requirements | | |
| --- | --- | --- | --- |
| Name | Type | Description |
| SM-001 | CAN network | Functional | CAN network with at least 1 ECU. |
| SM-002 | ECU1: Engine | Functional | Read/write Speed signal |
| SM-003 | ECU2: Lights | Functional | Read/write Light & hazard signal |
| SM-004 | ECU3: Display | Functional | Read/write panel values. |
| HW-009 | CAN Interface | Functional | Vector VN case 1640 |

Table 3. Simulated CAN network Requirements.

## TCP Client Requirements

| ID | TCP Client Requirements | | |
| --- | --- | --- | --- |
| Name | Type | Description |
| TCP-001 | TCP Client UI | Functional | GUI design and developed in LV. |
| TCP-002 | Modular Design | Functional | Supports additional states. |
| TCP-003 | Known Design Pattern | Functional | State Machine based application. |

Table 4. TCP Client Requirements

## Test Mode Requirements

As seen in figure 2, the Test Mode requirements are a separate entity from the HIL test tool. This is expected because each project will have its own Test Plan and test requirements. For demonstration purposes a set of 4 test modes are included as part of this project.

| ID | Test Mode Requirements | | |
| --- | --- | --- | --- |
| Name | Type | Description |
| TM-001 | Speed Engine | Functional | Verifies the speed set to the ECU. |
| TM-002 | Lights | Functional | Verifies the lights turn ON/OFF. |
| TM-003 | Hazards | Functional | Verifies the hazards turn ON/OFF |
| TM-004 | Engine status | Functional | Verifies the ignition status of the engine. |

## Non-Functional Requirements

The system has several non-functional requirements. One of them is the time it takes a command to reach the HIL Test Tool. This time can vary widely based on the load of the local area network (LAN). A second variable would be the acknowledgment sent from the Test Tool back to the TCP client. The tool is designed to work with any TCP client in the market that can send a string of characters. As long as the client is able to read a string of characters it will display the status of the tool.

# Project Elements

This section describes the parts of the project that were used both in hardware and software.

## Hardware – HIL Test Tool

The Test Tool hardware consists of a Nucleo-H723ZG which has an STM32H7 (Arm 32-bit Cortex-M7) with 1 Mbyte of Flash and 320 Kbytes of RAM. The board has access to 1 CAN controller supporting flexible data rate. The CAN interface is configured as CAN High Speed (HS) only because the information required for the test mode does not require more than 8 bytes of payload.

To communicate with a CAN network, the TJA1441AT CAN transceiver from NXP was used. This transceiver supports up to 5 Mbit/s in FD mode. The configured speed for the CAN controller is 500 Kbytes.

To display the status of the Test Tool, a small 1.8” TFT screen (ST7735) was connected using SPI communication protocol. The bus speed is set to 6 MBits/s. SCK signal is connected to PA5 and MOSI signal is connected to PD7 of the development board.

## Hardware – Simulated CAN Network

The simulated CAN network provides the right environment to test the HIL Test Tool. A VN1640A CAN case from Vector was used as interface to connect the HIL Test Tool to the real CAN network.

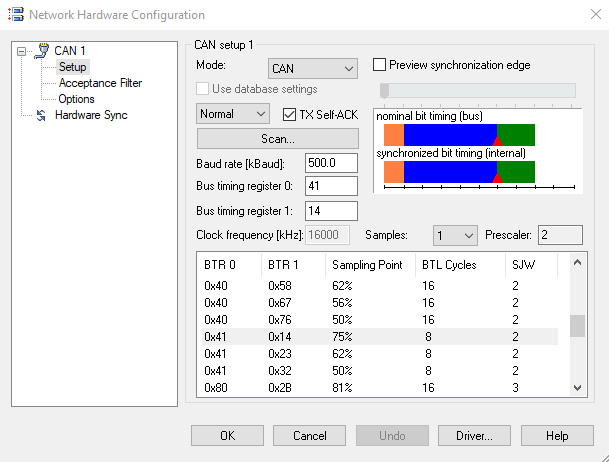
The VN1640A is a modular interface that supports CAN and LIN interfaces. CAN 2 channel was used as the CAN interface. The CANoe setup shown in Figure 5 was applied to achieve a 500Kbyte speed network.

Figure 5. CAN interface configuration in CANoe.

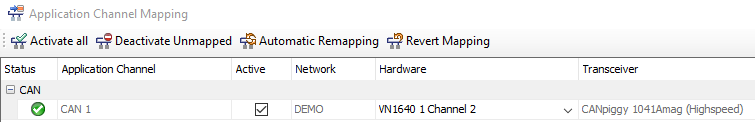
Figure 6 shows the mapping of the CAN channel number used to the interface with the ECU.

Figure 6. Physical CAN port mapping.

## Software – HIL Test Tool

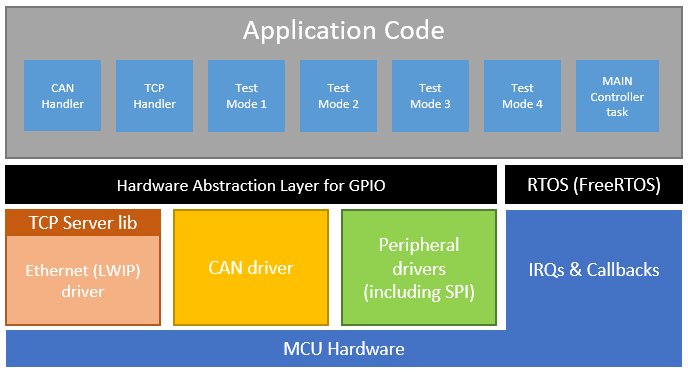
Software in the ECU uses a Real-Time Operative System (FreeRTOS) to handle the tasks of the project. Figure 7 shows the main software architecture.

Figure 7. HIL Test Tool software architecture.

## Software – Simulated CAN Network (CANoe)

The simulated CAN network was implemented using Vector CANoe. CANoe is a commercial off-the-shelf software tool to develop, test and analyze individual ECUs and entire networks. It comes preloaded with examples to quickly start analyzing automotive networks.

The following CAN network was implemented based on one of the examples that came with the tool and was modified to show the data being sent to and from the HIL Test Tool. Figure 8 shows the complete CAN network and the 3 ECUs (Engine, Light and Display).

The Engine ECU handles the ignition status as well as the speed of the vehicle. The Light ECU is in charge of handling the headlights and hazards of the vehicle and the Display ECU handles the indicators of the panels showing the speedometer and the rest of the indicators of the panels.

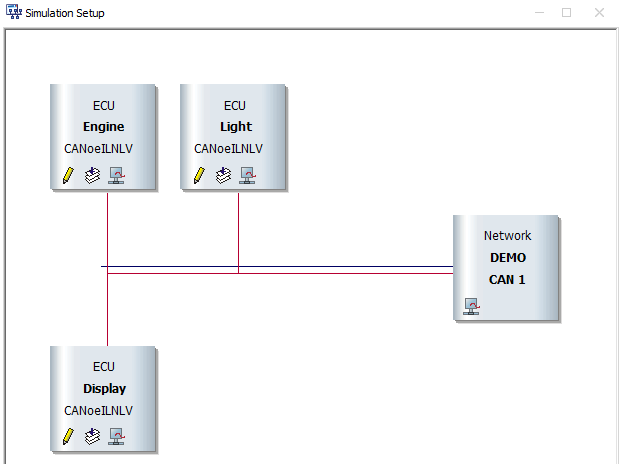
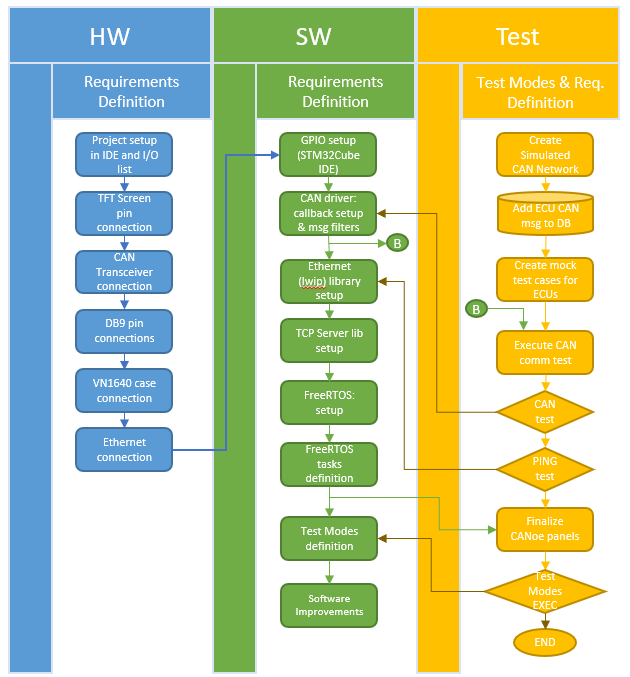


Figure 8. Simulated CAN Network.

# Design

## Project Development Process



## Software Design

### Controller Area Network

### Ethernet/TCP Server

### GPIO

### Real Time Operative System

The chosen OS was FreeRTOS. FreeRTOS provides a lightweight RTOS and allows modularization of tasks making it a good framework for this project.

### Tasks

A total of 7 RTOS tasks were created. Controller\_handler, . All the tasks are in freertos.c

#### Controller Handler

This is the main task of the application code,

### Interruptions

## Test Modes

# Test Results

# CONCLUSIONS

##### References

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*a**b* 

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