Open source vehicle ECU diagnostics and testing platform

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April 29, 2021
Declaration

I, Ashcon Mohseninia, of the Department of Computer Science, University of Reading, confirm that all the sentences, figures, tables, equations, code snippets, artworks, and illustrations in this report are original and have not been taken from any other person's work, except where the works of others have been explicitly acknowledged, quoted, and referenced. I understand that if failing to do so will be considered a case of plagiarism. Plagiarism is a form of academic misconduct and will be penalised accordingly.

Ashcon Mohseninia
April 29, 2021
Abstract

With the complexity of electronics in consumer vehicles, there currently only exists proprietary tools produced by various OEMs to diagnose their own vehicles. Each OEM has its own tool, and there is no easy way for a consumer to diagnose their own vehicle.

This project will explore the possibility of creating an entirely open source diagnostics software stack that will work with all ready existing diagnostic adapters that utilize the Passthru API (Which is used for a PC to communicate with a diagnostic adapter plugged into a vehicles OBD-II port). Additionally, this project will also explore creating an entirely open source Passthru API driver for an open source OBD-II adapter, whilst additionally porting the API from Win32 only to UNIX based operating systems such as Linux and OSX, allowing for a wider target audience compared to traditional diagnostic applications and adapters which only target Windows.
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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>CAN/CANBUS</td>
<td>Controlled area network</td>
</tr>
<tr>
<td>LIN/LINBUS</td>
<td>Local interconnect network</td>
</tr>
<tr>
<td>SAE J2534</td>
<td>The Passthru API</td>
</tr>
<tr>
<td>KWP2000</td>
<td>Keyword protocol 2000</td>
</tr>
<tr>
<td>UDS</td>
<td>Unified diagnostic services</td>
</tr>
<tr>
<td>API</td>
<td>Application programming Interface</td>
</tr>
<tr>
<td>ECU</td>
<td>Engine/Electronic control unit</td>
</tr>
<tr>
<td>OBD</td>
<td>On-board diagnostics</td>
</tr>
<tr>
<td>OBD-II</td>
<td>OBD protocol</td>
</tr>
<tr>
<td>ODX</td>
<td>Open Diagnostic eXchange format</td>
</tr>
<tr>
<td>DTC</td>
<td>Diagnostic Trouble Code</td>
</tr>
<tr>
<td>SCN</td>
<td>Software Calibration Number</td>
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Chapter 1

Introduction

In this chapter the current state of car diagnostics will be discussed, as well as a high level overview of the project breakdown and how it will hopefully change the current state of car diagnostics for consumers.

1.1 Background

Since the early 2000s, the automotive industry has seen an exponential increase in both the complexity of ECUs and the number of ECUs in consumer vehicles, with modern vehicles having more than 30 ECUs.

With increased complexity comes more points of failure. With modern ECUs being able to register fault codes at the slightest hint of trouble, and also requiring specialist software to calibrate them after certain mechanical parts are either replaced or modified on a vehicle.

This presents a unique problem. While DIY consumers have traditionally been able to easily replace or modify components on their vehicles, software issues such as ECU fault codes still require proprietary software which is only used by the OEM itself, or licensed to specific workshops as a huge premium, and also requires proprietary multiplexer hardware to plug into the car’s OBD-II port, which is also expensive.

Currently, there are simple OBD-II applications that can only communicate with the engine ECU in a vehicle to clear standard OBD-II error codes or read sensor data that is only outlined by the OBD-II specification, but there is no easily available software outside of the OEM’s own software (Which is licensed to workshops) which can diagnose all ECU’s within a vehicle, or run more complex diagnostic routines and tests. Also, the vast majority of OEM software currently available is only compiled for win32 (32bit Windows), and therefore is not up to date with modern computing, and also does not run on Linux or OSX. This is primarily because OEMs over the years have simply been adding features to their old diagnostic software, rather than spending resources on creating a whole new platform for more modern vehicles.

Therefore, in this project, the possibility and process of creating such an application that allows for communicating with all ECUs within a vehicle, and to run more advanced diagnostic functions on them, without the OEM’s own software will be explored. This will also include writing a open source driver for Macchina’s M2 OBD-II module to turn it into a diagnostic adapter using the J2534 / Passthru API, which can be used by any application utilizing the protocol, including some OEM software (Such as Daimler’s Xentry Passthru diagnostic suite). Additionally, the application and J2534 API will be ported to both 64bit versions of Linux and OSX unofficially, allowing for a much wider target audience of the system, since individuals would no longer be limited to just older versions of Windows.

Another objective of this project is to create a simple, easy to use database format in
CHAPTER 1. INTRODUCTION

JSON. Traditionally, OEM software uses proprietary binary based file formats to describe how the software communicates with ECUs within a vehicle, as well as how to interpret the ECUs responses.

1.2 Problem statement

This section will discuss the current issues with car diagnostics.

1.2.1 Lack of continuity or standards between OEMs diagnostic tools

With every OEM creating their own diagnostic software, there is no continuity between OEM’s, which hinders most independent workshops and consumers who wish to diagnose their own vehicles. For instance, Mercedes’ diagnostic software (Xentry) will never work on a Toyota vehicle, and vice versa, despite the fact that at a low level, both software suits will use the same hardware API to talk to a diagnostic adapter plugged into a vehicle.

To add to this, there is no standard format for storing diagnostic data about ECU’s. Each diagnostic tool set has its own file format, which has to be reverse engineered to extract any useful data from. In this project, the prospect of using an open, universal JSON format will be looked into.

1.2.2 Proprietary diagnostic hardware

Currently, there are two publicly available API’s for communicating with a vehicle using a multiplexer. ISO 22900-2 (D-PDU API) and SAE J2534 (Passthru API). Most OEM software supports either one or both of these APIs, or also supports their own proprietary hardware. There are currently two main issues with both of the APIs.

1. Windows only support. Since these API’s are designed for diagnostic software, and those are only designed for windows, there is currently no known diagnostic API that includes support for Linux or OSX.

2. Closed source. Although some of the API documentation is made public, vendors of the diagnostic multiplexers that utilize either API creates proprietary hardware with closed-source controller firmware, and sells the adapters at a premium, making it hard for the average consumer to easily attain one. There are Chinese ‘clone’ adapters that can be purchased on ebay for a cheap price, however these tend to not work or will encounter massive stability issues, so should never be trusted to work reliably.

1.3 Aims and objectives

Aims: This project has the following aims:

- Build a cross-platform, Graphical ECU diagnostic application (Using the J2534 passthru API)
- Port the J2534 API to Linux and OSX
- Write a custom J2534 driver for Macchina’s\(^1\) M2 Under the dash OBD-II module, allowing it to work on all 3 operating systems.

\(^1\)macchina.cc
• Define a JSON schema for describing the capabilities, fault codes, and diagnostic functions that can be ran on an ECU, and make it a viable replacement to proprietary data formats.

**NOTE:** ECU firmware Flashing or updating will not be part of this project. This is due to liability concerns of leaving an individual’s ECU in a bricked state, and also the difficulty in locating a legitimate software version for an ECU.

**Objectives:** To achieve the aims, the project has the following objectives:

• Read and clear non standard (OBD-II) ECU error codes from a test ECU, and a real vehicle

• Convert Daimler database files (CBF) into JSON as a proof of concept.

• Show that live data recording works on multiple ECU’s in a vehicle

• Show that the custom J2534 compatible adapter works with real OEM software that uses the J2534 API

1.4 **Solution approach**

Breaking down the full solution of the project yields the following sub objectives:

1.4.1 **JSON schema designing and converting**

For this, a JSON format will be described using UML, then written in code which can be serialized and deserialized to and from JSON. After, a parser will be written which is capable of converting Daimler’s CBF file format to the JSON. CBF is a proprietary diagnostic container file format used by Daimler’s diagnostic software suits, and is only used for older vehicles (Pre 2008), with their SMR-D file format superseding CBF, which is used by their newer software called Xentry. At a high level, CBF files contain the following data:

1. ECU software version names (An ECU can have different software versions)

2. Communication protocols to be used to communicate with the ECU

3. Payloads to send to the ECU for certain functions

4. List of all error codes, as well as a readable description of the error codes

5. Interpretation data for converting an ECU response packet into human readable text

**Important.** Since this will extract data from Daimler’s own CBF files, there are some social and legal issues to account for. Contained within the CBF files is data related to SCN coding. SCN Coding (Software Calibration number coding), is a way to write a coding string to an ECU in order to enable or disable features on it. The CBF files contain data regarding which regions in the ECU’s EEPROM relate to which features. Because SCN coding is something that Daimler sees as its own intellectual property, and charges a heavy fee for feature unlocking on their cars, this will NOT be something that is going to be extracted from the CBF files, and there will be no referencing to SCN regions in the extractor codebase either. The only things that will be extracted from the CBF files will be diagnostic routines, ECU identification data, and interpretation data.
1.4.2 Passthru driver creation

This component of the project will be attempted in the following steps.

1. Define a new standard for storing J2534 configuration data on Linux and OSX, since the J2534 API officially only supports win32 (32bit Windows).

2. Create a reliable cross-platform serial communication link between a PC and adapter, along with a defined protocol for the adapter and PC to exchange data.

3. Create a Rust library with the necessary exported J2534 functions such that any application can use the library and therefore adapter to talk to a vehicle.

4. Create C++ firmware for the adapter for managing physical communication links between the OBD-II port and ECUs in the vehicle, and listen for command requests from the PC and sending data back to the PC.

1.4.3 Application creation

This will be the largest part of the project. At a high level, this application has to be able to do the following, and shall be called OpenVehicleDiag:

1. Create an application that can utilize the J2534 API to communicate with a vehicle.

2. Create an abstraction layer for future use, which allows for more hardware to be utilized by OpenVehicleDiag other than J2534. (Examples: SocketCAN, D-PDU).

3. Create a useful GUI for data logging of ECUs based on the data found in the JSON schema.

4. Allow for basic commands to be sent to any ECU in a vehicle using KWP2000 or UDS. This should allow for reading and clearing error codes from the vast majority of vehicle ECUs, even if the vehicle does not have any JSON created for it.

5. Allow for a user to see raw data on their vehicles CAN Network (Targeted at individuals who wish to reverse-engineer their vehicles’ CAN network).

6. Based on the work done by [Nils Weiss, Sebastian Renner, Jürgen Mottok, Václav Matoušek (n.d.)], create an intuitive user interface which can exploit the ISO-TP protocol to scan for all UDS or KWP2000 ECU’s in any unknown vehicle.

1.5 Summary of contributions and achievements

All the code repositories for each part of this project can be located on github (See D). This project has ended up being very successful, gaining a large following online (150 stars on Github for the main OpenVehicleDiag repository). OpenVehicleDiag itself will continue to receive contributions and improvements in the future.

1.5.1 Passthru driver

The Passthru driver implementation has proven that adapters from the likes of Bosch are far too expensive, and there is no need for $1000+ adapters, when an open source alternative which was designed for this project does exactly the same job with open source hardware.
which costs a fraction of the commercial adapters. This report will even show that the adapter works with Commercial software from Daimler. Also, this report will show that the SAE J2534 API can indeed be ported to other operating systems, which in turn makes it easier for other operating system users to utilize the API with custom Diagnostic software such as OpenVehicleDiag.

1.5.2 JSON Schema

The JSON Schema has shown that it can be a compatible substitute for the ODX-D data storage format and other proprietary diagnostic container formats, and more importantly, is a lot easier and more accessible for users to read or create.

1.5.3 Diagnostic Application (OpenVehicleDiag)

OpenVehicleDiag has proven that the need for large scale OEM or expensive third party software is somewhat obsolete, when it comes to simple diagnostics such as DTC reading and clearing, as well as data gathering from the ECU. This should be enough for 90% of use cases where someone would take their vehicle to the dealer due to a software fault with an ECU. It has also proven that diagnostic applications can be intuitive for individuals to use, and can also run on other operating systems other than Windows.

1.6 Organization of the report

This report will first describe the current hardware, software and protocols currently utilized for car diagnostics, before explaining the solution approach and methodology. Each sub project (Passthru driver, JSON Schema, Diagnostic application), will have its own solution approach and methodology.

Towards the end of this report, the results and impact of the work will be discussed, as well as showing tests conducted with the custom Passthru adapter to prove it is SAE J2534 compliant, and works perfectly with commercial diagnostic software. Also future plans for this project will be discussed.
Chapter 2

Literature Review

In this chapter, existing vehicle communication protocols, diagnostic protocols, hardware APIs and diagnostic software will be looked at, with a comparison at the end comparing current diagnostic software and hardware to what is proposed for this project.

2.1 Communication protocols found in vehicles

Within modern vehicles, there are many different protocols used for allowing ECUs in a vehicle to communicate with each other, or to allow an ECU to communicate with primitive components on the car. In this part, the 2 most common protocols (CAN and LIN) will be discussed, outlying how each protocol works, and what they are used for.

2.1.1 CAN

CAN / CANBUS is a high speed transport network used for ECU communication. It consists of 2 separate ISO specifications:

1. ISO11898-2 - High-Speed CAN (Up to 1Mb/s)
2. ISO11898-3 - Low-Speed CAN (Up to 125Kb/s), also known as fault-tolerant CAN

Both CAN Specifications work on similar principles, except with different electrical properties.

CAN Networks transmit CAN Packets. These are data packets containing up to 8 bytes of data, as well as a 11 or 29bit Identifier ID (Depending on if the CAN Network uses Standard of Extended addressing). There is also extra data in each CAN Frame (Bit stuffing and CRC Checks), however these extra bits are never exposed to the ECUs CPU as the CAN Controller deals with validating the CRC checks of the CAN Frame.

![Figure 2.1: Bit layout of both Standard and Extended CAN Frames](image)

Most commonly, the following data fields are exposed the ECU’s CPU:
CHAPTER 2. LITERATURE REVIEW

- **CAN ID** - This is the Unique identifier of the ECU subsystem which transmitted the frame (Some ECUs transmit multiple CAN Frames with different IDs)
- **CAN DLC** - The amount of bytes in the data portion of the CAN Frame
- **CAN Data** - 0-8 bytes of data contained within the CAN Frame
- **RTR** - Remote frame. This is sometimes used by an ECU to request data from another ECU. If this value is 1, then the ECU is requesting data from another ECU, if the value is 0, then there is data within the frame from the requested ECU.

Electrical properties of CAN

Depending on the type of CAN Network, the electrical properties of the bus differs slightly:

- **High-Speed CAN ISO11898-2** - Both CAN wires are terminated with a 120Ω resistor at each node on the bus. The recessive voltage of the CAN Network is 2.5V, with the dominant voltage being approximately 3.5V for CAN-H, whilst being approximately 1.5V for CAN-L.

- **Low-Speed CAN ISO11898-3** - CAN wires are not terminated with a resistor, however the overall resistance between both wires over the entire bus should not exceed 100Ω. The recessive voltage of the CAN Network is approximately 0V for CAN-H and 5V for CAN-L, whilst the dominant voltages are approximately 5V for CAN-H and 0V for CAN-L.

Both CAN Network types require that a logical '1' is the recessive voltage, and a logical '0' is the dominant voltage. The logical state of the CAN Network is calculated by applying a logical AND to both the CAN-H and CAN-L wires. Components on the CAN Networks (CAN Transceiver chips) are designed to handle anywhere between −27V to +40V without sustaining any damage. If both CAN Wires are not in the same logical state at the same time EG: CAN-H being in a dominant state whilst CAN-L is in a recessive state, all transmission on the network will stop immediately as all the CAN Transceiver chips on the network as detected that either a wire may be shorted to ground, or that a wire may be shorted to an ECU’s power supply, and therefore the network is in an unstable state.

This is not always the case however, as some CAN Networks based on ISO11898-3 can actually run in single wire mode, where the transceivers discard the erroneous wire voltage, and only use the voltage provided by the ‘good’ CAN wire.

Collision detection in a CAN Network

Since a CAN Network does not have `master ECU`, CAN networks have a passive method of detecting and avoiding packet collisions. As a logical '0' is a dominant voltage, it means that whilst an ECU is transmitting a '0', it is physically impossible for another ECU to flip the CAN Wire voltages to their recessive '1' state. During a frame transmission, each CAN Transceiver chip on the network checks the CAN Wire voltages after every bit is sent, and will stop sending if the CAN Wire voltages do not match the bit being sent in order to avoid a collision. This is why on a CAN Network, ID’s with a lower value have a higher ‘priority’ on the network, since lower ID’s will block the transmission of higher IDs in the event of a collision.
Table 2.1 shows how an ECU with a lower CAN ID (0x0005) can stop another ECU with a larger CAN ID of (0x000A) from transmitting. As soon as ECU transmitting the higher CAN ID detects the CAN networks logical state does not match that of the bit it just sent, it stops sending, and the data ECU 1 sent is not impacted. This is all handled by the CAN Transceiver chip, so the ECU’s Processor is not occupied with checking the CAN network state.

### 2.1.2 ISO-TP

ISO-TP (ISO15765-2) is a transport layer protocol that runs over a CAN Network, allowing for multiple ECUs to exchange up to 4096 bytes using multiple structured CAN Frames.

The ISO-TP Standard defines the following 4 frame types, which are denoted by the first nibble (Half byte) in the CAN Frame, also known as the PCI byte:

<table>
<thead>
<tr>
<th>CAN frame type</th>
<th>Nibble (Hex)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single frame</td>
<td>0</td>
<td>The single frame contains all the data in the payload</td>
</tr>
<tr>
<td>First frame</td>
<td>1</td>
<td>This is sent if the data is larger than a single CAN Frame can contain. It also contains the full length of the payload to be transmitted</td>
</tr>
<tr>
<td>Consecutive frame</td>
<td>2</td>
<td>Contains subsequent data for a larger data payload after a first frame was sent and the sender received a flow control message.</td>
</tr>
<tr>
<td>Flow control</td>
<td>3</td>
<td>This is sent in response to receiving a First frame. This frame tells the sending ECU how many CAN frames to send next before waiting for another flow control message, as well as how quickly to send the frames</td>
</tr>
</tbody>
</table>

A flow control frame contains the following 3 bytes:
### Byte name | Byte position | Purpose
--- | --- | ---
PCI | 0 | Identifies the frame as being a flow control frame. A PCI of 0x30 indicates that it is a flow control frame, and that the sender can proceed sending data, and respect the values indicated in BS and ST-MIN. A value of 0x31 indicates the ECU is currently busy, and the sender must wait before attempting to send again.
BS | 1 | The BS value (Block Size) indicates the maximum number of consecutive frames the sender can send before the receiving ECU sends another flow control frame to the sender. A value of 0x00 for block size indicates an infinite block size, so the sender must send all its data without waiting for another flow control message.
ST-MIN | 2 | This indicates the minimum separation time between the sender sending consecutive frames to the receiving ECU. Any value between 0x01 and 0xF0 is interpreted as milliseconds, and values between 0xF1 and 0xF9 is interpreted as 100-900 microseconds. A value of 0x00 here indicates the sender can send consecutive frames as quickly as it wants.

In order to identify lost data, or out of order CAN frames during multi frame transmissions, the PCI byte of the consecutive frame is used as a counter. The counter starts with a PCI of 0x21, then increases after every consecutive frame is sent until 0x2F, before wrapping round to 0x20 and counting up again.

Below is an ISO-TP exchange traced from the interior CAN Network of my Mercedes W203 C class. This exchange occurred between the Radio and Instrument cluster, where the Radio is telling the instrument cluster what text to display on the Radio page of its LCD. Red indicated bytes that are for the ISO-TP protocol

<table>
<thead>
<tr>
<th>CAN ID</th>
<th>CAN Data</th>
<th>ASCII</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x01A4</td>
<td>10 12 03 26 01 00 01 0B</td>
<td>........</td>
</tr>
<tr>
<td>0x01D0</td>
<td>30 08 28 00 00 00 00 00</td>
<td>0.(....</td>
</tr>
<tr>
<td>0x01A4</td>
<td>21 10 41 55 44 49 4F 20</td>
<td>!.AUDIO.</td>
</tr>
<tr>
<td>0x01A4</td>
<td>22 4F 46 46 00 C4 00 0B</td>
<td>&quot;OFF....</td>
</tr>
</tbody>
</table>

In this trace, we can see the Radio has a CAN ID of 0x01A4, and sent a 18 byte payload to the instrument cluster. Upon receiving the first CAN Frame, the instrument cluster responded on a CAN ID of 0x01D0, accepting the transmission of more data, and asking for a maximum of 8 packets to be sent before the radio should wait for another flow control message, and with each packet being sent at a minimum of 40ms apart. Reassembling the Radio’s payload without any of the ISO-TP protocol bytes shows the raw payload:

```
03 26 01 00 01 0B 10 41 55 44 4F 20 4F 46 46 00 C4
```

#### 2.1.3 LIN

LIN (Local interconnect Network) is a much cheaper and simpler interconnect network used in vehicles. Its main focus is for allowing ECUs to drive more primitive components simply, rather than using expensive network solutions such as CANBUS.

A LIN network consists of a single wire, which connects 1 master ECU with up to 16 slave components or ECUs. This single wire acts as a half-duplex serial interface, running at 12V DC. The data transfer rate of LIN Bus is relatively slow, ranging from 1-20kbps. However, due to its simplicity, LIN bus is preferred when driving primitive components. For example, the engine ECU in a vehicle can use a LIN network to drive items like the engine fan and AC...
compressor on the engine, allowing the engines ECU to also get feedback on the components state of operation.

A LIN network operates by the master ECU requesting data from a slave component on its network. The network is otherwise void of any traffic. When requesting data, the master ECU will send a header frame which looks like the following:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Length (Bits)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sync break</td>
<td>14+</td>
<td>Indicates the start of a new frame</td>
</tr>
<tr>
<td>Sync byte</td>
<td>8</td>
<td>Allows for resynchronization of slave nodes</td>
</tr>
<tr>
<td>ID byte</td>
<td>6</td>
<td>Frame Identifier</td>
</tr>
<tr>
<td>Parity</td>
<td>2</td>
<td>parity for the frames ID</td>
</tr>
</tbody>
</table>

As seen above, the ECU starts by sending a sync break. This notifies all the nodes on the LIN network to begin listening for incoming data and stop transmitting. Following this is the sync byte. This has a predefined value of 0x55 (01010101 in binary) and allows all the nodes on the network to calculate and determine the time between the high and low voltages on the bus, allowing them to listen in sync with the master sending the rest of the frame. Lastly is the ID followed by 2 bits for parity. This is the ID the ECU is requesting data from, and the matching node on the network will respond with a data frame, which is structured like so:

<table>
<thead>
<tr>
<th>Field name</th>
<th>Length (Bits)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1-64</td>
<td>Data to be transmitted</td>
</tr>
<tr>
<td>Checksum</td>
<td>8</td>
<td>Checksum calculation</td>
</tr>
</tbody>
</table>

The response sent back to the master ECU contains simply a data field (configurable between 1 and 64 bits) followed by an 8 byte checksum. Since LIN 2.0, the ID of the request determines the data size of the response:

<table>
<thead>
<tr>
<th>ID Range</th>
<th>Data length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-31</td>
<td>2 bytes</td>
</tr>
<tr>
<td>32-47</td>
<td>4 bytes</td>
</tr>
<tr>
<td>48-63</td>
<td>8 bytes</td>
</tr>
</tbody>
</table>

When calculating the checksum of the frame, the following code is used:

```c
uint8_t calculate_checksum ( uint8_t id , uint8_t* data_ptr , uint8_t data_len ,
uint8_t cs_mode ) {
    uint16_t tmp = 0; // 0 is default for classic checksum
    if ( cs_mode == ENHANCED ) { tmp = id; } // Enhanced checksum (LIN 2.0)
    for ( int i = 0; i < data_len; i++) {
        tmp += *data_ptr ++
        if ( tmp >= 256) {
            tmp -= 255; // Wrap when overflow
        }
    }
    return ~tmp & 0xff ; // Return the lower byte
}
```

Listing 2.1: C code snipped for calculating LIN frame checksum

The classic checksum method (For LIN 1.x slave nodes) does not include the ID as part as the checksum, where the enhanced method (For LIN 2.x slave nodes), does include the ID byte.

**The use of LIN for ECU diagnostics**

A variation of LIN called K-Line exists for diagnostic purposes only. This is a network which runs from the OBD-II port of the vehicle to a vehicles powertrain ECUs. This bus typically
runs at 10.4kbps and allows for the transmission of up to 255 bytes rather than the usual limit of 8 bytes when being used under the ISO14230-2 protocol (KWP2000).

As the bus is usually powered off during normal operation of the vehicle, it has to be woken up in one of 2 ways when a OBD-II adapter wants to send or receive data on the K-Line.

**Five baud initialization**
The Five baud initialization method is a slow wake-up method of the K-Line LIN network typically used for ISO9141-2 and works by the tester (The OBD-II adapter) sending the request ID at 5 bps. The requested ECU detects this slow initialization of the network and responds by waking up the network and sending its response ID back to the tester. Once the response ID has been received, the network is re-configured to run at 10.4 kbps. Once this is completed, no data can be sent or received for at least 300ms.

**Fast initialization**
The fast initialization method is another way to wake up a K-Line network, and is only used for ISO14230-2. With fast initialization, the tester sends a 25ms pulse on the K-Line, followed by the request ID at the networks usual bus speed (Typically 10.4kbps)

It should be noted that whilst the five baud initialization method and Fast initialization methods work very differently from one another, both can be achieved using the same physical hardware and transceivers.

**ISO9141-2**
ISO9141-2 ISO (1989) is the transport layer used for ISO9141-4 (OBD 2.3.1) when utilizing the K-Line diagnostic line of a vehicle. This configuration only utilizes the Five baud initialization sequence (Fast initialization is never used). This network configuration can run at multiple baud rates, ranging from 9.6kbps to 15.625kbps, however most common rates found are 9.6kbps and 10.4kbps. This configuration supports a maximum data size of up to 12 bytes, with an additional 1 byte used for checksum.

**ISO14230-2**
ISO14230-2 ISO (2000) is the transport layer used for ISO14230-4 (KWP2000 2.3.2) when utilizing the K-Line diagnostic line of a vehicle. This configuration of K-Line only runs at 10.4kbps (Unless its 5bps during the Five baud initialization sequence), and supports both Five baud initialization, or Fast initialization wake up methods. This configuration supports data sizes of up to 255 bytes, with an additional 1 byte for checksum.

With both of these network configurations, the target ECU on the K-Line will go back into a sleep state if no data is transferred in 5 seconds. Therefore, it is necessary for the tester to send periodic "Stay awake" messages on K-Line to keep the target ECU awake and in a diagnostic session.
CHAPTER 2. LITERATURE REVIEW

2.2 Diagnostic adapter hardware and APIs

In this section, I will be discussing the various hardware and software used by most commercial diagnostic software to communicate with a vehicle using a specialized adapter.

2.2.1 Hardware APIs

In order to make it easier for a third party company such as Bosch to create an adapter for multiple diagnostic software suits for various OEMs, there are 2 main adapter APIs that most OEM diagnostic software supports. SAE J2534 (Passthru) and ISO 22900-2 (D-PDU). Each API has its own requirements and supports different physical communication protocols with a vehicle.

It should be noted that some OEMs use proprietary protocols for communicating with their own in-house diagnostic adapters, however in more recent times, such adapters are rare as most OEM’s tend to support either Passthru or D-PDU, or sometimes both in their own diagnostic software suites, and offload the production cost of diagnostic adapters to third parties such as Bosch or XHorse.

SAE J2534

SAE J2534 (Passthru) Drew Technologies, Inc (2003) is a hardware API for diagnostic software to communicate with a supported adapter via a Windows DLL. It was originally created for Windows 2000 and Windows XP, however it still works on modern versions on Windows. A manufacturer of an adapter which supports the Passthru API can support any number of the following network layer protocols:

1. ISO 9141
2. ISO 14230-4
3. SAE J1850 41.6 KBPS PWM (Pulse width modulation)
4. SAE J1850 10.4 KBPS VPW (Variable pulse width)
5. CAN
6. ISO 15765-4 (ISO-TP)
7. SAE J2610 DaimlerChrysler SCI (Serial communication Interface)

Configuration data about each adapter and library which supports the Passthru API is stored in the Windows Registry. A typical registry entry for an adapter will contain the following information about the adapter:

- Hardware name
- Adapter vendor
- Supported protocols (From list above)
- Library path (Location to the Adapters DLL)

The J2534 API DLL must be compiled as a 32bit library DLL, meaning it is incompatible with 64bit software on modern systems. This is however not a problem as all diagnostic software is also compiled as a 32bit executable, in order to keep backwards compatibility with older systems.
ISO 22900-1 and ISO 22900-2

ISO 22900-1 (MVCI) and ISO 22900-2 (D-PDU API) Softing (2013) are both a hardware and software API for communicating with vehicles. Unlike SAE J2534, D-PDU is an entire protocol stack which includes diagnostic servers to do UDS (??), KWP2000 (??) and OBD-II (2.3.1), but for the context of this report, only ISO 22900-1 (hardware requirements) and ISO22900-2 (D-PDU API) will be discussed.

ISO 22900-1 mentions that an adapter that can be utilized by the D-PDU API can support any number of the following network layer protocols:

1. ISO 9141
2. ISO 14230-4
3. SAE J1850 41.6 KBPS PWM (Pulse width modulation)
4. SAE J1850 10.4 KBPS VPW (Variable pulse width)
5. CAN
6. CAN FD
7. ISO 15765-4 (ISO-TP)
8. Ethernet (DoIP)

Interestingly, ISO 22900-2 states that other third party adapter APIs can be utilized by D-PDU. This includes SAE J2534, however this is up to the application which implements the D-PDU API. This means that an application that uses the D-PDU API can work with an adapter that uses the SAE J2534 API, without actually having native support for the API itself, since D-PDU API server does the work with loading and calling the library for the J2534 adapter.

2.2.2 Hardware adapters

In this section, various diagnostic adapter hardware will be analysed and discussed. These adapters are used by a variety of different diagnostic tools/software.

Generic ELM327 BT adapters

ELM327 elmelectronics.com (2017) is a family of micro controllers which is used for communicating with vehicles using multiple network protocols. These controllers are most commonly found in cheap Bluetooth scan tools that only support OBD (ISO9141), however the micro controller itself can additionally support ISO 15765-4, ISO14230-4 and CAN, but these additional interfaces are rarely found in the cheaper scan tools as they utilize a 'cloned' version of the ELM327.

In order to interface with an ELM327, either USB or Bluetooth is utilized. The ELM327 receives and responds to a list of defined AT Commands. interestingly, since the AT Command set is publicly available and well documented, this has lead to open source projects which utilize micro controllers such as an ESP32 to emulate an ELM327. An example of such project can be found here [https://github.com/collin80/A0RET]

The most common application which utilizes the ELM327 is Torque for Android (See 2.4.1).

A typical cost for an ELM327 Bluetooth adapter is about £10.0-20.0. However it is unknown if these adapter use a genuine ELM327 chipset of a cloned chipset.
SDConnect C4

The SDConnect C4 adapter is a diagnostic adapter which Daimler will ship with their diagnostic tool set (2.4.3) when provided to authorized workshops and dealers.

Due to this, not much is known about the cost of the adapter, however it is known it supports the D-PDU API, as well as Daimler’s own proprietary protocol for talking to their in-house diagnostic adapters.

Whilst Daimler only provide the adapter to authorized workshops, there appears to be a huge amount of listings on ebay for this adapter, ranging in price from £500-£1000. However, it is apparent that some of these SDConnect listings might be cloned Chinese manufactured adapters, rather than a genuine adapter which has come from Daimler.

Bosch VCI

The Bosch VCI adapter is a series of diagnostic adapters which Bosch sells. For this section, the specifications of the Bosch MTS 6516 VCI adapter will be used.

This adapter can be used with both SAE J2534 and ISO 22900-1/2. It features 3 separate CAN channels (for CAN and ISO15765-4), 2 UART channels (For ISO9141 and ISO14230-2), 1 J1850 channel for either J1850VPW or J1850PWM. In order to connect to a PC, either WIFI or USB can be used with this adapter.

Cost of this adapter is unknown, however a similar used adapters by Bosch can be found on auction sites like Ebay for around £1000-£2000. So it can be concluded that these VCI adapters are very expensive, and out of the reach of the majority of consumers.

2.3 ECU Diagnostic protocols

In this section, the most common three diagnostic server protocols used in vehicles will be discussed (OBD-II, UDS and KWP2000).

To begin with, it should be noted that all these 3 services utilizes the same request and response message structure:

```
  0  8  16  24  32
SID  PID  Data...
```

Figure 2.2: Data format of a service request with PID and data

```
  0  8  16  24  32
SID + 0x40  PID  Response...
```

Figure 2.3: Data format of a positive ECU response

```
  0  8  16  24
0x7F  SID  Error code
```

Figure 2.4: Data format of a negative ECU response

In the above figures, it should be noted that some services (Such as in OBD-II), do not require
a PID or Data, meaning only 1 byte of data (SID) is sent to the ECU. The entire length of the request and positive response messages can be as long as the underlying transport protocol. For example, ISO-TP can handle payloads of up to 4096 bytes, where as ISO14230-2 can only support up to 255 bytes.

### 2.3.1 OBD-II

On-Board Diagnostics (OBD-II) is a relatively simple and read-only diagnostic protocol, and is a legal requirement on all vehicles since 2001. It is a standard way to communicate with the engines ECU in a diagnostic session in order to read standard error codes, read sensor data from the ECU and carry out emissions tests. OBD-II can be used on any network layer protocol, but is mainly found to use ISO9141-2 on older vehicles, and ISO-TP on all cars found after 2008.

OBD have 9 pre-defined services, OEMs are free to choose which services their cars support, however most commonly services 01,02,03,04,09 are always implemented. It should be noted as well that OEMs are free to implement their own custom services beyond this range.

- 0x01 - Request current powertrain data
- 0x02 - Request powertrain freeze frame data
- 0x03 - Request emission-related diagnostic trouble codes (DTC)
- 0x04 - Clear/Reset emissions-related diagnostic information
- 0x05 - Request oxygen sensor monitoring test results
- 0x06 - Request ob-board monitoring test results for specific monitored systems
- 0x07 - Request emissions-related diagnostic trouble codes detected during the current or previous drive cycle
- 0x08 - Request control of on-board systems
- 0x09 - Request vehicle information
- 0x0A - Permanent DTCs

Every service (SID) has a child PID which will return which subfunctions are supported by the ECU for the SID. For example, taking a look at the response for SID 0x01, PID 0x00, which gets the supported PIDs for service 0x01 from 0x00 to 0x20:

```
1   REQUEST:  0x01 0x00
2   RESPONSE: 0x41 0x00 0xBE 0x1F 0xA8 0x13
```

<table>
<thead>
<tr>
<th>Hexadecimal</th>
<th>B</th>
<th>E</th>
<th>I</th>
<th>F</th>
<th>A</th>
<th>E</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID supported</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>PID ID (Hex)</td>
<td>0x01 0x02 0x03 0x04 0x05 0x06 0x07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Encoding example of supported PIDs for Service 01

From this, we can see that this engine ECU supports Service 01 PIDs 0x01, 0x03, 0x04, 0x05, 0x06, 0x07, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x13, 0x15, 0x1F and 0x20.
Service 0x01

Service 01 is used to retrieve live data metrics from the engine, PIDs 0x00, 0x20, 0x40, 0x60, 0x80, 0xA0, 0xC0 are special pids that are used to retrieve the next 32 supported PIDs, as shown in 2.2. A full list of PIDs are found at Wikipedia (2021).

Any response from Service 01 PIDs will result in 4 bytes or less being returned from the ECU, which are typically converted using either as enumerated values, or using mathematical formulas.

An example of how this works would be to look at decoding the Odometer reading over Service 01 (PID 0xA6):

\[
\text{REQUEST: } \quad 0x01 \ 0xA6 \\
\text{RESPONSE: } \quad 0x41 \ 0xA6 \ 0x00 \ 0xA0 \ 0xC1 \ 0x0F \\
\]

The conversion formula is as follows:

\[
\text{Odometer (Hm)} = \frac{A(\text{2}^{24}) + B(\text{2}^{16}) + C(\text{2}^{8}) + D}{10}
\]

The \( ABCD \) encoding comes from the response bytes of the ECU, starting at the third byte in the response payload, since the first byte of a response is always a conformation of the Service ID being requested, and the second byte being the requested PID. The unit 'hm' implies Hectometre. \( 10 \text{ Hectometres} = 1 \text{ km} \)

In this case, the bytes are converted to decimal as shown:

<table>
<thead>
<tr>
<th>Byte</th>
<th>Hex</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0x00</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0xA0</td>
<td>160</td>
</tr>
<tr>
<td>C</td>
<td>0xC1</td>
<td>193</td>
</tr>
<tr>
<td>D</td>
<td>0x0F</td>
<td>15</td>
</tr>
</tbody>
</table>

Applied to the bytes from the ECU, the conversion occurs:

\[
= \frac{0(\text{2}^{24}) + 160(\text{2}^{16}) + 193(\text{2}^{8}) + 15}{10} \\
= \frac{0 + 10485760 + 49408 + 15}{10} \\
= \frac{10535183}{10} \\
= 10535183 \text{ hm} \implies 105351.83 \text{ km}
\]

Service 0x02

Service 02 works the same way as 01, however in addition to the PID, the Freeze frame number is also provided, and the ECU will return the sensor reading when the Freeze Frame occurred.

Service 0x03, 0x07 and 0x0A

Services 03, 07 and 0A are all used to retrieve DTCs (Diagnostic trouble codes) that are stored on the ECU, and all function in the same manner. Service 03 is used to retrieve DTCs that are stored on the ECU (malfunctions that have occurred more than once and will result in the check engine light activating). Service 07 is used to retrieve DTCs that are pending (malfunctions that have been detected during the current/last drive cycle only, and haven't
since reoccurred). Service 0A is used to retrieve DTCs that are permanent (malfunctions that cannot be cleared with service 04 and will result in a failure in emissions test).

For all these services, no PID byte is given, and the ECU will return a list of error codes which are applicable to each service (2 bytes per DTC).

**Service 0x04**

Service 04 is used to clear any DTCs that are stored on the ECU. No PID bytes are required for this service, and the ECU does not respond back with any data. This service can only be used to clear stored and pending DTCs. Permanent DTCs cannot be cleared with this service, as they usually require the dealers specialist tool to clear.

**Service 0x05 and 0x06**

Services 05 and 06 work in identical ways, except service 05 is designed for non ISO-TP network transport layers, whereas service 06 will only be executed on ISO-TP. Both services are used to monitor oxygen sensors in the engine which is a compulsory part of most emissions tests.

**Service 0x08**

Service 08 is used to control components in the vehicle when performing tests. For example, for the duration of some tests, the tester would tell the ECU with service 08 to not log any DTCs for the duration of the test. Once the test is over, the tester will use service 08 to tell the ECU to go back to its default state and monitor components and log DTCs.

**Service 0x09**

Service 09 is used to request vehicle information from the engine ECU. This can include data such as VIN (Vehicle Identification Number), Calibration ID, Calibration verification numbers (CVN), ECU Name and more. The majority of data returned in service 09 is returned as ASCII encoded strings.

Example of requesting the VIN:

```plaintext
REQUEST : 0x09 0x02
RESPONSE : 0x49 0x02 0x01 0x57 0x43 0x43 0x31 0x30 0x31 0x30 0x30 0x38 0x32 0x42 0x32 0x37 0x33 0x39 0x32 0x32
```

Parsed VIN: **WCC1010082B273922**

### 2.3.2 KWP2000 and UDS

Keyword protocol 2000 (KWP2000 / ISO-14230-4) DaimlerChrysler (2002) is a diagnostic server protocol utilized by most vehicles from 2000, and was eventually replaced by UDS.

Unified diagnostic services (UDS) ISO (2006) is a diagnostic server protocol utilized by most vehicles from 2008. It is derived from KWP2000, thus shares a lot of similarities between KWP2000. Since most commands in UDS share the same functionality in KWP2000, refer to C.3 for a list of commands in both KWP2000 and UDS, as which ones are identical between protocols.

Both KWP2000 and UDS are both more advanced with OBD-II, relying on a diagnostic server on the ECU itself to communicate with diagnostic software over either UDS or KWP2000. The diagnostic server on the ECU can have different modes, which modify the behavior of the ECU. A default state is what the ECU is typically in on power on, then can
be modified to enter an extended diagnostic session, flash session (For firmware updates), or other protocol dependent modes. In these non-default modes, the ECU can behave unpredictably, or with reduced functionality. KWP2000 and UDS both have the ability to clear Permanent DTCs from an ECU, which OBD-II cannot do.

Both UDS and KWP2000 function over ISO-TP (2.1.2), however KWP2000 can also function on top of ISO14230-2 (2.1.3) and UDS can additionally function on DoIP (Diagnostic over IP). However, DoIP is typically only utilized during firmware updates of large ECUs such as infotainment systems in modern vehicles, which utilize a full Operating system. This dramatically reduces firmware update times from 10-12 hours (Over ISO-TP), to a few minutes (Over DoIP). This is due to DoIP using half duplex ethernet with a maximum bandwidth of 200Mbps, whilst ISO-TP is a lot slower, due to the underlying CAN network having a maximum speed of 500kbps, and also the ISO-TP protocol itself having an additional performance and bandwidth overhead.

2.4 Existing diagnostic software

In this section, the various diagnostic software available for vehicles will be discussed, ranging from basic OBD-II software to software made by the car manufacturers.

2.4.1 Torque for Android (Generic OBD)

Torque for android is an OBD-II diagnostic tool set designed for Android smartphones. It can utilize a wide range of adapters, but mainly ELM327 based bluetooth adapters, and comes in two versions. The 'Lite' edition is a free version and supports DTC Reading and clearing, and the ability to display a few Service 01 PIDs on graphs. The 'Pro' version costs £3.6 and supports everything that the Lite version does, but also includes all the Service 01 PIDs, GPS data logging and the ability to use external plugins.

2.4.2 Carly (Third party software)

Carly is a third party diagnostic mobile application. They provide specialist mobile apps for a lot of car manufactures, but also have a generic OBD-II mobile app for other car brands they don’t natively support. The Carly application is free to use, but requires their own bluetooth OBD-II adapter must be used, which costs £64.90.

For supported car manufactures, Carly supports advanced code reading (Via KWP2000 / UDS), as well as the ability to do SCN coding on select ECUs to enable or disable features on a vehicle. It also has an easy to use interface which can perform a 'used car buy check', which scans all the ECUs in a vehicle to ensure all the ECUs have the same mileage reported, to verify that they have not been tampered with.

2.4.3 Xentry (Dealer software)

Xentry diagnostic suite is Daimler’s in-house diagnostic software. It consists of two main programs, DAS (Diagnostic assist service), which is utilized on pre 2008 vehicles, and Xentry, which is utilized on all vehicles manufactured after 2008.

In terms of data formats, DAS utilizes the older CBF File format, whilst Xentry utilizes a newer binary data format called SMR-D.

Both pieces of software work in nearly the same way. When the software is connected to a vehicle via the means of a valid diagnostic adapter, the software first attempts to retrieve the vehicles VIN number, which is then used to decode what ECUs the vehicle has. With that
knowledge, the diagnostic application can then scan all the ECUs within the vehicle using the correct communication protocols and typically using KWP2000 or UDS diagnostic servers. This can be viewed in A.1.

Once the application has established contact with all the ECUs within the vehicle, the tester (The engineer who uses the software) is then free to probe each individual ECU in the vehicle in order to locate a problem (A.2). Each ECU in the vehicle has a list of adaptations and tests that can be carried out in order to test a potential problematic component. The tester is guided throughout the tests by the diagnostic software as to what to do next, for instance turning on/off the vehicle. Some tests can even be carried out by the ECU fully autonomously, with the results being displayed to the user once the test has completed.

Each ECU also has its own view dedicated to displaying a list of error codes stored on the ECU (DTCs), as well as displaying what the ECU was doing at the time of the error (Freeze Frame data). The tester can view an error as well as a full description of the error.

### 2.5 Open Diagnostics eXchange (ODX)

The Open Diagnostic eXchange format (ODX) is a way for vehicle manufactures to define an entire specification for an ECU or vehicle, which then gets distributed to both ECU manufacturers, such as Bosch or Delphi and the organizations which create commercial diagnostic software for both the OEM and third parties.

The ODX specification consists of six main categories:

<table>
<thead>
<tr>
<th>ODX-D</th>
<th>Diagnostic data</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODX-C</td>
<td>Communication parameters</td>
</tr>
<tr>
<td>ODX-V</td>
<td>Vehicle topology</td>
</tr>
<tr>
<td>ODX-F</td>
<td>Flash data container</td>
</tr>
<tr>
<td>ODX-E</td>
<td>ECU Coding data</td>
</tr>
<tr>
<td>ODX-FD</td>
<td>Mapping to functions</td>
</tr>
</tbody>
</table>

There are very few free tools which can read and interpret ODX files. Instead, companies such as Vector and Softing have commercial licensed tools that can generate ODX data files, as well other tools that can be used to test an ECU’s implementation of the ODX data.

Diagnostic software typically utilizes data from all the above ODX categories, which the OEM or diagnostic software creator will then use to compile custom binary files for their own tools based on the data from ODX. This is done so that the raw ODX data is no longer in a raw format, which can be easily understood by individuals, and also saves a lot of space compared to using the raw XML based ODX containers. An example of this proprietary binary format that will be utilized in this report is Daimler’s CBF file format.

### 2.6 The OBD-II port

The OBD-II diagnostic port is a standard connector found on all commercial vehicles since 1996. The connector is very recognizable as a female J1962 plug with 16 (2 rows of 8) pins.

The OBD-II standard dictates that the female plug must be within 2 feet of the steering wheel of the vehicle, and on the inside of the vehicle. The Standard pin out of the J1962 connector is as follows:
CHAPTER 2. LITERATURE REVIEW

However, the pin layout of this connector is modified if the plug is compliant with 13400-2, or DoIP (Diagnostic over IP). This is a recent addition, and only a few OEM’s currently use it, however it allows for a DoIP compliant diagnostics adapter to connect to the vehicle’s internal Ethernet network for performing operations such as firmware updates.

2.7 Comparisons to the proposed project

As mentioned in (2.2) and (2.4), there are multiple existing solutions for diagnostic adapters and diagnostic software for vehicles. In this section, a comparison will be made between the various adapters and existing software, also including the proposed solution for each category.

2.7.1 Hardware adapters

<table>
<thead>
<tr>
<th>Feature</th>
<th>Bosch VCI</th>
<th>Elm327</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>£500</td>
<td>£20</td>
<td>£60</td>
</tr>
<tr>
<td>OS Support</td>
<td>win32</td>
<td>Any</td>
<td>win32, OSX, Linux</td>
</tr>
<tr>
<td>J2534 API</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>D-PDU API</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>CAN</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ISO-TP</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ISO14230-2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ISO9141</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Connection method</td>
<td>USB/Ethernet</td>
<td>BT/USB</td>
<td>USB</td>
</tr>
</tbody>
</table>

Table 2.3: Comparison between existing adapters and proposed solution

As seen in the above table, the proposed adapter solution will be the only one which can support the J2534 API on all desktop operating systems. One thing to note about the ELM327 column. As discussed in (2.2.2), there can be many clone adapters, which won’t support all the transport protocols such as ISO-TP, instead, only supporting ISO9141 so that they can be used with mobile applications such as Torque.
2.7.2 Diagnostic software

<table>
<thead>
<tr>
<th>Feature</th>
<th>Xentry (Dealer)</th>
<th>Carly (Third party)</th>
<th>Torque (OBD)</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Unknown</td>
<td>£69 (With adapter)</td>
<td>£3</td>
<td>Free</td>
</tr>
<tr>
<td>OS Support</td>
<td>Win32</td>
<td>Mobile</td>
<td>Mobile</td>
<td>Win32,OSX,Linux</td>
</tr>
<tr>
<td>J2534 API</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>SocketCAN</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Future</td>
</tr>
<tr>
<td>D-PDU API</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Future</td>
</tr>
<tr>
<td>OBD-II support</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>KWP2000 support</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>UDS support</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Clear permanent DTCs</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Communicate with all</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>ECU in a vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live data reading</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (OBD only)</td>
<td>Yes</td>
</tr>
<tr>
<td>ECU test execution</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2.4: Comparison between existing diagnostic software and proposed solution

As seen in this table, the proposed solution will be the only one which can support Linux and OSX. Also, SocketCAN and D-PDU are proposed as future additions to the application, but for the current scope, they will not be included due to time constraints.
Chapter 3

Methodology

This section will cover the design and implementation of all 3 parts of the project, referencing content discussed in the literature review. Each part is broken down into its design, implementation and justification.

3.1 Test setup

Prior to designing and implementing any parts of the solution, it was clear that a permanent test setup would be needed to test with, in order to avoid the risk of accidentally damaging something in a real vehicle. Therefore, it was decided to use the following test ECUs on a desk to form a simulated setup of a real vehicle. In this case, the following ECUs were used which can replicate part of a Mercedes W203.

<table>
<thead>
<tr>
<th>ECU Name</th>
<th>Description</th>
<th>CAN C</th>
<th>CAN B</th>
<th>K-Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC203</td>
<td>Instrument cluster</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>CRD</td>
<td>Engine ECU</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>EGS52</td>
<td>Transmission controller</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 3.1: ECU List in the desk test setup

In this test setup, the 'Gateway' is simply An arduino with 2 CAN interfaces on it. Its job is to relay CAN Frames to and from the CAN C Network (Black) and the CAN B network (Orange). This is because for diagnostics, the cluster only responds if the diagnostic packets are sent over CAN B, and not CAN C. In a real vehicle, this functionality is usually handled by the ignition switch ECU which acts as a CAN Gateway. However, this could not be purchased for this setup due to its cost.
CHAPTER 3. METHODOLOGY

3.2 Rust

As part of this project, the Rust programming language was utilized rather than other languages such as C++ or Java for the majority of the development process, however C++ had to be used for the Passthru adapter firmware [3.4], due to limitations with the standard Arduino libraries. Rust has some unique advantages compared to other languages, to name a few:

- Thread and memory safety guaranteed at compile time
- Easy dependency management with Cargo
- Easy cross-compilation support
- Bare-metal performance (Unlike JVM based languages)

However, at the time of writing this, Rust does have bindings for platform GUI library’s, such as QT, GTK and WINAPI, but not have a mature cross-platform GUI library, which would be required for the Diagnostic application, as will be mentioned in section 3.5. However, an experimental cross-platform library called Iced [https://github.com/hecrj/iced] does exist. This GUI library supports all three major operating systems (Linux, Windows and MacOS), as well as the Web for WASM build targets. Everything in this library is drawn to the screen using either Vulkan, OpenGL, Metal or DX11 depending on the platform.

Iced is inspired by the Elm Architecture, meaning that the GUI is built in pure code, rather than having external XML files to describe the UI. Also due to it being inspired by Elm, the GUI architecture is split into four main components. Application state, message events within the UI, view logic and update logic.

3.3 JSON schema creation and CBF parsing

As mentioned in 1, this section will cover the creation of OpenVehicleDiag’s JSON Schema which is used as a easy-to-read replacement for ODX-D [2.5].

3.3.1 JSON structure

Since Rust has an excellent JSON Serialization with Serde [https://serde.rs/], the following UML class diagrams will show the design of the underlying structs used in the application. This then gets serialized into JSON by Serde. A full JSON Schema is available in section E, as well a full example of the JSON in section C.4.

Since it is almost guaranteed that the data will be similar, or at least comparable to what is found in ODX-D [2.5], [emotive de (2014b)] and [emotive de (2014a)] were used as references when designing the JSON structure, which heavily document the various data types and presentation formats found in ODX files.
**CHAPTER 3. METHODOLOGY**

Figure 3.2: UML representation of ovdECU Root object, ECUVariantDefinition and Connection properties

Figure 3.3: UML representation of JSON Service and ECUDTC
Figure 3.2 shows the root object UML representation, as well as connection properties and the main object for storing a ECU Variant object.

**OvdECU** is the root structure of the JSON. This contains the name of the ECU, a description of the ECU, connection properties of the ECU, and all ECU Variants. A ECU must have at least 1 Connection method and at least VariantDefinition.

**Connection** is used to define what transport and diagnostic protocols are used when communicating with the ECU. This contains data such as the bus speed (baud) of the connection method as well as various ID’s to use whilst in a diagnostic session. An ECU can have multiple connection methods, such as KWP2000 over ISO-TP (CAN), or KWP2000 over K-Line (ISO 14230-2). In either configuration, the ECU’s addresses will differ. send_id is used to identify which ID on either network type the tester should send diagnostic messages on. recv_id denotes which ID the ECU will respond on, and the tester will listen for data with this ID. global_send_id is an optional entry, and is only used for some ECUs. This value is required in situations where the TesterPresent message is to be broadcast on a separate address to the diagnostic request message (Normally they are the same address). In the case of my test vehicle, this is used for all interior CAN devices located on CAN-B.

**ConType** represents an interface for each physical network connection method to inherit, with various attributes related to the network setup. For instance, ISO-TP configuration requires attributes attaining to block size, default separation time, and extended addressing, whilst the LIN connection (K-Line) requires a maximum packet size that the ECU supports, as well as which wake up method to use when activating the K-Line network.

**ECUVariantDefinition** contains the definition for each ECU Variant. A ECU Variant is an equivalent to a software version on a desktop PC. An ECU can receive updates over time (via firmware flashes). With each firmware update, diagnostic routines can be altered, as well as lists of errors, or even in some cases, the description of certain errors changes from variant to variant. Each ECU Variant can be implemented by multiple hardware manufactures.
such as Bosch or Delphi. Because of this, the ECUVariantPattern class is required here. This small class contains the name of the manufacture (Vendor), as well as a defined vendor ID. This vendor ID can be retrieved over both KWP2000 and UDS, and is unique to the software version and ECU manufacturer.

Figure 3.3 shows how both Service and ECUDTC both use the Parameter object.

**Service** represents an IO function that can be executed on the ECU. Each function requires a name, description of what the function does, a raw payload to send to the ECU, and a list of input and/or output parameters. Input parameters modify the payload that is sent to the ECU, whilst output parameters are used to convert the ECU’s response message into something that can be easily interpreted by an individual.

**ECUDTC** represents a Diagnostic trouble code (DTC) that can be stored on the ECU. Each DTC has a unique name, such as ‘P202A’, a summary of what the error means, and a more detailed description string of what the error means. The envs array is a list of parameters that are used when querying freeze frame data about the DTC, which is then interpreted using the list of parameters to decode the freeze frame data into something that is human readable. Freeze frame data can be acquired with both KWP2000 and UDS.

**Parameter** contains data which has been interpreted from the ODX-D data structure [emotive de (2014a)]. Each parameter contains a name which denotes what the parameter means, as well as an optional unit, which can be used to denote the unit of the parameter, such as °C or Engine RPM. start_bit denotes where in the payload the parameter starts at, and length_bits denotes how big the parameter is in bits. This is because the ECU response message can contain values that are tightly packed, and at odd bit offsets. data_format denotes which Data format interpreter to use for the raw data within the given bit range. Lastly, valid_bounds is an optional class which can be specified. If it is declared in a Parameter which is stored in a parent services’ input_parameters section, then it is used to check the user input is within range. If it is stored in a parameter which lies within a parent services’ output_parameters section, then it used to set the upper and lower bounds for graphing. Note that valid_bounds is ignored if it is specified in a parameter which cannot be converted to a number data type.

Figure 3.4 Shows the classes which inherit the DataFormat interface. Classes that appear in blue exist in code as a placeholder, and do not do anything at this time. They are derived from the ODX-D specification.

**Bool** data format is used when the parent parameter shall be interpreted as a boolean. This class has two optional parameters, which can be used to override the default ‘True’, ‘False’ interpretation of booleans. This data type can be used for graphing.

**Linear** format is used when a raw value is to be manipulated using a simple \( y = mx + c \) equation. The input value is \( x \), whilst ‘multiplier’ represents \( m \), and ‘offset’ represents \( c \). This data format can be used for graphing.

**String** format is used when the parent parameters byte range is to be interpreted as a raw string. This data format has a parameter (encoding), which denotes what text encoding to use when encoding and decoding the string. This can either be ASCII, Utf8 or Utf16. This data type cannot be used for graphing.

**Binary** format is used when the parent parameter shall be interpreted as a binary string, such as ‘0b00110011’. It should be noted that this data type is not in the ODX-D specification, but was added at a later date due to finding that Daimler seemed to use Enum tables to represent binary strings in their CBF files, meaning that an 8 byte parameter would have
256 enum entries! This data type cannot be graphed.

**HexDump** format simply returns a formatted string of the bytes within the parent parameters bit range.

**Identical** format is used for when the raw bytes of the parent parameter is to be interpreted as a 32bit integer and returned as is without any manipulation such as with the Linear data type. The parent parameter’s byte_order will specify how to interpret the bytes which make up the integer. This data type can be graphed.

**Table** format is used for representing enum values. This means that a number value or range is mapped to a string. This data type takes a compulsory list of more than 1 TableData entries. Each entry consists of a minimum (inclusive) and maximum (inclusive) value, as well as the definition string. A number range is used here rather than a one to one mapping since this is what the ODX-D specification states. This data type cannot be graphed.

### 3.3.2 Code implementation of the JSON Schema

To translate the UML diagrams to code was a very simple process. Below is the code implementation of the OvdECU Struct:

```rust
#[derive(Debug, Clone, Serialize, Deserialize)]
pub struct OvdECU {
    pub name: String,
    pub description: String,
    pub variants: Vec<ECUVariantDefinition>,
    pub connections: Vec<Connection>
}
```

On line 1, the `#[derive]` attribute tells the compiler to implement traits for the Struct at compile time. Serialize, Deserialize are traits that come from the Serde library, and will enable this Struct to be serialized and deserialized to and from JSON without any additional code needing to be written.

Looking at the Service Struct, the implementation in code is a bit more complicated:

```rust
#[derive(Debug, Clone, Serialize, Deserialize, PartialEq)]
pub struct Service {
    pub name: String,
    pub description: String,
    #[serde(as = "serde_with::hex::Hex<serde_with::formats::Uppercase>")]
    pub payload: Vec<u8>,
    #[serde(skip_serializing_if = "Vec::is_empty")]
    #[serde(default = "Vec::new")]
    pub input_params: Vec<Parameter>,
    #[serde(skip_serializing_if = "Vec::is_empty")]
    #[serde(default = "Vec::new")]
    pub output_params: Vec<Parameter>
}
```

In this structure, there are few more additional tags that are used by Serde. `skip_serializing_if` is used to tell Serde to skip Serialization if a condition is met for the value. In this case, if the Vector is empty, Serialization is skipped in order to reduce the Serialized file size. `default` tells Serde what to do if the value is not found in JSON when deserializing. In this case, replace the value with an empty vector. Lastly, the `serde_as` online 6 tells Serde to serialize the payload as an upper case Hex String. This because by default Serde will serialize the payload as a list of numbers, which get re-interpreted as bytes during deserialization. This was not optimal as both KWP2000 and UDS use Hex bytes in documentation rather than numbers. Therefore, this tells Serde to strictly serialize the payload as a hex string, which is more easily understood by people reading the file.
Implementing Parameter functions

As shown in figure 3.3, the Parameter object has functions that are used to decode the parameter to either string or integer. This is then used by any application which utilizes the JSON Schema to decode an ECU byte stream. The following Matrix denotes which function is supported by which internal DataFormat (Figure 3.4):

<table>
<thead>
<tr>
<th>Data format name</th>
<th>Format as string?</th>
<th>Format as number?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HexDump</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Binary</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>String</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bool</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Table</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Identical</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Linear</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 3.2: Supported format options for DataFormat

If decode_value_to_number() is called on a Parameter which cannot be encoded as a number (such as String), then an Error of type DecodeNotSupported is returned from the function. This table also shows that decode_value_to_string() is supported by every data format type.

Both functions work in the same manner. They take a byte stream, which is the ECU response message to a command, and extract bytes within a specific byte range, then process the bytes. In the event that the parameter bit range lies outside the ECU response message (For example, receiving a message of length 120 bits, but the parameter specified a start bit of 150), the an Error of type BitRangeError is returned.

If either decoder expects its data type to be a number, then get_number() is called, which can at most return a 32bit long number. This seemingly arbitrary restriction of 32bits is due to after extensive testing, all ECUs seem to only handle 32bit numbers and nothing more. This restriction can be increased to 64bits with a simple addition to the codebase.

```rust
fn get_number(&self, resp: &[u8]) -> std::result::Result<u32, ParamDecodeError> {  if self.length_bits < 32 {  let result = std::panic::catch_unwind(|| {  resp.get_bits(self.start_bit..self.start_bit+self.length_bits) as u32  })  } else {  let mut res = 0;  let mut buf = Vec::new();  let mut start = self.start_bit;  while start < self.length_bits + self.start_bit {  let max_read = min(self.start_bit + self.length_bits, start + 8);  let mut res = match self.byte_order {  ParamByteOrder::BigEndian => BigEndian::read_u32(&buf),  ParamByteOrder::LittleEndian => LittleEndian::read_u32(&buf)  };  if buf.len() >= 4 {  panic!("Number too big!") // Cannot handle more than 32bits atm  } else {  if buf.len() >= 2 {  res = match self.byte_order {  ParamByteOrder::BigEndian => BigEndian::read_u16(&buf) as u32,  ParamByteOrder::LittleEndian => LittleEndian::read_u16(&buf) as u32  };  } else {  res = u32  }  }  buf.push(resp.get_bits(start..max_read));  start += 8;  }  buf.push(resp.get_bits(start..max_read));  start += 8;  }  if buf.len() > 4 {  panic!("Number too big!") // Cannot handle more than 32bits atm  } else {  if buf.len() >= 2 {  res = match self.byte_order {  ParamByteOrder::BigEndian => BigEndian::read_u16(&buf) as u32,  ParamByteOrder::LittleEndian => LittleEndian::read_u16(&buf) as u32  };  } else {  res = u32  }  }  return std::result::Result::new(res);  }
```
This function essentially extracts a 1-32bit long number from the input byte stream, using the Parameters start bit and length bits values to work out where to extract the number in the input array. As seen in this code, it also takes into account the Endianness of the expected value.

When decoding a value to String, each DataFormat has its own parser function that runs on the input byte stream. Below is a couple examples:

```rust
DataFormat::Bool { pos_name, neg_name } => {
    return match self.get_number(input)? {
        0 => Ok(neg_name.clone().unwrap_or("False".into())),
        _ => Ok(pos_name.clone().unwrap_or("True".into()))
    }
},
```

As seen here, both Bool and HexDump return early with their formatted Strings, whilst Linear doesn’t return early, this is because it is a number and therefore might have a unit associated with it. Further down the decoder there is a check for this, and if a unit exits, it is appended to the ‘result’ string, before being returned.

### 3.3.3 Parsing Daimler CBF Files to JSON

For this section, CaesarSuite [https://github.com/jglim/CaesarSuite/](https://github.com/jglim/CaesarSuite/) was heavily used as a reference on how to extract data from Daimlers CBF Files. CaesarSuites creator (JinGen Lim) has spent countless hours reverse engineering `c32s.dll`, which is a DLL file which ships with Daimler’s diagnostic tool set, and is responsible for loading CBF files amongst other things.

After re-writing the majority of the CBF Parser code found in CaesarSuite to Rust (CBF-Parser), the codebase now had to convert between Daimler’s CBF representation structures to the JSON Schema structure. This proved to be a challenge since the data structures are completely different. Below is the UML representation of a CBF File, without any field values:
As shown in figure 3.5, a CBF File has a completely different data structure when compared to the JSON Schema. To solve this, a parser script was written to process the root Container and convert this data structure to the JSON structures. This will be very briefly touched upon here, since the code to convert to the JSON schema is far too long.

As an example, here is the code which converts the ComParameter’s found in InterfaceSubType to a Connection property for the JSON:

```rust
let mut connections = Vec::new();
for x in e.interface_sub_types.iter() {
    let connection = if x.com_params.iter().any(|x| x.param_name == "CP_REQUEST_CANIDENTIFIER") {
        // ISOTP
        Connection {
            baud: x.get_cp_by_name("CP_BAUDRATE").expect("No CAN Baudrate on interface!")!
            send_id: x.get_cp_by_name("CP_REQUEST_CANIDENTIFIER").expect("No CAN ReqID on interface!")!
            global_send_id: x.get_cp_by_name("CP_GLOBAL_REQUEST_CANIDENTIFIER").unwrap_or(20).
            connection_type: ConType::ISOTP { blocksize: 8, // Some reason MB always uses 8
                st_min: x.get_cp_by_name("CP_STMIN_SUG").unwrap_or(20).unwrap() > 0x7FF // Seems default for MB
                ext_isotp_addr: false, // MB never use extended ISO−TP addressing
                ext_can_addr: x.get_cp_by_name("CP_REQUEST_CANIDENTIFIER").unwrap() > 0x7FF
            },
            server_type: if x.qualifier.contains("UDS") {
                // Interface type is in qualifier name for ISO−TP
                ServerType::UDS
            } else { // Assume LIN (ISO14230−2)
                ServerType::KWP2000
            }
        }
    } else {
        // Assume LIN (ISO14230−2)
        Connection {
            baud: 10400, // Always for ISO14230−2 with MB
            send_id: x.get_cp_by_name("CP_REQTARGETBYTE").expect("No LIN Request ID on interface!")!
            recv_id: x.get_cp_by_name("CP_RESPONSEMASTER").expect("No LIN Response ID on interface!")!
            global_send_id: x.get_cp_by_name("CP_TESTERPRESENTADDRESS").unwrap_or(254) // Default for ISO14230−2
            connection_type: ConType::LIN {
                wake_up_method: LinWakeUpType::FiveBaudInit, // MB always uses this with ISO14230−2
            },
            server_type: ServerType::KWP2000 // Always with LIN
        };
        connections.push(connection);}
    }
}
```

What this code does is iterate over each of the CBF’s InterfaceSubTypes, which represents
a connection method for the ECU, and try to work out what kind of connection it is based on the ComParameters found in the InterfaceSubType, then mapping the ComParameters to data in the Connection object for the JSON Schema.

The name of the ComParameters (EG: `CP_BAUDRATE`) are all found within the ODX specification, so it is simple to know what they do. Also to note is that especially for a LIN connection type, there is a lot of assumptions about what Mercedes utilizes. This was done by looking at how Daimler's own software tries to initialize contact with an ECU using ISO14230-2 for over 50 different ECUs in various cars that supported ISO1423-4.

**CBF parser optimizations**

After processing many CBF files, it was noticed that CBF files seem to contain many Services with the same request payload, and only the output_params would vary. This significantly increased the size of the output JSON file. An example of this behavior is shown below from parsing the CRD ECU’s CBF file:

```json
"downloads": [
  {
    "name": "DT IOC0 Dip spy cata temp nvv 5",
    "description": "cata temperature in regeneration [5]: 610 C",
    "payload": "30C01",
    "output_params": [
      {
        "name": "CRD. PRES_Conversion 52 Status",
        "unit": "",
        "start_bit": 2024,
        "length_bits": 16,
        "bytes_order": "BigEndian",
        "data_format": {
          "Linear": {
            "multiplier": 1.0,
            "offset": 0.0
          }
        }
      }
    ]
  },
  {
    "name": "DT IOC0 Dip spy cata temp nvv 6",
    "description": "cata temperature in regeneration [6]: 620 C",
    "payload": "30C01",
    "output_params": [
      {
        "name": "CRD. PRES_Conversion 52 Status",
        "unit": "",
        "start_bit": 2040,
        "length_bits": 16,
        "bytes_order": "BigEndian",
        "data_format": {
          "Linear": {
            "multiplier": 1.0,
            "offset": 0.0
          }
        }
      }
    ]
  }
]
```

This is just one example. The CRD ECU in total has over 3500 services that look like this. By grouping services' output_params together based on the request payload, it was possible to significantly reduce the file size of the output JSON. Below is the same service's grouped together:

```json
"downloads": [
  {
    "name": "DT IOC0 Dip spy cata temp nvv 5",
    "description": "Data download 30 C0",
    "payload": "30C01",
    "output_params": [
      {
        "name": "counter for the conditions at the end of the regeneration [0]",
        "unit": "",
        "start_bit": 56,
        "length_bits": 16,
        "bytes_order": "BigEndian",
        "data_format": {
        }
      }
    ]
  }
]
```
The only downside to this approach is that the name and description of the parent service is now a generic name, since the name is now no longer known. However, this is not a problem as shown in section 3.5, the GUI for interfacing with this generated JSON will search both input and output parameters for a user’s search terms, meaning that the parent service name doesn’t have to be descriptive. Also, by doing this the file size of the output JSON shrunk by approximately 15%, which in turn decreases parse times and load times in OpenVehicleDiag.

3.4 Cross platform Passthru adapter

The Macchina M2 Under-the-dash adapter was chosen for this task, primarily due to the following reasons:

- Open source hardware schematics available on Github
- Excellent support with library authors
- Built on a mature platform based on hardware found in the Arduino Due
- Can be easily programmed using existing tools designed for Arduino based devices such as Arduino IDE or VSCode
- Native USB support - Data transfers over a USB cable can occur at much higher speeds when compared to other Arduino based solutions that require a USB to Serial converter chip. This is a feature of the AT91SAM3X8E CPU rather than an explicit feature of this OBD-II adapter.
- Supports all of the necessary interfaces for the J2534 API (CAN, LIN, J1850, SCI)
- Reasonably priced at $99 - Which is a lot cheaper compared to a lot of alternative J2534 devices as discussed in section 2.2

![Figure 3.6: Macchina’s M2 Under the dash OBD-II module](image)
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(a) Processor board  (b) Interface board

Figure 3.7: Macchina M2 board layouts

The SAE J2534 reference manual [Drew Technologies, Inc (2003)] was used as a reference for the API implementation. Specifically, this will be an implementation of V04.04 of the Passthru API. Due to the short time constraints of this project, Only CAN and ISO-TP will be implemented.

3.4.1 Architecture

In order to reliably allow the J2534 library and adapter to communicate, the architecture of the communication between the adapter and J2534 library will revolve around Request and Response messages. This can be executed without overly complex code since the J2534 API states the the API is designed to be single threaded, meaning that any application that utilizes the J2534 API will not be making asynchronous calls to the library.

The above figure shows how communication between the library and adapter itself will be handled. The library will contain various functions for tasks like channel creation or transmitting data, and they will construct Payloads to send to the adapter. These payloads are forwarded to a communication server which is part of the library, and sends the payload as a byte stream to the adapter. The adapter will execute what the payload specifies, and then return a response message to indicate if the action completed successfully, or failed (Which will contain the error message). This response is then forwarded back to the caller library function.

Since the M2 has 5 LED’s and an additional RGB LED, it was decided to utilize these LEDs so the user knows what is going on without the need to check log files:

---

1 List of Passthru API functions: C.1
### 3.4.2 Creating the driver in Rust

Firstly, the J2534 library had to be ported to Rust from C++. This means converting the definitions found in the J2534 API [Comer352L (2019)], to something that Rust's type system can work with more easily. As part of this conversion process. Most of the define's found in the J2534 header file were converted to enum decelerations in Rust.

Below is an example of the protocols' section of J2534.h:

```plaintext
1 // Protocols:
2 #define J1850VPW 0x01
3 #define J1850PWM 0x02
4 #define ISO9141 0x03
5 #define ISO14230 0x04
6 #define CAN 0x05
7 #define ISO15765 0x06
8 #define SCI_A_ENGINE 0x07
9 #define SCI_A_TRANS 0x08
10 #define SCI_B_ENGINE 0x09
11 #define SCI_B_TRANS 0x0A
```

and here is how that is translated into an enum structure in Rust:

```rust
1 // [repr(u32)]
2 // [derive(Debug, Copy, Clone, FromPrimitive, Deserialize, Serialize)]
3 // [allow(non_camel_case_types, dead_code)]
4 pub enum Protocol {
5     J1850VPW = 0x01,
6     J1850PWM = 0x02,
7     ISO9141 = 0x03,
8     ISO14230 = 0x04,
9     CAN = 0x05,
10    ISO15765 = 0x06,
11    SCI_A_ENGINE = 0x07,
12    SCI_A_TRANS = 0x08,
13    SCI_B_ENGINE = 0x09,
14    SCI_B_TRANS = 0x0A,
15 }
```

and here is an example of how the Passthru function calls are converted from C++ to Rust:

```c
1 #if defined __WIN32__
2 # define APICALL __stdcall
3 # else
4 # define APICALL
5 # endif
6 ...
7 typedef long APICALL (*J2534_PassThruWriteMsgs)(unsigned long ChannelID,
8 PASSTHRU_MSG *pMsg, unsigned long *pNumMsgs, unsigned long Timeout);
9 ...
```

and here the function is declared in Rust:
The \texttt{\#[no_mangle]} macro tells Rust’s compiler to not mangle or modify the function name, but to keep it as is in order for the function to be exposed as part of a library and for it to be callable by external applications.

**Windows ordinals**

During testing, it was found that some applications such as Daimler’s DAS software would call the PassThru API functions by their ordinal numbers rather than function name. An ordinal is a unique ID assigned to a function. Since Rust’s compiler assigns a random ordinal number to each function by default, this would cause the custom PassThru library to not load, since the ordinal numbers did not match to the correct PassThru function. Therefore, a fix was to utilize a .def file with Windows’ MSVC compiler in order to force Rust to assign the correct ordinal number to each function in the PassThru library:

```
LIBRARY
EXPORTS
PassThruOpen 01
PassThruClose 02
PassThruConnect 03
PassThruDisconnect 04
PassThruReadMsgs 05
PassThruWriteMsgs 06
PassThruStartPeriodicMsg 07
PassThruStopPeriodicMsg 08
PassThruStartMsgFilter 09
PassThruStopMsgFilter 10
PassThruSetProgrammingVoltage 11
PassThruReadVersion 12
PassThruGetLastError 13
PassThruIoctl 14
```

Then, using a custom build.rs file (Which gets executed by the compiler), it’s possible to tell the compiler to use the .def file during the compile process, but only under Windows:

```
use std::env;
fn main() {
    let target_os = env::var("CARGO_CFG_TARGET_OS");
    match target_os.as_ref().map(|x| &**x) {
        Ok("macos") | Ok("linux") => {}
        Ok("windows") => println!("cargo:rustc-cdylib-link-arg=-DEF:driver.def"),
        _ => panic!("unknown target os {:?}!", tos),
    }
}
```

### 3.4.3 Communication between the adapter and driver

As mentioned in section 3.4, the Macchina M2 utilizes native USB in order to send and receive data, rather than an onboard UART to USB converter. The Serial functionality is instead provided by a virtual serial port driver. The Serialport-Rs library\footnote{https://gitlab.com/susurrus/serialport-rs} provides an easy to use, cross platform Rust library for serial communication. Although there were initial issues with
the serial communication API under Windows\textsuperscript{3}, the library was able to function as expected and transfer data between the M2 and a PC, regardless of the operating system.

The following data structure was defined on both the firmware and Rust library, in order for both ends to send and receive data correctly. Below is the C++ definition in the adapter firmware:

\begin{verbatim}
#define COMM_MSG_SIZE 4096
#define COMM_MSG_ARG_SIZE COMM_MSG_SIZE -4

struct __attribute__ ((packed)) COMM_MSG {
    uint8_t msg_id;
    uint8_t msg_type;
    uint16_t arg_size;
    uint8_t args[COMM_MSG_ARG_SIZE];
};
\end{verbatim}

The attributes in the message are used as follows:

1. **msg_id** - Unique identifier of the message. This ID will keep repeating in the range of 1-254, (0x01-0xFF), and is used by the PC and Firmware to identify a response message to a requested command. Each request and response message will have the same ID. Messages that do not require a response will have a message ID of 0x00.

2. **msg_type** - A byte which identifies what kind of message is being sent by either the adapter of PC driver. See section C.2 for a full list of the message types and what they signify, as well as which end sends and receives them.

3. **arg_size** - A 2 byte value indicating how long the parameters of the message are which reside in **args**

4. **args** - The parameters or payload of the message itself.

**Communication server**

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{sequence_diagram}
\caption{Expanded sequence diagram of communication server}
\end{figure}

\textsuperscript{3}See B.1.1
Figure 3.8 shows an expanded view of the communication server sequence diagram. The 'server' endpoint is the interface other functions in the Passthru library can call to send messages to the Adapter. A sent message is sent to the server’s sender thread, which then attempts to send the payload to the adapter. A maximum of 3 attempts are used to try and send the payload. If all 3 attempts fail, a Tx Fail status is sent back to the caller function, which then handles the appropriate action, as it assumes that the adapter is not connected to the PC. If payload sending was completed successfully, a Tx OK message is sent back to the caller function. In this event, the caller will now poll for a maximum of 2 seconds for a response message. Constantly in the background, there is the poller thread, which constantly polls the serial port for new bytes, reading them in order to ensure the serial port’s buffer is not full (Linux has a maximum serial buffer size of 4096 bytes whereas Windows’ is 16384 bytes). When a full payload is received by the poller thread, the response message is sent back to the sender via a thread channel. If the incoming message is a log message (See below), the poller instead logs the message to the libraries log file. In order to ensure the sender and receiver message are for the same operation, the server checks the message ID, which is unique to each IO operation which requires a response. If a response is not received in 2 seconds, the server terminates and returns a Timeout error back to the caller function. This Timeout is also sent back to the poller thread, which will then discard the received message if it does eventually get read. A timeout of 2 seconds is considered adequate as during testing, all commands usually get executed within 10ms.

### 3.4.4 Reading battery voltage

In order to read the battery voltage of the M2, there is a library called M2_12VIO\(^4\) that can be used to read the voltage on pin 16 of the OBD-II connector, which connects directly to the car’s battery. However, this library is slightly inaccurate as the below table shows:

<table>
<thead>
<tr>
<th>PSU Voltage V</th>
<th>Reported voltage V</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2 (Stock)</td>
<td>6.1V</td>
</tr>
<tr>
<td>Multimeter</td>
<td>6.1V</td>
</tr>
<tr>
<td>M2 (Corrected)</td>
<td>6.1V</td>
</tr>
</tbody>
</table>

![Figure 3.9: Voltage reading comparison between M2 (Stock and corrected) and Multimeter](image)

As figure 3.9 shows, the reported voltage by the M2_12VIO library seems to level out at 6.1V, even if the actual supply voltage is lower than 6.1V. Therefore, the adapter firmware

\(^4\)https://github.com/TDoust/M2_12VIO
(Black line) will cut off the voltage, interpreting any value less or equal to 6.1V as 0.0V. This way, when the adapter is unplugged from the vehicle, it will report 0V rather than 6.1V, which makes more sense.

3.4.5 ISO-TP Communication

![Sequence diagram for sending ISO-TP Data to an ECU](diagram.png)

When transmitting ISO-TP data to an ECU, PassthruConnect is first called. This tells the adapter to open an ISO-TP Communication channel, with a specified baud rate, and also indications as to whether the CAN Network uses extended addressing or if ISO-TP uses extended addressing.

Then StartMsgFilter is called, this tells the adapter to apply 3 filters. Pattern and Mask (which are both applied to listen to a specific CAN ID), and the Flow control filter. This filter is only used for ISO-TP and contains the CAN ID to transmit data on back to the ECU.

After this, PassthruWriteMsgs is called, where the application tries to transmit data to the ECU. This payload can be up to 4096 bytes long. The adapter receives this payload and sends the ISO-TP First frame to the ECU, initiating the data transfer.

The ECU then responds back with a flow control frame. The adapter reads this, and applies the necessary block size and separation time, before transmitting ISO-TP consecutive frames to the ECU.

Once the transmission is complete, the adapter sends a message back to the Passthru library to indicate the data transfer is now complete. During the entire data transfer process, the Application has been polling the Passthru library for new data. When the data transfer
is complete, a blank message is returned to the Application, with the TX_MSG_TYPE bit set to 1, indicating data transfer complete.

![Sequence diagram for receiving ISO-TP Data from an ECU](image)

When receiving data from an ECU, PassthruConnect and StartMsgFilter are called just like when transmitting data. Once the filters have been applied, the adapter can listen to incoming data from the ECU.

When adapter receives a first frame indication from an ECU, it sends a flow control frame back to the ECU, initiating the rest of the data transfer. At the same time, the adapter sends a message to the Passthru library which contains the CAN ID of the sending ECU with the ISO15765_FIRSTF bit set. This message is then read by the user application and it will then begin polling for the full payload.

Upon receiving the flow control frame from the adapter, the ECU then sends all the consecutive CAN Frames which make up the full payload. Once the adapter verifies it has all the data, it sends the full payload back to the Passthru library, which is then read by the user application.

3.4.6 Porting the Passthru API to Linux and OSX

In order to port the J2534 API to Linux and OSX, 2 potential issues has to be overcome:

1. Mac OS X has a very tight security policy forbidding modification to its root filesystem.
   This means that a user cannot simply copy the library file to a directory like `/usr/share/`

2. Mac OS X and Linux have no equivalent to the Windows registry system
To work around the issue mentioned in 1, it was decided that the J2434 library driver and info
data should reside in ~/.passthru/. This is because on both Linux and OSX, writing to the
users home directory (~/) does not require any elevated privileges.

To mitigate the section issue mentioned 2, it was decided the best approach would be to
create a JSON file containing the attribute data defined in the J2534 API:

```json
{
  "CAN": true,
  "ISO15765": true,
  "ISO9141": true,
  "ISO14230": true,
  "SCI_A_TRANS": true,
  "SCI_A_ENGINE": true,
  "SCI_B_TRANS": false,
  "SCI_B_ENGINE": false,
  "J1850VPW": false,
  "J1850PWM": false,
  "FUNCTION_LIB": "~/passthru/macchina.so",
  "NAME": "Macchina M2 Under the dash",
  "VENDOR": "rnd-ash@github.com",
  "COM-PORT": "/dev/ttyACM0"
}
```

This means that every potential J2534 device would have its own JSON file stored in ~/passthru/. The above example being ~/passthru/macchinam2.json for the created Macchina M2 driver.

Every key name within this JSON is an exact copy of the key names found in the official J2534 specification for the Windows Registry.

From within the passthru library code itself, fetching the COM-PORT attribute now requires 2 code bases, one for Windows to locate the registry key within the Registry, and another for UNIX OS’s to read the JSON file and find the COM-PORT attribute.

This was done with the conditional compilation flags on the library code to generate 2 versions of the get_com_port function, based on the compile target:

```rust
#[cfg(windows)]
fn get_com_port() -> Option<String> {
    if let Ok(reg) = RegKey::predef(HKEY_LOCAL_MACHINE).open_subkey("SOFTWARE\\\WOW6432Node\\PassThruSupport.04.04\\Macchina-Passthru") {
        return match reg.get_value("COM-PORT") {
            Ok(s) => Some(s),
            Err(_) => None
        }
    }
    None
}

#[cfg(unix)]
fn get_com_port() -> Option<String> {
    if let Ok(content) = std::fs::read_to_string(shellexpand::tilde("~/passthru/macchina.json").to_string()) {
        return match serde_json::from_str::<serde_json::Value>(content.as_str()) {
            Ok(v) => v["COM-PORT"].as_str().map(String::from),
            Err(_) => None
        }
    }
    None
}
```

Both functions work in the same way. They try to locate the COM-PORT key and read it. If the value was successfully read, then the COM-PORT value is returned, if it wasn’t found, None is returned.
3.4.7 Logging activity

In order to aid debugging, log messages generated by either the M2 itself or passthru library are saved to a log file. On Linux, this Log file exists in `~/.passthru/macchina_log.txt` and on Windows it exists in `C:\Program Files (x86)\macchina\passthru\macchina_log.txt`.

Each log message generated has a unique tag:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[DEBUG]</td>
<td>Messages for debugging only. These messages do not appear in release builds of the driver.</td>
</tr>
<tr>
<td>[ERROR]</td>
<td>Error messages, something has gone terribly wrong and the Passthru adapter cannot continue functioning.</td>
</tr>
<tr>
<td>[WARN ]</td>
<td>An error has occurred somewhere, but the adapter can continue to function.</td>
</tr>
<tr>
<td>[INFO ]</td>
<td>Info messages that can track what the adapter is doing.</td>
</tr>
<tr>
<td>[M2LOG]</td>
<td>Messages that originate from the adapter itself.</td>
</tr>
</tbody>
</table>

The generated log file has a dual purpose. It aids debugging of the library when used by an external application, but also shows in detail what the adapter is doing with regards to setting up CAN and ISO-TP channels, which can aid reverse engineering by snooping what a diagnostic application is requesting an adapter to listen for. An example of some log messages:

1 \[INFO\] — PassthruOpen called
2 \[DEBUG\] — M2 serial writer thread starting!
3 \[DEBUG\] — M2 channel sender thread starting!
4 \[DEBUG\] — M2 serial reader thread starting!
5 \[DEBUG\] — Requesting channel open, ID: 0, Protocol: ISO15765, baud: 83333, flags: 0x0000
6 \[M2LOG\] — Standard CAN detected!
7 \[M2LOG\] — Normal ISO-TP Addressing detected!
8 \[DEBUG\] — Command took 15544 us to execute
9 \[DEBUG\] — M2 opened channel!
10 \[DEBUG\] — Filter specified. Type: Mask filter, Data: [0, 0, 255, 255]
11 \[DEBUG\] — Filter specified. Type: Pattern filter, Data: [0, 0, 4, 244]
12 \[DEBUG\] — Filter specified. Type: Flow control filter, Data: [0, 0, 5, 180]
13 \[DEBUG\] — Setting ISO-TP flow control filter (ID: 0) on channel 0. Mask: [00, 00, 04, F4]. FlowControl: [00, 00, 05, B4]

3.4.8 Performance optimizations with CAN Interrupts

During testing, it was found that the adapter would miss incoming CAN Frames on high traffic CAN Networks, with prevents ISO-TP receiving from working properly. This was because the default behavior of the M2’s CAN Library is to have an Rx queue of CAN Frames, and pile all incoming CAN Frames onto the queue, which only has 30 slots. Once this queue is full, Any more incoming CAN Frames are simply dropped.

The solution to this problem was to register a callback for each of the 7 CAN mailbox’s on the M2. When a frame is received by the mailbox, it triggers a hardware interrupt, which then executes the callback function. The callback function then places each incoming CAN Frame onto an assigned FIFO queue for each Mailbox.

Since the Passthru API can have 0-7 CAN Filters active at once (0-7 mailboxes with unique mask and pattern filters), the FIFO Queues are created dynamically in order to save memory. If a mailbox is not active, then no FIFO queue exists for it. Each FIFO queue is actually a Ring buffer, with a fixed size. Below is a few code snippets in order to allow for this unique interrupt handling:

```c
// Each mailbox has a rxMailbox of 10 frames
#define MAX_RX_QUEUE 10
struct rxQueue {
    volatile CAN_FRAME buffer[MAX_RX_QUEUE];
    uint8_t head;
    uint8_t tail;
};
```
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#### Listing 3.1: RxQueue structure

```cpp
void CustomCan::enableCanFilter(int id, uint32_t pattern, uint32_t mask, bool isExtended) {
  if (id < 0 || id >= 7) return; // Invalid mailbox ID
  // Set pattern and mask on the specified mailbox
  Can0.setRXFilter(id, pattern, mask, isExtended);
  // Delete any old buffer if it for some reason exists
  delete_check_rx_ring(id);
  // Create our new ring
  create_check_rx_ring(id);
  // Now register the callback so that frames get pushed to our mailbox
}
```

#### Listing 3.2: Function to enable CAN Filter. This sets up the RxQueue for the specified mailbox

```cpp
void CustomCan::disableCanFilter(int id) {
  if (id < 0 || id >= 7) return; // Invalid mailbox ID
  Can0.setRXFilter(id, 0xFFFF, 0x0000, false);
  delete_check_rx_ring(id);
}
```

#### Listing 3.3: Function that removes the CAN Filter from the mailbox and deletes the RxQueue

```cpp
void CustomCan::rxQueuePushFrame(canQueue &r, CAN_FRAME &f) {
  int nextEntry = (r.head + 1) % MAX_RX_QUEUE;
  // Queue is full, data is lost
  if (nextEntry == r.tail) return;
  memcpy((void *)&r.buffer[r.head], (void *)&f, sizeof(CAN_FRAME));
  r.head = nextEntry;
}
```

#### Listing 3.4: Function that pushes a CAN Frame to a RxQueue during an interrupt

```cpp
// This function gets called by the channels
bool CustomCan::receiveFrame(int mailbox_id, CAN_FRAME &f) {
  if (mailbox_id < 0 || mailbox_id >= 7) return false; // Invalid mailbox ID
  return rxQueuePushFrame(rxQueues[mailbox_id], &f);
}
```

#### Listing 3.5: Functions which handles pulling CAN Frames from a specific mailboxes’ RxQueue when requested.

```cpp
void CustomCan::callback_mb0(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[0], &f); }
void CustomCan::callback_mb1(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[1], &f); }
void CustomCan::callback_mb2(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[2], &f); }
void CustomCan::callback_mb3(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[3], &f); }
void CustomCan::callback_mb4(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[4], &f); }
void CustomCan::callback_mb5(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[5], &f); }
void CustomCan::callback_mb6(CAN_FRAME &f) { rxQueuePushFrame(rxQueues[6], &f); }
```

#### Listing 3.6: Callback functions for each mailbox

### 3.5 Diagnostic GUI

As described in (1.4.3), the diagnostic application must be able to do the following things:

1. Allow the user to scan for UDS/KWP2000 compatible ECUs in their vehicle that rely on the ISO-TP transport protocol as described by [Nils Weiss, Sebastian Renner, Jürgen Mottok, Václav Matoušek (n.d.)]

2. Allow the user to select an ECU from their vehicle, and for the application to establish a diagnostic session with the ECU
3. Allow a user to run basic KWP2000/UDS commands on an ECU whilst the ECU is in its diagnostic session

4. Have a simple CAN analyzer page for showing CAN Traffic on the OBD-II port

5. Use the OVD JSON (3.3) to run advanced functions on an ECU that are usually only able to be executed by commercial diagnostic software, and to interpret DTC Error codes and freeze frame data.

Due to the complexity of the user interface and underlying architecture, only the major points will be discussed in this report. Refer to D for the full code of the user interface.

### 3.5.1 Diagnostic server architecture

![Diagram of diagnostic servers UML overview](image)

As discussed in (2.3), KWP2000, UDS and OBD all inherit the same request and response message format, with only the actual SID and PID’s differing. Therefore, figure 3.12 shows how all three diagnostic servers inherit the same common interface. This will allow all diagnostic servers to work under a common UI interface, using dynamic dispatch to call the appropriate diagnostic server. Also to note, the storage format will be the same regardless of the protocol used. The DTC object can accommodate the DTC format of all 3 diagnostic protocols.

### 3.5.2 Communication server architecture

As discussed earlier, the idea of the communication server is to create a common server type system, which can use dynamic dispatch to load different adapter protocols. Although only SAE J2534 (Passthru) API implementation is planned for now, it’s worth creating a dynamic system so that in future, D-PDU and SocketCAN can be added easily to the application without major code modifications.

In its current form, the communication server UML is structured like so:
As seen in figure 3.13, there are multiple data classes to represent data such as CAN and ISO-TP payloads. This is done because each communication API has its own way of transmitting data to and from hardware with various communication protocols. Therefore, data types such as ISO15765Data exist as a portable data type that the rest of the application can work with, and the implementors of ComServer (Such as passthru_api) will internally convert to and from data types.
The DeviceCapabilities object is to be implemented by every API, and contains data about which functions the device supports. Currently, this does nothing, other than be displayed in the Applications home page. However, it is planned for future releases to use this capability data to automatically select the best protocol for communicating with an ECU. For an example, if the device does not support ISO14230, then there is no point in having a button in the user interface for the user to try and establish communication with the ECU using a protocol that is not supported by the adapter. The batt_voltage capability is currently used in order to enable or disable battery voltage monitoring. This avoids 0.0V being displayed in the user interface in the event the adapter does not support it. Instead, “Not supported” will be displayed in grey.

3.5.3 Implementation of the Passthru API

OpenVehicleDiags Passthru library implementation is an abstraction layer over the Passthru API. It is designed to use as little unsafe code as possible. The libloading\(^5\) library is used as a cross platform library loader, being able to load Windows DLLs and Linux SO files and OSX dynlib files. This library also contains functions to locate the library data automatically (Windows uses Registry, Linux/OSX uses JSON).

Passthru functions are declared as type aliases in the Passthru library like so:

```rust
pub type Result<T> = std::result::Result<T, j2534_rust::PassthruError>;
type PassThruCloseFn = unsafe extern "stdcall" fn(device_id: u32) -> i32;
```

The first line in this extract creates a type alias for the library. This way, if a function returns an error code (Rather than 0 - OK), it gets wrapped in Rust’s return Err type. However if the function succeeded, then the Error’s OK variant is returned, along with any data.

The second line shows an example of defining the Passthru API’s functions as a type alias (Example shown is for PassThruClose).

The API also contains a struct which encapsulates all the library functions and reference to the loaded passthru library:

```rust
# [derive(Clone)]
pub struct PassThruDrv {
    lib: Arc<libloading::Library>,
    /// Open device connection
    open_fn: PassThruOpenFn,
    /// Close device connection
    close_fn: PassThruCloseFn,
    /// Connect a communication channel
    connect_fn: PassThruConnectFn,
    /// Disconnect a communication channel
    disconnect_fn: PassThruDisconnectFn,
    /// Read messages from a communication channel
    read_msg_fn: PassThruReadMsgsFn,
    /// Write messages to a communication channel
    write_msg_fn: PassThruWriteMsgsFn,
    /// Start a periodic message
    start_periodic_fn: PassThruStartPeriodicMsgFn,
    /// Stop a periodic message
    stop_periodic_fn: PassThruStopPeriodicMsgFn,
    /// Start a filter on a channel
    start_filter_fn: PassThruStartMsgFilterFn,
    /// Stop a filter on a channel
    stop_filter_fn: PassThruStopMsgFilterFn,
    /// Set programming voltage
    set_prog_v_fn: PassThruSetProgrammingVoltageFn,
    /// Get the last driver error description if ERR_FAILED
    get_last_err_fn: PassThruGetLastErrorFn,
    ioclt_fn: PassThruIoctlFn,
    /// Get driver details
    read_version_fn: PassThruReadVersionFn,
}
```

In order to call the Passthru API functions, the Passthru library contains wrapper functions such as the one shown below:

\(^5\)https://github.com/nagisa/rust_libloading
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The function above shows the abstraction libraries implementation of PassthruClose. This function takes a mutable reference to the PassthruDrv struct (Similar to 'this' in other languages), as well as the device ID to close. The function returns a Result with OK variant type of unit. Then, the PassthruDrv's close function is called in an unsafe block. The unsafe block here is necessary as it is calling external code, which might not guarantee the same memory safety as Rust. If the function succeeded, the the OK Variant is returned. If the function call failed, then the Result's Err variant is returned, along with the error code.

Another example of the abstraction this library does is with PassthruReadMsgs function. This function is supposed to take a mutable reference to an array of PASSTHRU_MSGS, and attempts to fill the array up based on what the adapter can read. Instead, the abstraction library's implementation looks like the following:

This function simplifies the PassthruReadMsgs call significantly for the application. It internally constructs an array to pass a mutable pointer to PassthruReadMsgs itself, then return a Vector of PassthruMsgs that have been read by the adapter. If no messages are read, by default the Passthru library will return an error (ERR_BUFFER_EMPTY). This function can catch that error and simply return an empty array of messages, which is easier to handle in higher levels of the communication server.
3.5.4 User Interface

The Iced GUI library was utilized for the user interface, allowing for the user interface to be defined entirely in the rust codebase. Due to Iced being inspired by the Elm architecture, every page within the user interface has three main functions. An initialization function, an update function, which takes a Message type unique to each page, and a view function, which draws the user interface itself. Each page is stored in the form of a Struct with internal variables that can be only updated from the update function. To make the UI do something, the view function can place elements such as buttons, which emit a message which is sent to the update function. By default, Iced contains the following useful widgets:

- button
- Progress bar
- Drop-down
- Image view
- Radio button
- Checkbox
- Text view
- Text input view
- Scroll view
- Padding widget

Each element of the user interface can have its own custom 'style' struct applied to it, and also have its own alignment (Relative to its parent in the user interface)

Interface style

Iced has the ability to apply a 'style’ struct on each element of the user interface. It was decided that as part of the user interface, there should be a dark theme. This will hopefully allow for less eye-strain when working with the application, especially in darker environments such as garages.

To theme the entire user interface, there is a global variable which indicates which theme is currently in use:

```rust
static mut CURR_THEME: Style = Style::Dark;

#[derive(Debug, Copy, Clone, Ord, PartialOrd, Eq, PartialEq)]
pub enum Style {
    Light,
    Dark,
}

pub fn set_dark_theme() {
    unsafe { CURR_THEME = Style::Dark }
}

pub fn set_light_theme() {
    unsafe { CURR_THEME = Style::Light }
}

pub fn toggle_theme() {
    if *get_theme() == Style::Light {
        set_dark_theme()
    } else {
        set_light_theme()
    }
}
```
For the main user interface components, builder functions were created which can apply, then return a newly created user interface element. Only helper for button creation will be shown, but a similar process occurs for other UI elements. The user interface is somewhat inspired by the Material design guidelines.

Buttons in the user interface come in two flavours. Outlined, and Solid. Each button flavour has eight different themes. Primary colour, Secondary colour, Success, Danger, Warning, Info, Light and Dark.

To create the buttons, the following code is used:

```rust
pub enum ButtonType {
    Primary,
    Secondary,
    Success,
    Danger,
    Warning,
    Info,
    Light,
    Dark,
}

impl ButtonType {
    pub (crate) fn get_theme(&'a) -> &'a Style {

        unsafe { ACUIR_THEME }
    }
}
```

```rust
24 pub fn button_coloured<'a, T: Clone>(
    state: &mut button::State,
    text: &str,
    btn_type: ButtonType,
) -> Button<'a, T> {
    let color = btn_type.get_colour();
    Button::new(state, Text::new(text))
        .style(ButtonStyle::new(color, false))
        .padding(8)
}
```

The `ButtonType` enum has an implementation for each element to retrieve the desired colour of the button. These colours come from the Material design guidelines. When creating a button (`button_coloured`), a standard Iced button is created, then a style is applied to it, along with a desired padding.

The process of creating the style for the button looks like this:

```rust
pub struct ButtonStyle {
    color: Color,
    is_outlined: bool,
}

impl ButtonStyle {
    pub fn new(color: Color, is_outlined: bool) -> Self {
        Self { color, is_outlined }
    }
}

impl button::StyleSheet for ButtonStyle {
    fn active(&self) -> Style {
        match super::get_theme() {
            super::Style::Light => button::Style {
                shadow_offset: Default::default(),
                background: if self.is_outlined {
                    WHITE.into()
                } else {
                    self.color.into()
                },
                border_radius: BUTTON_RADIUS,
                border_width: if self.is_outlined {
                    BUTTON_BORDER_WIDTH
                } else {
                    0.0
                },
            }
```
In this code block, the theme style for the button changes based on the global theme of the rest of the interface (Dark/Light). Then the returned button style is also modified based on if the button is supposed to be coloured (solid), or outlined. Not shown here is the styling for a hovered button, pressed button, or disabled button. All 3 follow the exact same method of creating the return style as the active button style, except with different colours.

**Launcher**

The launcher is responsible for enumerating located diagnostic adapters on the users computer, and to then display them to the user, allowing them to select which adapter to use with OpenVehicleDiag.

When the user selects Launch after selecting an adapter. A ComServer is created with the specified adapter API. If an error occurs during this process, then the launcher bails out and displays the error to the end user.

![OpenVehicleDiag's launcher (Passthru device enumeration)](image-url)
As seen in figure 3.15, the Passthru library for the M2 was loaded, but returned an error as the M2 was not connected to the PC. This error is then displayed in the launcher.

The code to achieve this looks like the following in the Launcher's update function:

```rust
pub fn update(&mut self, msg: &LauncherMessage) -> Option<WindowMessage> {
    match msg {
        LauncherMessage::SwitchAPI(api) => self.api_selection = api,
        LauncherMessage::DeviceSelected(d) => {
            if self.api_selection == API::Passthru {
                self.selected_device_passthru = d.clone()
            } else if self.api_selection == API::DPdu {
                self.selected_device_dpdu = d.clone()
            }
        }
        LauncherMessage::LaunchRequested => {
            if self.api_selection == API::Passthru {
                Ok((details, driver)) => {
                    let mut server = PassthruApi::new(details, driver);
                    if let Err(e) = server.open_device() {
                        self.status_text = e.to_string()
                    } else {
                        // Ready to launch OVD!
                        return Some(WindowMessage::StartApp(server.clone_box()));
                    }
                }
            } else if self.api_selection == API::DPdu {
                // TODO D-PDU Launching
            }
            Err(x) => self.status_text = x.to_string(),
        }
        LauncherMessage::Error => self.status_text = x.to_string(),
        None
    }
}
```

This code block receives a signal 'msg' when a UI element is interacted with. In the case of "LaunchRequested", which occurs when the Launch button is pressed. When this occurs, if the API selection is Passthru, and the listed device was located, the PassthruAPI library attempts to load the device. If it was OK, then a message is emitted to the Main Window, telling it to launch the Home page. As part of this message, the dynamic ComServer (from the PassthruAPI) is passed to the main window.

If the loading of the Passthru device was unsuccessful, then the status_text is set to the error message returned by the Passthru API.

**Home page**

The home page is a gateway to all of OpenVehicleDiag’s various functions and pages. It also displays details about the application, and adapter specifications being utilized.
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The "Supported Protocols" section is built by querying the ComServer’s DeviceCapabilities value to see which communication interfaces are supported. 'Yes' (Green) indicates a method is supported by both the adapter API and the adapter itself. 'No' (Red) indicates that the API (EG: Passthru) does support the communication method, but the adapter itself does not. 'N/A' (Grey) indicates that the adapter API itself does not support the communication protocol.

**Status bar**

The status bar is a small part of the overall user interface. Taking its inspiration from Daimler’s DAS software, it provides status on the connection to the vehicle (If an interface is currently open and communicating with a vehicle), and also the battery voltage of the vehicle. The status bar also provides a 'Go Home' button, and also a 'Back' button which allows users to quickly go back, or go to the home page. Both the 'Back' and 'Go Home' button can be disabled by any page in the user interface. This is used so that certain operations can be cancelled safely within the main user interface, rather than by clicking Go back or home, which forcibly destroys the current page.

The battery voltage is queried every two seconds. This is done by submitting 'events' to the main window every two seconds:

```rust
fn subscription(&self) -> Subscription<Self::Message> {
    let mut batch: Vec<Subscription<WindowMessage>> = vec![];
    if self.poll_voltage {
        batch.push(
            time::every(std::time::Duration::from_secs(2)).map(WindowMessage::StatusUpdate),
        );
        Subscription::batch(batch)
    }
}
```

This allows for the battery voltage to be polled every two seconds, but to also be done on the same thread as the user interface, rather than a background thread. This is done because certain API's such as Passthru do not support multi-threading.

The variable 'poll_voltage' is set when the main window loads, by querying the ComServer’s DeviceCapabilities. If battery voltage reading is supported, 'poll_voltage' is true, else it is false.

This is then utilized by the Status bar draw code:

```rust
let v = if self.poll_voltage {
    if self.voltage < 12.0 || self.voltage > 11.5 {
        text(format!("{}V", self.voltage).as_str(), TextType::Warning) // Amber
    } else if self.voltage < 11.5 {
        text(format!("{}V", self.voltage).as_str(), TextType::Danger) // Red
    } else {
        text(format!("{}V", self.voltage).as_str(), TextType::Success) // Green
    }
} else {
```
As seen above, there are 4 styles for battery voltage display. If the voltage is between 11.5V and 12.0V, then the battery voltage colour will be Amber. If the voltage is less that 11.5V, the text is Red. Any voltage higher than 12.0V is displayed in Green. If battery voltage reading is not supported by the adapter, Grey text saying "Not Supported" will be displayed.

**CAN Analyser**

The CAN Analyser is a simple page which is designed to show CAN traffic on the OBD-II port. The user interface initially has a simple 'Connect' button. When pressed, the CAN Analyser will begin by setting up an open CAN interface on the ComServer, and wake up the OBD-II port by sending an OBD-II over CAN request message. This message is used since the vast majority of cars will respond to it, thus wake up the OBD-II port allowing for traffic to be monitored. This button is also togglable to disable the CAN Interface. When pressed, the following code is executed:

```cpp
if self.is_connected { // Already connected — We are disconnecting CAN
    self.status_text = format("Error closing CAN Interface {}", e);
} else {
    self.is_connected = false;
    self.can_queue.clear();
}
// Try to open CAN Interface (Detect error if any)
else if let Err(e) = self.server.as_mut().open_can_interface(500_000, false) {
    self.status_text = format("Error opening CAN Interface {}", e);
} else { // Opening CAN interface was OK!
    self.is_connected = true;
    if let Err(e) = self.server.as_mut() .add_can_filter( FileType::Pass, 0x0000, 0x0000)
        self.status_text = format("Error setting CAN Filter {}", e);
    // Send OBD-II wakeup packet to wake up car’s OBD-II port
    else if let Err(e) = self.server.send_can_packets(
        &CanFrame::new(0x07DF,
            &0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00),
            0);
    }
    self.status_text = format("Error sending wake-up packet {}", e);
}
```

Once connected, the CAN interface is polled every 10 milliseconds for new data:

```cpp
pub fn subscription(&mut self) -> Subscription<TracerMessage> {
    if self.is_connected { return time::every(std::time::Duration::from_millis(10)).map(TracerMessage::NewData);
    }
    Subscription::none()
}
```

When the message is received, the following code is executed to push each CAN Frame to its own location within a HashMap.
### 3.5.5 KWP2000 and UDS implementations

As mentioned in section 2.3, KWP2000 and UDS are very similar. Therefore, they will both be covered in this section.

Each Diagnostic server uses the same function for sending and receiving command responses from an ECU over an ISO-TP connection:

```rust
fn run_command_iso_tp(
    server: &dyn ComServer,
    send_id: u32,
    cmd: u8,
    args: &[u8],
    receive_require: bool,
    response_timeout: u128,
) -> std::result::Result<Vec<u8>, ProtocolError> {
    let mut data = ISO15765Data {
        id: send_id,
        data: vec![cmd],
        pad_frame: false,
        ext_addressing: true,
    };
    data.data.extend_from_slice(args);
    if !receive_require {
        server.send_iso15765(&[data], 0)
            .map(|_| vec![0])
            .map_err(ProtocolError::CommError)
    } else {
        // Await max 1 second for response
        let res = server.send_receive_iso15765(data, 1000, 1)?;
        if res.is_empty() {
```
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This function starts by building an ISO15765Data payload to transmit to the ECU. The 'cmd' byte is the SID of the protocol, and args contain any additional data. If 'receive_response' is set, the server does not require a response from the ECU, so it immediately bails upon sending the data. If response from the ECU is required, it begins waiting for up to 2 seconds for a response from the ECU.

If the ECU responds with an error, it is returned as a ProtocolError. However, if the error code is 0x78, then the server begins a holding sequence, blocking the thread for up to another 2 seconds until the ECU responds. This is because the error 0x78 implies the ECU has accepted the request, but is unable to respond to the request immediately. Both KWP2000 and UDS state that in this event, the diagnostic server is to stop sending any data to the ECU (Including TesterPresent commands), until the ECU responds, or a timeout occurs. This second timeout is 2 seconds. If the ECU responds with a positive response, the response is returned as a byte array back to whichever diagnostic server sent the message.

Utilizing both the KWP2000 specification [DaimlerChrysler (2002)] and UDS specification [ISO (2006)], basic diagnostic functions were implemented such as clear / Read DTCs, as well as some additional functions for KWP2000 which allow for querying detailed ECU software and hardware version data.

For reading DTCs from ECUs, each protocol returns a different data format, so the Diagnostic servers consolidate the data into a generic DTC structure. Below is the code to read DTCs with KWP2000:

```rust
fn read_errors(&self) -> ProtocolResult<Vec<DTC>> {
    if 0x02 == self.run_command(Service::ReadDTCs.into(), &[0x02, 0xFF, 0x00])?.
        bytes.drain() .
    let mut res = self.run_command(Service::ReadDTCs.into(), &[0x02, 0xFF, 0x00])?.
        bytes.drain();
    let count = bytes[0] as usize;
    let mut res: Vec<DTC> = Vec::new();
    for i in 0..count {
        let name = format!("{02X}\{02X}\", bytes[0], bytes[1]);
        let status = bytes[2];
        if bytes[3] >> 4 & 0b00000001 > 0;
        let storage_state = (status >> 5) & 0b00000001;
        let state = match storage_state {
            1 => DTCState::Stored,
            2 => DTCState::Pending,
            3 => DTCState::Permanent,
            _ => DTCState::None,
        }
    }
    res
}
3.5.6 Automated ECU Scanner

The Automated ISO-TP ECU Scanner is the main part of OpenVehicleDiag. Based on the work done in [Nils Weiss, Sebastian Renner, Jürgen Mottok, Václav Matoušek (n.d.)], it shows it is possible to detect ISO-TP endpoints in a vehicle by sending bogus ISO-TP First frames to the ECU, as it will always respond with a flow control message, regardless if the incoming data is valid or not.

Prior to the scan, a warning message must be presented to the user. This message is to notify the users in advance that many warning lights might briefly illuminate on their instrument cluster, as will be shown later on.

![Warning message presented to the user prior to the ECU scan](image)

To begin the scan, the scanner begins by setting up an open CAN Interface on the applications ComServer, and configures the filter to be open to all incoming traffic:

```rust
1 self.server.open_can_interface(500000, false);
2 self.server.add_can_filter(commapi::comm_api::FilterType::Pass, 0x00000000, 0x00000000);
```

This allows for OpenVehicleDiag to receive ALL incoming CAN Packets from the OBD-II port as it is an open filter.

Next, an OBD-II request is sent to the OBD-II ports CAN interface. This is done to wake-up the CAN Interface on the vehicles side:

```rust
1 self.server.send_can_packets(&[CanFrame::new(0x07DF, &[0x09, 0x02])], 0)
```

The next step is important. In order to ensure that OpenVehicleDiag does not accidentally send a CAN Frame to a vehicle which already exists on the bus, it listens to traffic on the OBD-II port for 15 seconds. During this listening period, any incoming CAN Traffic is noted, and the CAN ID’s of the incoming traffic are added to a blacklist of CAN ID’s to not send to the vehicle for probing ISO-TP endpoints.
After the initial poll period, the scan begins iterating over every CAN ID between 0x000 and 0x7FF (CAN’s Maximum CAN ID with Standard 11 bit addressing). During every iteration, it will send a fake ISO-TP Start frame, and poll for 100ms for incoming data that is not in the existing blacklist. If the incoming data looks like an ISO-TP Flow control message, it is added to an array, along with the Send CAN ID used.

```rust
1 self.get_next_canid();
2 self.server.clear_rx_buffer();
3 // Send a fake ISO-TP first frame. Tell the potential ECU we are sending 16 bytes to it. If it uses ISO-TP, it
4 // will send back a
5 // flow control message back to OVD
6 self.server.send_can_packets(&CanFrame::new(self.curr_scan_id),
7 &CanFrame::new(self.curr_scan_id),
8 // Fake payload to target address. Sending 0x10 bytes of data {16 bytes)
9 &[0x10, 0x10, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00],
10 });
11 // self.clock = Instant::now();
12 while self.clock.elapsed().as_millis() < 100 {
13 // Keep polling CAN!
14 for frame in &self.server.read_can_packets(0, 10000).unwrap_or_default() {
15 if self.can_traffic_id_list.get(&frame.id).is_none() {
16 // It's a new frame we haven't seen before!
17 let payload = frame.get_data();
18 if payload[0] == 0x30 && payload.len() == 8 {
19 // Possible recv ID? — It might pick up multiple IDs during the scan, we filter it later on
20 if let Some(r) = self.stage2_results.get_mut(&self.curr_scan_id) {
21 r.push(frame.id)
22 } else {
23 self.stage2_results.insert(self.curr_scan_id, vec![frame.id]);
24 }
25 }
26 }
27 }
28 }
29 }
```

Once this initial list of potential ISO-TP endpoints has been created, it is then iterated over again, but this time using a specified CAN Filter in order to remove any false positives. If the incoming frame is seen again with the CAN filter applied, then it is defiantly an ISO-TP endpoint.

```rust
1 let keys: Vec<u32> = self.stage2_results.keys().copied().collect();
2 let filter_id = self
3 .stage2_results
4 .get(&keys[self.curr_scan_id as usize])
5 .unwrap();
6 self.filter_idx = self
7 .server
```
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Figure 3.20: Finalizing ISO-TP scan results

At this point, a full list of positive ISO-TP endpoints on the vehicle have been recorded. Next, the scanner needs to determine which diagnostic protocol each endpoint supports. For each ISO15765 Config generated in the ISO-TP scan, it is iterated over, and both a KWP2000 and UDS diagnostic server are created for the ISO-TP endpoint. Due to the architecture of both servers, if the ECU rejects the start diagnostic session command ([0x10, 0x03] for UDS, [0x10, 0x92] for KWP2000), then the diagnostic server will return an Error upon initialization, and therefore the scanner knows the ECU does not support the protocol.

```rust
let ecu = self.stage3_results[&self.curr_scan_id as usize];

let mut ecu_res = ECUDiagSettings {
    name: "$unknown ECU name", into(),
    send_id: ecu.send_id,
    recv_id: ecu.recv_id,
    flow_control_id: ecu.flow_control_id,
    block_size: ecu.block_size,
    sep_time_ms: ecu.sep_time,
    uds_support: false,
    kwp_support: false,
};

// Interrogate the ECU with KWP2000 extended diagnostic session
match KWP2000ECU::start_diag_session(self.server.clone(), &ecu, None) {
    Ok(mut s) => {
        if let Ok(id) = read_dcm_mmc_id(&s) {
            ecu_res.name = format!("ECU Part number: \
```
Since KWP2000 has a standard way of reading the ECU part number, Line 16 shows that the KWP2000 scan attempt also tries to grab the part number from the ECU. If successful, this part number replaces the default "Unknown ECU Name" text. This is because this part number can be easily searched online to find out what ECU it is.

![Testing ECUs for UDS Capabilities](image)

Figure 3.21: Scan progress for UDS compatible ECUs

As mentioned above, the reason for showing a large warning to the end user prior to starting the scan is because putting ECUs into diagnostic mode will cause them to partially deactivate. On modern cars, this can result in hundreds of warning lights illuminating on the users instrument cluster. These warning messages disappear after a couple seconds (As the ECU returns into its default session state).

![Instrument cluster warning lights being displayed](image)

Figure 3.22: Instrument cluster warning lights being displayed during the final stages of ECU detection

The last stage is to present the results of the scan to the user, and save the results to a JSON File.
3.5.7 JSON Diagnostic session

The JSON diagnostic session UI is what allows the OpenVehicleDiag JSON to be used for diagnostics. It is the highest level of the diagnostic architecture for the application. As a sequence diagram, it communicated with the ECU like so:

![Sequence Diagram]

When a JSON file is loaded into OpenVehicleDiag, it is automatically deserialized into the code structs described in section 3.3. From here, the diagnostic session server type and communication parameters are setup and applied. Next, OpenVehicleDiag attempts to read the variant ID from the ECU. This returns the software ID of the ECU. It is then matched against the variant list in the JSON. If nothing is found, the JSON session bails out and returns an error "No matching ECU variants discovered". If an ECU variant is located, the data about that variant is loaded into the JSON diagnostic session and the session begins.
As the above image shows, this is the home page of the JSON diagnostic session. At the top is the name of the ECU along with the vendor name and software version of the ECU. This is all found within the JSON.

The above code reads the JSON data about connection info before building an ISOTP configuration setting, and applying it to a special 'DiagServer' class. This class is a dynamic wrapper around both the KWP2000 and UDS diagnostic servers.

**DTC Errors**

When the ‘read errors’ button is pressed, the JSON Session requests the underlying diagnostic server to read all the DTCs stored on the ECU. Then, for every DTC which is read, the session will then query freeze frame data about it. This returns both a DTC struct, and a sequence of bytes which represents the DTC Freeze frame request response message. Using the decoder function within the JSON, as mentioned earlier in section 3.3, the freeze frame bytes are fed through a decoder for the DTC’s freeze frame array, in order to extract data about the freeze frame. Also, each read DTC’s ID is cross-referenced with the DTC list in JSON. If a matching name is found, the error description is also presented to the end user. This is all shown in the DTC error view:
The user can click on each DTC, and the freeze frame table will display the interpreted freeze-frame data from the ECU. There is also a button to clear DTCs stored on the ECU. Since this utilizes KWP2000 or UDS, it is indeed possible to clear Permanent DTCs, unlike with generic OBD-II applications.

**Reading ECU data**

In OpenVehicleDiag’s current state, only Read functions are executable (Reading data from an ECU using a defined payload without any additional user input). Loaded from JSON are a list of readable functions for the ECU:

When selected and executed, the log view displays the outputted presentation data using the decoder functions found in section 3.3. If the ECU responds negatively to the request, a human readable error message is displayed in red:
These error messages come from either the ComServer (indicating something wrong with the adapter), or DiagServer (indicating the ECU Rejected the request message).

### 3.6 Summary

As shown in this chapter, it has been shown that it is possible to implement all 3 major parts of this project, and all whilst keeping the code modular enough to be easily expanded on at a later date.

Especially with OpenVehicleDiag’s UI, there are a lot of details not covered by this report, mainly due to the length of the implementation, however this report has covered the major points which would be useful to 99% of end users when it comes to car diagnostics.
Chapter 4

Results, Discussion and Analysis

In this chapter, results and conclusions of utilizing OpenVehicleDiag will be discussed, as well as validating that the Open source J2534 (Passthru) driver works with other software that utilizes the Passthru protocol.

4.1 Passthru driver

Due to time constraints, as mentioned in section 3.4, the driver is currently limited to CAN and ISO-TP protocols, since there was not enough time to implement all 6 protocols that the J2534 specification uses. However, this adapter is still in its current form J2534 compliant, since the driver details indicate the adapter currently only supports CAN and ISO-TP.

For verifying J2534 compliance, a copy of Mercedes' DAS diagnostic system was utilized (Diagnostic Assistance System), which supports the J2534 API.

![Figure 4.1: DAS utilizing the custom J2534 adapter](image)

However, DAS only transmit small ISO-TP payloads to and from the ECU. Nothing comes close to the maximum 4096 byte limit of the ISO-TP protocol. Therefore, in order to verify that the driver and adapter can indeed handle the limits of the ISO-TP protocol, my own cars ECU was purposely bricked (Put into a bootloader state), and using Veidmao (Daimler’s ECU Flashing tool that supports the J2534 API), was successfully restored. As shown in the below
image, Vediamo sends thousands of 4096 byte ISO-TP payloads to the adapter to send to the ECU over ISO-TP, which contain the data to be flashed onto the ECU. Also transmitted are some smaller payloads, which keep the ECU in a flash diagnostic session and to control other ECUs in the vehicle.

Vediamo tells the other ECUs in the vehicle to stop sending normal CAN messages, and go silent. This allows the full 500kbps of the CAN Network to be utilized for the firmware update, which in turn reduces the chances of lost CAN Packets and makes the flashing process faster.

![Figure 4.2: Vediamo utilizing the custom J2534 adapter to flash a ECU](image)

From running these 2 applications with the custom Passthru driver, it is possible to conclude that for the 2 implemented protocols (CAN and ISO-TP), the adapter is fully function and therefore is a success.

### 4.2 Diagnostic application

In this section, parts of the diagnostic application will be tested on multiple vehicles, as well as the impact it has on consumer car diagnostics. All tests and findings mentioned in this part of the report will be based on the following two vehicles:

For testing, two vehicles were used in order to verify both UDS and KWP2000 function:

1. Mercedes W203 (2006 C class) - For KWP2000
2. Mercedes W246 (2018 B class) - For UDS

#### 4.2.1 Automated ISO-TP Scanner

After completing a scan on both cars, the following ISO-TP endpoints were discovered:
### Table 4.1: Automated scan results on the Mercedes W203

<table>
<thead>
<tr>
<th>ISO-TP configuration</th>
<th>Diagnostic info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send addr.</td>
<td>Receive addr.</td>
</tr>
<tr>
<td>0x0563</td>
<td>0x04E3</td>
</tr>
<tr>
<td>0x05B4</td>
<td>0x04F4</td>
</tr>
<tr>
<td>0x0662</td>
<td>0x04E2</td>
</tr>
<tr>
<td>0x0667</td>
<td>0x04E7</td>
</tr>
<tr>
<td>0x06C8</td>
<td>0x04E8</td>
</tr>
<tr>
<td>0x06CA</td>
<td>0x04EA</td>
</tr>
<tr>
<td>0x0749</td>
<td>0x04E9</td>
</tr>
<tr>
<td>0x074B</td>
<td>0x04EB</td>
</tr>
<tr>
<td>0x0778</td>
<td>0x0789</td>
</tr>
<tr>
<td>0x07E0</td>
<td>0x07E8</td>
</tr>
<tr>
<td>0x07E1</td>
<td>0x07E9</td>
</tr>
<tr>
<td>0x0784</td>
<td>0x0785</td>
</tr>
</tbody>
</table>

### Table 4.2: Automated scan results on the Mercedes W246

<table>
<thead>
<tr>
<th>ISO-TP configuration</th>
<th>Diagnostic info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send addr.</td>
<td>Receive addr.</td>
</tr>
<tr>
<td>0x06C9</td>
<td>0x0459</td>
</tr>
<tr>
<td>0x0642</td>
<td>0x0488</td>
</tr>
<tr>
<td>0x06F3</td>
<td>0x04DE</td>
</tr>
<tr>
<td>0x07E3</td>
<td>0x07EB</td>
</tr>
<tr>
<td>0x0753</td>
<td>0x04EA</td>
</tr>
<tr>
<td>0x064A</td>
<td>0x0489</td>
</tr>
<tr>
<td>0x0703</td>
<td>0x04E0</td>
</tr>
<tr>
<td>0x06A3</td>
<td>0x04D4</td>
</tr>
<tr>
<td>0x07E5</td>
<td>0x07ED</td>
</tr>
<tr>
<td>0x068B</td>
<td>0x04D1</td>
</tr>
<tr>
<td>0x07F1</td>
<td>0x07F9</td>
</tr>
<tr>
<td>0x0632</td>
<td>0x0486</td>
</tr>
<tr>
<td>0x06A9</td>
<td>0x0455</td>
</tr>
<tr>
<td>0x078A</td>
<td>0x04B1</td>
</tr>
<tr>
<td>0x0691</td>
<td>0x0452</td>
</tr>
<tr>
<td>0x065A</td>
<td>0x048B</td>
</tr>
<tr>
<td>0x0622</td>
<td>0x0484</td>
</tr>
<tr>
<td>0x06B2</td>
<td>0x0496</td>
</tr>
<tr>
<td>0x0612</td>
<td>0x0482</td>
</tr>
<tr>
<td>0x0652</td>
<td>0x048A</td>
</tr>
<tr>
<td>0x06E2</td>
<td>0x06E1</td>
</tr>
<tr>
<td>0x0743</td>
<td>0x04E8</td>
</tr>
<tr>
<td>0x06E1</td>
<td>0x06E2</td>
</tr>
<tr>
<td>0x063B</td>
<td>0x04C7</td>
</tr>
<tr>
<td>0x070B</td>
<td>0x04E1</td>
</tr>
<tr>
<td>0x0732</td>
<td>0x04A6</td>
</tr>
<tr>
<td>0x07E0</td>
<td>0x07E8</td>
</tr>
<tr>
<td>0x07E1</td>
<td>0x07E9</td>
</tr>
<tr>
<td>0x0733</td>
<td>0x04E6</td>
</tr>
</tbody>
</table>
As seen in table 4.1, the automated scanner only located diagnosable ECUs. The ECU name is found by cross referencing the part number in the JSON with google, which gives the name of the ECU. This unfortunately is not possible with UDS, so table 4.2 does not show ECU identification data.

One interesting thing about these two results is that in the W203, it appears the OBD-II port is properly firewalled, only allowing diagnosable ISO-TP addresses to be located, without also locating other ISO-TP endpoints such as Radio to Instrument cluster communication. This however is not true for the W246, as it located multiple ISO-TP endpoints in the vehicle which don’t support either UDS or KWP2000, meaning these are likely ECU to ECU ISO-TP endpoints.

### 4.2.2 Diagnostic session mode (JSON)

The main thing users would be using this for is to get a clear description of error codes stored on an ECU, and to clear the error codes. Here, DTC errors are shown using data provided by JSON, as well as the description of each error, the status of each error, and additional freeze frame data about each error when the user selects an error in the top table.

<table>
<thead>
<tr>
<th>Error</th>
<th>Description</th>
<th>State</th>
<th>MIL on</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Fuel temperature sensor-HP Pump-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>2035</td>
<td>Engine coolant temperature sensor-Engine Bloc-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>2086</td>
<td>Air pressure P1 sensor-in AMF-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>2379</td>
<td>Oil temperature sensor-Engine Block-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>238A</td>
<td>EGR Cooler by-pass actuator -none-electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>206D</td>
<td>Inlet Air temperature sensor-in AMF-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>22A5</td>
<td>Exhaust temperature-sensor before turbine-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>2003</td>
<td>EGR actuator-none-Driver fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>2067</td>
<td>Inlet Metering Valve-HP Pump-Drive fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>201A</td>
<td>Boost pressure sensor-none-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
<tr>
<td>22A0</td>
<td>High Pressure valve-Hall-Electrical fault</td>
<td>Permanent</td>
<td>NO</td>
</tr>
</tbody>
</table>

**Freeze frame data**

- Engine Speed: 0 rpm
- U-Grenz 1. Auftreten: 0
- Battery Voltage: 11.921569 V
- Boost Pressure Actuator duty cycle: 49.80392 %
- Boost Pressure: 0.9803922 bar
- Inlet Air Temperature: 20 °C
- Total Fuel Demand: 0 mg/h
- Engine state: SMC_STOPPED
- Total Distance: 0 Km

When pressing the ‘clear errors’ button, the ECU successfully clears all these errors, the JSON session re-reads the DTCs on the ECU immediately after clearing to verify that the errors have actually been cleared.
To prove that this works with multiple ECUs that are not necessarily engine ECUs, here is OpenVehicleDiag communicating with EGS52. This is a transmission controller for the 722.6 series gearboxes by Mercedes. In this picture, OpenVehicleDiag is connected to the ECU and reading data from the ECU about solenoid pressures. This data can only normally be retrieved using Daimler’s own diagnostic software.

Lastly, here is the JSON sesion working with the Mercedes W246. In the below image, the JSON session is being used to talk to the vehicles instrument cluster to read various data:

This proves that both KWP2000 and UDS have been correctly implemented within OpenVehicleDiag, and work reliably to do ECU diagnostics on both older and modern vehicles without any proprietary software.

4.2.3 Generic diagnostic session

As mentioned in section 3.5, a lot of features were not discussed in their implementation. One of those features was the Generic diagnostic session. This is launched within the application by using the results of an ECU detection scan (Or entering manual ISO-TP details). This
allows for basic diagnostics, but still being able to read and clear DTCs from ECUs that cannot normally be done under OBD-II. This works by opening up a generic KWP2000 or UDS session based on the output of the ECU scan results:

In this interface, the user has to manually enter commands to the ECU in hex form (However there is a button to read and clear DTCs). When reading DTCs in this mode, only the name of the error and state of the DTC can be read, the description of the error is unknown:

4.3 Summary

As shown in this chapter, everything mentioned in section 1 has been achieved, and is working reliably enough for it to be used in vehicles. Since a lot of OpenVehicleDiag’s UI features are dynamic, a lot of the user interface has not been demonstrated in this chapter, just the main points. However, there is a video\(^1\) that shows the entire interface and feature-set in use. There are also additional images of other parts of OpenVehicleDiag’s user interface located at A.0.2.

The JSON diagnostic session results show that the decoder functions in JSON Schema code work perfectly as well, being able to decode Enums, Booleans, Integers and Strings from ECU response message byte streams, and nicely present them to the end user in a way which they can understand. The only thing that could not be tested here is verifying the decoder works with different endiannes. This is because the vast majority of ECUs utilize Big-Endian.

\(^1\)https://youtube.com/_k-dWdNRVr0
Chapter 5

Conclusions and Future Work

5.1 Conclusions

With the initial goal of this project being to attempt to create an open source alternative to commercial / proprietary diagnostic software for vehicle ECUs, as well as an open storage format for ECU diagnostic data, the initial results as outlined in this report have shown that it is indeed possible.

The Passthru library has shown that it is indeed possible to write firmware for a custom Passthru compliant adapter, and utilize it with applications that utilize the API. Although K-Line and J1850 based protocols were not implemented as part of this project, the testing with just CAN and ISO-TP protocols proves that the M2 is fully compliant with the API protocol, and more importantly, is stable.

With OpenVehicleDiag, the application has proven that a cross-platform ECU diagnostics platform can be achieved, and more importantly, be done in a way which can theoretically work with any vehicle, without any prior knowledge of the vehicle (For basic diagnostics with OBD-II, KWP2000 and UDS). Combining OpenVehicleDiag with the JSON Schema can improve the diagnostic capability of the application significantly, allowing for some functions only found in OEM tools.

The JSON Schema has shown that there can be an easy accessible replacement for the ODX specification. However, there are things that are missing, which would need to be added later on in order for it to be a true competitor to the ODX specification. In diagnostic tools, there are tests which are defined as a list of operations to perform on the ECU.

5.2 Future work

With the success of this project so far, this project will be continued long into the future. This is especially relevant at the time of writing with movements such as ‘Right to repair’ gaining traction in the United States and European Union, as such an application would open the possibility for consumers to diagnose ECUs themselves with a simple, easy to use application.

The Macchina M2 Passthru library has also been successful, proving that expensive proprietary adapters are not necessarily needed for car diagnostics. At the time of writing, work is already underway\(^1\) to create a unified repository based on the code that was written for the M2 adapter, and port it to the Macchina A0. The A0 is a cheaper and smaller adapter which only supports CAN, and is based on the ESP32 micro-controller running FreeRTOS. This means that it is only good for more modern vehicles built around 2006 and newer. Eventually, there

\(^1\)https://github.com/rnd-ash/Macchina-J2534
are also plans to create a D-PDU (2.2.1) driver for both the M2 and A0, and add D-PDU functionality to OpenVehicleDiag itself, which would widen the list of supported protocols and existing adapter that can be utilized.

OpenVehicleDiag at the time of writing this now has initial support for SocketCAN [kernel.org (n.d.)] on Linux based OS’s, meaning that in theory it is possible to use OpenVehicleDiag on nothing more than a raspberry Pi and a $5 CAN Shield based on the MCP2515 CAN Transceiver (Assuming the target vehicle supports CAN). This will hopefully encourage more users to utilize OpenVehicleDiag due just how low cost this solution will be compared to purchasing other adapter.

Stated in 1, it was mentioned that ECU Flashing will not be a part of OpenVehicleDiag, however, eventually it might be a good idea to add ECU firmware dumping to OpenVehicle-Diag, which would allow more advanced users who want to reverse engineer their own ECUs to dump the firmware of the ECU and load it up in a disassembler such as Ghidra to understand how it operates. This would aid in the development of open source ECU firmware, such as projects like Speeduino\(^2\). This is because every engine operates slightly differently, and also modern engine ECUs broadcast tons of CAN Data to other ECUs in a vehicle. Reverse engineering ECU firmware will allow such projects to cater for more engines and vehicles.

Lastly, one area of future work would be to create a Graphical user interface for users to create the JSON format used for ECU diagnostics, using simple ‘drag and drop’ blocks. This would vastly simplify the process of creating ECU diagnostic data in JSON. This would be a direct parallel to Vector’s ODXStudio, which allows for OEMs to create ODX diagnostic data using a graphical tool, and then for the data to be saved in an ODX XML file.

\(^2\)https://speeduino.com/home
Chapter 6

Reflection

This project has given me loads of insights and understanding of how ECU diagnostic protocols function and how easy they actually are to implement once obtaining the correct knowledge on the specification. One interesting skill from this project is creating a user interface dynamically in pure code without any form of UI designer. When looking back at the original objectives of the project, the outcome was more than was originally planned, and with the community support received during the projects development, the project will live on and gain more features over time.

With regards to the JSON Schema for OpenVehicleDiag, this was probably the hardest component out of the the three components developed for this project, since the ODX file specification is not well known. Therefore, creating my own parallel for ODX-D but in JSON opens the possibility for others to create diagnostic containers for ECUs without the need of advanced commercial tools.

The Passthru library creation using Macchina’s M2 has shown that it is indeed possible to create an open source alternative to professional diagnostic adapters. Although difficult to implement, it was interesting to see how its possible to create a cross-platform of an API which was originally designed for older versions of Windows, utilizing certain cross-platform libraries in Rust.
References

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kernel.org (n.d.), ‘Readme file for the controller area network protocol family (aka socketcan)’.
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URL: https://www.slideshare.net/linhdoanbro/d-pduapi-usermanual

72
Wikipedia (2021), ‘Obd-ii pids’.

**URL:** https://en.wikipedia.org/wiki/OBD-II_PIDs
Appendix A

Screenshots and diagrams

A.0.1 Daimler Xentry software

Figure A.1: Xentry Diagnostics establishing communication with all the ECUs within a vehicle. During this stage of diagnostics, Xentry is trying to locate all the ECUs on the vehicle, and checking what variation each ECU is in order to parse their diagnostic data correctly.
Figure A.2: Xentry diagnostics with a list of all possible ECUs in the vehicle to talk to, each in their own category.

Figure A.3: Obtaining advanced data from the ECU in Xentry - Querying various attributes about the ESP ECU. The serial number of this part has been hidden.

Figure A.4: Xentry showing a live ‘actuation’ value of certain items the ESP ECU controls.
APPENDIX A. SCREENSHOTS AND DIAGRAMS

Figure A.5: Show Xentry obtaining real-time data from the CDI Engine ECU. The values in Green are within tolerance, and values in red are outside tolerance. Black values indicate no tolerances are specified for the value.

Figure A.6: Xentry showing advanced real-time data from the CDI Engine ECU. This allows for advanced analytics of how the engine is performing.
APPENDIX A. SCREENSHOTS AND DIAGRAMS

Figure A.7: More advanced real-time diagnostics with the CDI Engine ECU. This shows the injector calibration values for the number 1 cylinder

A.0.2 OpenVehicleDiag

Figure A.8: OVD Home page (Dark theme)
Welcome to OpenVehicleDiag
Version 1.0.0

Adapter Info:
Hardware API: SAE J2534
Hardware name: Maicchina M2 Under the dash (FW Version 1.0.0_M2)
Hardware vendor: nid-mash@github.com
Library path: /home/ashcom/paottoz/maicchina_driver_m2.so (Version 0.5.0)

Supported protocols
<table>
<thead>
<tr>
<th>Protocol</th>
<th>CAN</th>
<th>ISO-TP</th>
<th>ISO9141</th>
<th>ISO14230</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Tools
- CAN Analyzer
- Diagnostic Scanner
- OBD Tools

Figure A.9: OVD Home page (Light theme)

Figure A.10: OVD Can Scanner (Hex mode)

Figure A.11: OVD Can Scanner (Binary mode)
APPENDIX A. SCREENSHOTS AND DIAGRAMS

Figure A.12: Loading a ECU Scan save file in OVD

Figure A.13: Selected CRD ECU in OVD

Figure A.14: OVD KWP2000 generic session - Home

Figure A.15: OVD KWP2000 generic session - Scanning DTCs
APPENDIX A. SCREENSHOTS AND DIAGRAMS

Figure A.16: OVD KWP2000 generic session - Clearing DTCs

Figure A.17: OVD KWP2000 generic session - Sending valid manual payload

Figure A.18: OVD KWP2000 generic session - Sending invalid manual payload

Figure A.19: OVD Json session - Connected to CRD engine ECU
Figure A.20: OVD Json session - ECU Info page

Figure A.21: OVD Json session - DTC page
Figure A.22: OVD Json session - DTC page with Freeze frame interpretation

Figure A.23: OVD Json session - Selecting function to read data from
Figure A.24: OVD Json session - Data presentation

Figure A.25: OVD Json session - Reading data from EGS52 transmission ECU
Appendix B

Issues and resolutions

B.1 A full list of issues encountered during development of the M2 driver

B.1.1 Windows Serial API

The serialport-rs library has a flaw in Windows due to Windows’s poorly documented Serial API. Unlike the UNIX world, In Windows, reading and writing to a COM Port are blocking by default, and will only return if the serial buffer is full. This means that if loads of data is being sent from the M2 module, the buffer would overflow before the driver has a chance to read all the data from within the buffer. This issue is still on-going, and can be tracked with an open issue with the serial library https://gitlab.com/susurrus/serialport-rs/-/issues/95

B.1.2 CAN Due library

During development with the CAN Interface on the M2, it transpired that the due_can library does not support mailbox reading (The ability to poll an individual Can Rx mailbox), even though the library does contain functions to do so.

After a discussion with Colin (The library Author), it was suggested that the M2 driver instead take advantage of the hardware interrupt feature of the CAN Mailboxes. This then led to the creation of ‘custom_can.cpp’ in which each mailbox now has its own Ring buffer, and whenever a CAN Frame is received by the mailbox, it triggers a hardware interrupt which allows the M2 to move the incoming CAN Frame to the mailboxes own ring buffer.
Appendix C

Code snippets and tables

C.1 List of SAE J2534 API functions

The following table is from [Drew Technologies, Inc (2003)]

<table>
<thead>
<tr>
<th>Function name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PassThruConnect</td>
<td>Establish a logical communication channel using the specified vehicle network protocol. Protocols supported can be extended by the Scan Tool vendor</td>
</tr>
<tr>
<td>PassThruDisconnect</td>
<td>Terminate an existing logical communication channel</td>
</tr>
<tr>
<td>PassThruReadMsgs</td>
<td>Receive network protocol messages from an existing logical communication channel</td>
</tr>
<tr>
<td>PassThruWriteMsgs</td>
<td>Transmit network protocol messages over an existing logical communication channel</td>
</tr>
<tr>
<td>PassThruStartPeriodicMsg</td>
<td>Transmit network protocol messages at the specified time interval over an existing logical communication channel</td>
</tr>
<tr>
<td>PassThruStopPeriodicMsg</td>
<td>Terminate the specified periodic message</td>
</tr>
<tr>
<td>PassThruStartMsgFilter</td>
<td>Transmit a network protocol filter that will selectively restrict or limit network protocol messages received by the User Application</td>
</tr>
<tr>
<td>PassThruStopMsgFilter</td>
<td>Terminate the specified message filter</td>
</tr>
<tr>
<td>PassThruSetProgrammingVoltage</td>
<td>Set the programmable voltage level on the specified J1962 connector</td>
</tr>
<tr>
<td>PassThruReadVersion</td>
<td>Retrieve the PassThru device firmware version, DLL version and API version information</td>
</tr>
<tr>
<td>PassThruGetLastError</td>
<td>Retrieve the text description for the last PassThru function that generated an error</td>
</tr>
<tr>
<td>PassThruIOCTL</td>
<td>General purpose I/O control function for retrieving and setting the various network protocol timing related parameters. Can be extended by the Scan Tool vendor to provide tool specific functionality</td>
</tr>
</tbody>
</table>

C.2 A full list of driver message types

For this table, the Sender column indicates which endpoint sent the first message containing this message type. The other end has to respond to the message unless stated otherwise.
<table>
<thead>
<tr>
<th>Value</th>
<th>Definition (comm.h)</th>
<th>Sender</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00</td>
<td>MSG_NO_RESPONSE</td>
<td>Either</td>
<td>Identifies a message where no acknowledgment response is required from either the driver or firmware.</td>
</tr>
<tr>
<td>0x01</td>
<td>MSG_LOG</td>
<td>Adapter</td>
<td>Identifies a log message from the adapter firmware. The payload bytes of this message shall me an ASCII String, which the PC driver will log.</td>
</tr>
<tr>
<td>0x02</td>
<td>MSG_OPEN_CHANNEL</td>
<td>Driver</td>
<td>This message indicates the driver has requested that the adapter opens a logical communication channel on one of the OBD-II interfaces. The args of this message include the request Channel ID, the interface type, baud rate, and any additional arguments that are interface specific (e.g., ISO-TP interface requires an additional argument to indicate if it is using extended addressing or not).</td>
</tr>
<tr>
<td>0x03</td>
<td>MSG_CLOSE_CHANNEL</td>
<td>Driver</td>
<td>This message indicates the driver wants the adapter to close a logical communication interface with the vehicle that was opened with MSG_OPEN_CHANNEL.</td>
</tr>
<tr>
<td>0x04</td>
<td>MSG_SET_CHAN_FILT</td>
<td>Driver</td>
<td>This message tells the adapter to set a filter on a channel. The message's parameters will contain the target channel ID, msg lengths and filter bytes.</td>
</tr>
<tr>
<td>0x05</td>
<td>MSG_REM_CHAN_FILT</td>
<td>Driver</td>
<td>This message tells the adapter to destroy a filter on a specified channel. The parameters will contain both the filter ID and channel ID.</td>
</tr>
<tr>
<td>0x06</td>
<td>MSG_TX_CHAN_DATA</td>
<td>Driver</td>
<td>This message is sent to the adapter when data is to be transmitted to the vehicle. The parameters of this message will contain the channel ID as well as the raw bytes of the data to be sent to the vehicle.</td>
</tr>
<tr>
<td>0x07</td>
<td>MSG_RX_CHAN_DATA</td>
<td>Adapter</td>
<td>This message is sent to the driver from the adapter whenever the adapter has received any data on any active interface channels. Upon receiving this message, the drive will buffer the data in PASSTHRU_MSG structures and send them back to the user application when PassthruReadMsgs is called for the receiving channel.</td>
</tr>
<tr>
<td>0x08</td>
<td>MSG_READ_BATT</td>
<td>Driver</td>
<td>Requests the adapter to read the battery voltage on pin 16 of the OBD-II port. The response message args are formatted as a Big endian unsigned integer representing the voltage in millivolts.</td>
</tr>
<tr>
<td>0x09</td>
<td>MSG_IOCTL_SET</td>
<td>Driver</td>
<td>Requests the adapter to set a specified IOCTL parameter for a specified channel to a specified value.</td>
</tr>
<tr>
<td>0x10</td>
<td>MSG_IOCTL_GET</td>
<td>Driver</td>
<td>Requests the adapter to return a specified IOCTL parameter value for a specified channel.</td>
</tr>
<tr>
<td>0xAA</td>
<td>MSG_STATUS</td>
<td>Driver</td>
<td>This message is sent to the adapter when the driver first loads or when the driver is unloaded, and is used to tell the adapter to either get ready to receive messages (On driver load), or to destroy all channels and reset to its default state (On driver unload).</td>
</tr>
<tr>
<td>0xAB</td>
<td>MSG_GET_FW_VERSION</td>
<td>Driver</td>
<td>Requests the adapter shall return a response message with an ASCII String in the parameters section which represents the current firmware version running on the adapter.</td>
</tr>
<tr>
<td>0xFF</td>
<td>MSG_TEST</td>
<td>Driver</td>
<td>Only used in tests and test compiled firmware. The adapter shall echo back this message with whatever data was received.</td>
</tr>
</tbody>
</table>
## C.3 List of KWP2000 and UDS Services

<table>
<thead>
<tr>
<th>SID Hex</th>
<th>KWP2000 Service name</th>
<th>UDS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>StartDiagnosticSession</td>
<td>DiagnosticSessionControl</td>
<td>Used to control which diagnostic session the ECU is in. A default session is what the ECU is in after power on, and prohibits certain commands. Extended diagnostic session can be used to execute all commands. Flash session mode is typically used during firmware updates.</td>
</tr>
<tr>
<td>11</td>
<td>ECUReset</td>
<td></td>
<td>Used to tell the ECU to reset with a specified reset method. Once the ECU is reset, it will be back in a default session.</td>
</tr>
<tr>
<td>14</td>
<td>ClearDiagnosticInfo</td>
<td></td>
<td>Used to clear DTCs from the ECU. A mask is typically provided, and DTCs which match the mask are cleared from the ECU.</td>
</tr>
<tr>
<td>17</td>
<td>ReadStatusOfDTC</td>
<td></td>
<td>Used to retrieve freeze frame data from the ECU about a given DTC code.</td>
</tr>
<tr>
<td>18</td>
<td>ReadDTCByStatus</td>
<td></td>
<td>Used to retrieve DTCs from the ECU by a provided status flag.</td>
</tr>
<tr>
<td>19</td>
<td>ReadDTCInformation</td>
<td></td>
<td>Used to retrieve DTCs from the vehicle by either status, group or mask.</td>
</tr>
<tr>
<td>1A</td>
<td>ReadECUIdentification</td>
<td></td>
<td>Requests identification data from the ECU.</td>
</tr>
<tr>
<td>21</td>
<td>ReadDataByLocalIdentifier</td>
<td></td>
<td>Reads data from the ECU’s memory by a Local ID. A local ID is used to define what kind of data to retrieve. Multiple Local IDs can be provided within the same request message. Each local ID corresponds to an attribute in the ECU such as VIN number or OS version.</td>
</tr>
<tr>
<td>22</td>
<td>ReadDataByIdentifier</td>
<td></td>
<td>Used to request blocks of data from the ECU. The ID’s are the same as what is used by WriteDataByIdentifier.</td>
</tr>
<tr>
<td>23</td>
<td>ReadMemoryByAddress</td>
<td></td>
<td>Used to retrieve data from the ECU’s memory given a raw memory address.</td>
</tr>
<tr>
<td>24</td>
<td>ReadScalingDataByIdentifier</td>
<td></td>
<td>Same as ReadDataByIdentifier, except the ECU shall respond with a scaling data type (EG: Integer or Float), along with the algorithm used to convert it from raw to parsed.</td>
</tr>
<tr>
<td>27</td>
<td>SecurityAccess</td>
<td></td>
<td>Used to either generate a seed key, or to input a response to the ECU. If the response is valid to the provided seed key, the ECU will allow writing and reading of protected memory areas.</td>
</tr>
<tr>
<td>28</td>
<td>DisableNormalMsgTransmission</td>
<td></td>
<td>Used to disable normal ECU communication with other ECUs, leaving only diagnostic traffic untouched. This is typically sent to all ECUs in a vehicle prior to flashing a ECU in the vehicle as it allows for more bandwidth on the vehicles communication networks to be used for flashing.</td>
</tr>
<tr>
<td>28</td>
<td>CommunicationControl</td>
<td></td>
<td>Works in the same way as KWP2000’s DisableNormalMsgTransmission and EnableNormalMsgTransmission commands.</td>
</tr>
<tr>
<td>29</td>
<td>EnableNormalMsgTransmission</td>
<td></td>
<td>Used to re-enable normal ECU communication after they have been disabled with DisableNormalMsgTransmission.</td>
</tr>
<tr>
<td>2C</td>
<td>DynamicallyDefineDataIdentifier</td>
<td></td>
<td>Used to dynamically create a new Local Identifier if none exists on the ECU already.</td>
</tr>
<tr>
<td>Code</td>
<td>Function</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>2E</td>
<td>WriteDataByIdentifier</td>
<td>Used to write blocks of data to the ECU. The ID’s are the same as what is used by ReadDataByIdentifier.</td>
<td></td>
</tr>
<tr>
<td>2F</td>
<td>IoctlByIdentifier</td>
<td>Used to control input and output of the ECU for a specific component attached to the ECU. For example, the tester can use this function to manually actuate components on the ECU, then once done, return control back to the ECU.</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>IoctlByIdentifier</td>
<td>Used to control input and output of the ECU for a specific component attached to the ECU. For example, the tester can use this function to manually actuate components on the ECU, then once done, return control back to the ECU.</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>StartRoutineByLocalIdentifier</td>
<td>Used to start execution of a test or routine in the ECU’s memory. These routines will run a sequence of operations on the ECU’s components. The test will not stop on the ECU’s own accord, instead StopRoutineByLocalIdentifier must be used to stop the routine.</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>RoutineControl</td>
<td>This function combines the functionalities found in KWP2000’s StopRoutineByLocalIdentifier, StartRoutineByLocalIdentifier and RequestRoutineResultsBylocalIdentifier commands.</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>StopRoutineByLocalIdentifier</td>
<td>Used to stop or terminate a routine that was started with StartRoutineByLocalIdentifier.</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>RequestRoutineResultsBylocalIdentifier</td>
<td>Used to retrieve the results of a routine execution that was started with StartRoutineByLocalIdentifier and stopped with StopRoutineByLocalIdentifier.</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>RequestDownload</td>
<td>Used to start a transfer between the tester and ECU. It is typically used in Flash routines. This function provides the memory address and compression type and uncompressed size of the data to be downloaded.</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>RequestUpload</td>
<td>Used to start a data transfer between the ECU and Tester. This function provides the memory address and compression type and uncompressed size of the data to be uploaded.</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>TransferData</td>
<td>Used to transfer data between the tester and ECU. The direction of data transfer would have been determined depending on if RequestDownload or RequestUpload was first executed.</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>RequestTransferExit</td>
<td>This is used to indicate that a data transfer has been completed.</td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td>WriteDataByLocalIdentifier</td>
<td>Used to write data to the ECU given a specified Local ID. Each local ID corresponds to a attribute in the ECU such as VIN number or OS version.</td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>WriteMemoryByAddress</td>
<td>Used to write data to the ECU’s memory given a raw memory address and content.</td>
<td></td>
</tr>
<tr>
<td>3E</td>
<td>TesterPresent</td>
<td>Sent periodically to the ECU in order to keep the ECU in a non-default diagnostic session.</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>AccessTimingParameter</td>
<td>Used to read and modify the default timing parameters utilizes for the communication link during a diagnostic session.</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX C. CODE SNIPPETS AND TABLES

<table>
<thead>
<tr>
<th>SecuredDataTransmission</th>
<th>Used to transfer data between the tester and ECU in a secure fashion, which is protected from attacks from third parties.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ControlDTCSetting</td>
<td>Used to enable or disable the logging of DTCs on the ECU.</td>
</tr>
<tr>
<td>ResponseOnEvent</td>
<td>Used to tell the ECU to either start or stop transmission of response messages on a specified event type, during a given window. An event can be anything which the ECU has access to such as timer interrupts, fault settings etc.</td>
</tr>
<tr>
<td>LinkControl</td>
<td>This is used in order to modify the baud rate of the transport protocol the ECU is utilizing during the diagnostic session.</td>
</tr>
</tbody>
</table>

### C.4 Extract of OVD’s JSON (EGS52) from CBFParser

The following is an extract from the JSON created by CBFParser for EGS52 (722.6 transmission TCM). All Strings here have been converted from German to English for easier understanding.

```json
{
  "name": "EGS52",
  "description": "new Control unit For NAG",
  "variants": [
    {
      "name": "Diagversion02",
      "description": "EGS52_Diagversion02",
      "patterns": [
        {
          "vendor": "Siemens",
          "vendorId": 4294935042
        },
        {
          "vendor": "Siemens",
          "vendorId": 514
        }
      ]
    },
    "errors": [
      {
        "error_name": "P2000",
        "summary": "58: Control unit EGS (Test internal Watchdog)",
        "description": "EPS_Error detection since Init",
        "start_bit": 48,
        "length_bits": 8,
        "byte_order": "BigEndian",
        "data_format": {
          "Bool": {
            "pos_name": "detected since Init",
            "neg_name": "restored out Storage"
          }
        }
      },
      {
        "name": "EPS_Error_status_internally",
        "unit": "sec",
        "start_bit": 48,
        "length_bits": 8,
        "byte_order": "BigEndian",
        "data_format": "HexDump"
      },
      {
        "name": "EPS_time after Reset, last Occur",
        "unit": "sec",
        "start_bit": 248,
        "length_bits": 16,
        "byte_order": "BigEndian",
        "data_format": {
          "Linear": {
            "multiplier": 1.0,
            "offset": 0.0
          }
        }
      }
    ]
  }
}
```
"downloads": [
{
"name": "DT,21,33",
"description": "Data download 21 33",
"payload": "2133",
"output_params": [
{
"name": "Valves_Flag",
"unit": ",",
"start_bit": 16,
"length_bits": 1,
"byte_order": "BigEndian",
"data_format": {
"Bool": {
"pos_name": "Active",
"neg_name": "Inactive"
}
}
}
],
"name": "Should activate solenoid 1–2/4–5",
"unit": ",",
"start_bit": 18,
"length_bits": 1,
"byte_order": "BigEndian",
"data_format": {
"Bool": {
"pos_name": "Active",
"neg_name": "Inactive"
}
}
}
],
"name": "Shift solenoid target status",
"unit": "",
"start_bit": 24,
"length_bits": 8,
"byte_order": "BigEndian",
"data_format": {
"Table": [
{
"name": "None",
"start": 0.0,
"end": 0.0
}
{
"name": "1–2/4–5",
"start": 1.0,
"end": 1.0
}
{
"name": "2–3",
"start": 2.0,
"end": 2.0
}
{
"name": "1–2/4–5 and 2–3",
"start": 3.0,
"end": 3.0
}
{
"name": "3–4",
"start": 4.0,
"end": 4.0
}
{
"name": "1–2/4–5 and 3–4",
"start": 5.0,
"end": 5.0
}
{
"name": "2–3 and 3–4",
"start": 6.0,
"end": 6.0
}
{
"name": "1–2/4–5 and 2–3 and 3–4",
"start": 7.0,
"end": 7.0
}
}
"name": "Should activate solenoid 2–3",
"unit": "",
"start_bit": 25,
"length_bits": 1,
"byte_order": "BigEndian",
"data_format": {

"Bool": {  
  "pos_name": "Active",  
  "neg_name": "Inactive"
}
}  

{  
  "name": "Should activate solenoid 3−4",  
  "unit": "",  
  "start_bit": 26,  
  "length_bits": 1,  
  "byte_order": "BigEndian",  
  "data_format": {  
    "Bool": {  
      "pos_name": "Active",  
      "neg_name": "Inactive"
    }
  }
},  

{  
  "name": "Solenoid 1−2/4−5",  
  "unit": "",  
  "start_bit": 27,  
  "length_bits": 1,  
  "byte_order": "BigEndian",  
  "data_format": {  
    "Bool": {  
      "pos_name": "Active",  
      "neg_name": "Inactive"
    }
  }
},  

{  
  "name": "Solenoid 2−3",  
  "unit": "",  
  "start_bit": 28,  
  "length_bits": 1,  
  "byte_order": "BigEndian",  
  "data_format": {  
    "Bool": {  
      "pos_name": "Active",  
      "neg_name": "Inactive"
    }
  }
},  

{  
  "name": "Solenoid 3−4",  
  "unit": "",  
  "start_bit": 29,  
  "length_bits": 1,  
  "byte_order": "BigEndian",  
  "data_format": {  
    "Bool": {  
      "pos_name": "Active",  
      "neg_name": "Inactive"
    }
  }
},  

{  
  "name": "Shift pressure",  
  "unit": "mbar",  
  "start_bit": 32,  
  "length_bits": 16,  
  "byte_order": "BigEndian",  
  "data_format": "Identical"
},  

{  
  "name": "Modulating pressure",  
  "unit": "mbar",  
  "start_bit": 48,  
  "length_bits": 16,  
  "byte_order": "BigEndian",  
  "data_format": "Identical"
},  

{  
  "name": "Switching pressure: Target current",  
  "unit": "mA",  
  "start_bit": 64,  
  "length_bits": 16,  
  "byte_order": "BigEndian",  
  "data_format": "Identical"
},  

{  
  "name": "Switching pressure: Actual current",  
  "unit": "mA",  
  "start_bit": 80,  
  "length_bits": 16,  
  "byte_order": "BigEndian",  
  "data_format": "Identical"
},  

{  
  "name": "Modulating pressure: Target current",  
  "unit": "mA",  
  "start_bit": 96,  
  "length_bits": 16,
"bytes_order": "BigEndian",
"data_format": "Identical"
}],

"name": "Modulating pressure: Actual current",
"unit": "mA",
"start_bit": 112,
"length_bits": 16,
"bytes_order": "BigEndian",
"data_format": "Identical"
}],

"name": "Torque converter target lookup",
"unit": "1/255",
"start_bit": 128,
"length_bits": 8,
"bytes_order": "BigEndian",
"data_format": "Identical"}]}
Appendix D

A list of project repositories

The below repositories are where the code for this thesis is located at. Each repository has its own purpose.

- Macchina M2 Passthru driver - https://github.com/rnd-ash/MacchinaM2-J2534-Rust/
- OpenVehicleDiag application and CBFParse - https://github.com/rnd-ash/OpenVehicleDiag/tree/v1.0.0
- Common J2534 code (Rust) - https://github.com/rnd-ash/J2534-Rust
Appendix E

OpenVehicleDiag JSON Schema

The following has been adapted from the Json Schema document from the OpenVehicleDiag repository at release 1.0

Version 1.0 (31/03/2021)

This document outlines the JSON Specification which OpenVehicleDiag uses for ECU diagnostics. It is designed to be a simple, easy to understand replacement for ODX, and proprietary data formats such as Daimler’ CBF and SMR-D data format.

JSON Root

Example

```json
{
  "name": "Awesome ECU",
  "description": "My awesome engine ECU!",
  "variants": [],
  "connections": []
}
```

Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>String</td>
<td>Yes</td>
</tr>
<tr>
<td>description</td>
<td>String</td>
<td>Yes</td>
</tr>
<tr>
<td>variants</td>
<td>Array of ECU Variants (See below)</td>
<td>Yes</td>
</tr>
<tr>
<td>connections</td>
<td>Array of connection methods for communicating with the ECU. See below</td>
<td>Yes</td>
</tr>
</tbody>
</table>

ECU Variant

An ECU Variant is used to identify a particular software version of an ECU. Since an ECU can get software updates over time, this is necessary as with certain software updates, an ECU can change or modify error code descriptions and also add or remove diagnostic routines.

Example

1https://github.com/rnd-ash/OpenVehicleDiag/blob/v1.0.0/SCHEMA.md
```json
{
  "name": "SW_V_01",
  "description": "My Awesome ECU software version 0.1",
  "patterns": [],
  "errors": [],
  "adjustments": [],
  "actuations": [],
  "functions": [],
  "downloads": []
}
```

### Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>A short version string of the ECU software version</td>
<td>Yes</td>
</tr>
<tr>
<td>description</td>
<td>Description of the ECU software version</td>
<td>Yes</td>
</tr>
<tr>
<td>patterns</td>
<td>A list of pattern objects that are used to identify the hardware vendor which implements this variant of ECU software</td>
<td>Yes</td>
</tr>
<tr>
<td>errors</td>
<td>A list of errors that this ECU variant could potentially throw</td>
<td>Yes</td>
</tr>
<tr>
<td>adjustments</td>
<td>A list of services that can be executed on the ECU variant in order to permanently modify certain features of the ECU, such as setting a new idle RPM. It should be noted that these services do not require seed key access prior to execution</td>
<td>Yes</td>
</tr>
<tr>
<td>actuations</td>
<td>A list of services that can be executed on the ECU variant in order to manipulate components temporarily during a diagnostic session</td>
<td>Yes</td>
</tr>
<tr>
<td>functions</td>
<td>A list of services that can be executed on the ECU variant that have no user input or output. These can include things such as ECU Reset or modifying the diagnostic session type</td>
<td>Yes</td>
</tr>
<tr>
<td>downloads</td>
<td>A list of services that can be executed on the ECU variant in order to read data from the ECU</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Pattern

An ECU Pattern is used to identify which hardware vendor is responsible for implementing the parent variant software version, since it's possible for 1 ECU software to be installed on multiple vendors' ECUs, such as Bosch, Simens and Delphi.

#### Example

```json
{
  "vendor": "rnd-ash@github.com",
  "vendor_id": 12345
}
```

### Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>vendor</td>
<td>The manufacture name of the ECU</td>
<td>Yes</td>
</tr>
<tr>
<td>vendor_id</td>
<td>The vendor ID pattern. Every vendor has a unique vendor_id for every ECU. This is a 2 or 4 byte integer retrieved with read_dcs_id or read_dcx_mmc_id with ECUs that utilize KWP2000, or read_vendor_id for ECUs that utilize UDS</td>
<td>Yes</td>
</tr>
</tbody>
</table>
APPENDIX E. OPENVEHICLEDIAG JSON SCHEMA

Error

An error block represents a DTC (Diagnostic trouble code) which the ECU could potentially throw under certain circumstances to signify something is wrong.

Example

```json
{
    "error_name": "P2082-002",
    "summary": "MAF implausible",
    "description": "Mass airflow sensor is producing inconsistent readings",
    "envs": []
}
```

Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>error_name</td>
<td>The shorthand error code, usually in the SAE J2012 or ISO 15031-6 format</td>
<td>Yes</td>
</tr>
<tr>
<td>summary</td>
<td>The summary of what the error signifies</td>
<td>Yes</td>
</tr>
<tr>
<td>description</td>
<td>A more detailed description of the error</td>
<td>Yes</td>
</tr>
<tr>
<td>envs</td>
<td>A list of parameters for interpreting data returned about the DTC using get_error_status. This essentially interprets the ECU specific freeze frame data, which is a list of sensor measurements that the ECU captures when the error is triggered, which can be useful for debugging the error.</td>
<td>No</td>
</tr>
</tbody>
</table>

Service

A service is used to describe an operation that can be executed on the ECU during a diagnostic session.

Example

```json
{
    "name": "Read injector status",
    "description": "Retrieves the injector quantity per stroke for all cylinders",
    "payload": "22 FB",
    "input_params": [],
    "output_params": []
}
```

Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>The name of the service</td>
<td>Yes</td>
</tr>
<tr>
<td>description</td>
<td>A description of what the service does</td>
<td>Yes</td>
</tr>
<tr>
<td>payload</td>
<td>The raw payload to be sent to the ECU</td>
<td>Yes</td>
</tr>
<tr>
<td>input_params</td>
<td>A list of parameters that are used for interpreting user input for values to append to the ECU request payload</td>
<td>No</td>
</tr>
<tr>
<td>output_params</td>
<td>A list of parameters that are used to decode the ECU’s positive response message to the command</td>
<td>No</td>
</tr>
</tbody>
</table>

Parameter

A parameter is used to define the data format used for either input or output data that the ECU uses, as well as defining where in the ECU Request or response message the value is
located at.

**Example**

```json
{
    "name": "Supply voltage",
    "description": "Supply voltage being measured by the ECU",
    "unit": "V",
    "start_bit": 32,
    "length_bits": 8,
    "byte_order": "BigEndian",
    "data_format": "Identical",
    "valid_bounds": {
        "upper": 100.0,
        "lower": 0.0
    }
}
```

### Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>String</td>
<td>Name of the parameter</td>
</tr>
<tr>
<td>description</td>
<td>String</td>
<td>Description of the parameter</td>
</tr>
<tr>
<td>unit</td>
<td>String</td>
<td>Optional unit string, which will be appended to the output value when being displayed as a string</td>
</tr>
<tr>
<td>start_bit</td>
<td>Integer</td>
<td>The position in the ECU payload or response where this parameter is located at</td>
</tr>
<tr>
<td>length_bits</td>
<td>Integer</td>
<td>The length in bits of the parameter</td>
</tr>
<tr>
<td>byte_order</td>
<td>String</td>
<td>The byte order of the parameter. Allowed values are BigEndian or LittleEndian</td>
</tr>
<tr>
<td>data_format</td>
<td>Enum</td>
<td>Data format (see below) of the parameter</td>
</tr>
<tr>
<td>valid_bounds</td>
<td>JSON</td>
<td>Multi use. If the parameter is in the input parameters section of the parent service, this field denotes the upper and lower bounds of the user input. If the parameter is in the parent services’ output parameters section, it is used for denoting the maximum and minimum y axis values for graphing</td>
</tr>
</tbody>
</table>

### A list of valid data formats for Parameter

Below is a full list of all possible allowed entries in a Parameter.

**Binary**

**Description**: The output value is formatted as a binary string.

**Example JSON**

```json
"data_format": "Binary",
```

**Example parsing**

```json
INPUT: [0x20]
OUTPUT: "0b00100000"

INPUT: [0x20, 0xFF]
OUTPUT: "[0b00100000, 0b11111111]"
```
APPENDIX E. OPENVEHICLEDIAG JSON SCHEMA

HexDump

**Description:** The output value is formatted as a hex string like array.

**Example JSON**

```json
"data_format": "HexDump",
```

**Example parsing**

```python
INPUT: [0x20, 0xFF, 0x00]
OUTPUT: "[0x20, 0xFF, 0x00]"
```

String

**Description:** The output value is formatted as a String using a specified encoding option. This uses lossless decoding, so if bytes don’t map to specific characters, ◆ will be displayed in its place.

**Example JSON**

```json
"data_format": {
  "String": "Utf8"
}
```

**Example parsing**

```python
INPUT: [0x54, 0x65, 0x73, 0x74, 0x20, 0x6D, 0x65, 0x73, 0x73, 0x61, 0x67, 0x65]
OUTPUT: "Test message"
```

**Notes** For the string encoding option, 3 possible values are allowed:

- **ASCII** - The String is encoded as ASCII (1 byte per character)
- **Utf8** - The String is encoded as UTF-8 (1 byte per character)
- **Utf16** - The String is encoded as UTF-16 (2 bytes per character)

Bool

**Description:** The output value is formatted as a Boolean, where 0 is interpreted as False, and any other value is interpreted as True. If the fields `pos_name` and `neg_name` are present, then the strings in those fields will replace the default "True", "False" Strings.

**Example JSON**

```json
"data_format": "Bool",
"data_format": {
  "Bool": {
    "pos_name": "This is positive",
    "neg_name": "This is negative"
  }
}
```

**Example parsing**

```python
# First JSON example
INPUT: 0x01
OUTPUT: "True"
```

```python
INPUT: 0x00
OUTPUT: "False"
```
# Second JSON example

**INPUT**: 0x01
**OUTPUT**: "This is positive"

**INPUT**: 0xFF
**OUTPUT**: "This is positive"

**INPUT**: 0x00
**OUTPUT**: "This is negative"

## Table

**Description**: The output value is formatted as a String based on a table which represents an Enum. Each enum entry in the table has a defined start and end (inclusive) value. Any number between the start and end value are accepted into the enums variant. If no Enum could be found for a given input value, then "UNDEFINED" is returned (See example parsing below).

### Example JSON

```json
"data_format": {
  "Table": [ 
    { 
      "name": "This value is between 0 and 10",
      "start": 0.0,
      "end": 10.0
    },
    { 
      "name": "This value is only 11",
      "start": 11.0,
      "end": 11.0
    },
    { 
      "name": "This value is only 100",
      "start": 100.0,
      "end": 100.0
    }
  ]
},
```

### Example parsing

**INPUT**: [0x00]
**OUTPUT**: "This value is between 0 and 10"

**INPUT**: [0x05]
**OUTPUT**: "This value is between 0 and 10"

**INPUT**: [0x64]
**OUTPUT**: "This value is only 100"

**INPUT**: [0xFF]
**OUTPUT**: "UNDEFINED(0xFF)"

## Identical

**Description**: The output value is formatted as a number based on the raw value extracted from the parent parameter’s bit range.

### Example JSON

```json
"data_format": "Identical"
```
**Example parsing**

```plaintext
INPUT: [0x00]
OUTPUT: "0"

INPUT: [0x05]
OUTPUT: "5"

INPUT: [0x64]
OUTPUT: "100"

INPUT: [0xFF, 0xFF]
OUTPUT: "65565"
```

**Linear**

*Description:* The output value is calculated using a simple \( y = mx + c \) equation, where the "multiplier" field represents the \( m \) component of the equation, and the "offset" field represents the \( c \) component.

**Example JSON**

```json
"data_format": {
  "Linear": {
    "multiplier": 0.125,
    "offset": -40.0
  }
}
```

**Example parsing**

```plaintext
INPUT: [0x00]
OUTPUT: "-40.0"

INPUT: [0x10]
OUTPUT: "-38.0"

INPUT: [0xFF]
OUTPUT: "-8.125"
```

**ScaleLinear**

*This does not function in OpenVehicleDiag 1.0!*

*Description:* The output value is calculated using a table of linear functions.

**RatFunc**

*This does not function in OpenVehicleDiag 1.0!*

*Description:* The output value is calculated using a rational function.

**ScaleRatFunc**

*This does not function in OpenVehicleDiag 1.0!*

*Description:* The output value is calculated using a table of rational functions.
Table Interpretation

This does not function in OpenVehicleDiag 1.0!

**Description:** The output value is calculated using defined interpolation.

Compucode

This does not function in OpenVehicleDiag 1.0!

**Description:** The output value is calculated using a Java virtual machine that runs bytecode of a class that implements the `I_CompuCode()` interface.

Connection

Example

```json
1 { 
2   "baud": 500000, 
3   "send_id": 2016, 
4   "global_send_id": 2016, 
5   "connection_type": { 
6     "ISOTP": { 
7       "blocksize": 8, 
8       "st_min": 20 
9      } 
10   }, 
11   "server_type": "KWP2000", 
12   "recv_id": 2024 
13 }
```

**Properties**

<table>
<thead>
<tr>
<th>Type</th>
<th>Type</th>
<th>Description</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>baud</td>
<td>Integer</td>
<td>The baud speed (bus speed) of the connection</td>
<td>Yes</td>
</tr>
<tr>
<td>send_id</td>
<td>Integer</td>
<td>The diagnostic tester ID</td>
<td>Yes</td>
</tr>
<tr>
<td>recv_id</td>
<td>Integer</td>
<td>The diagnostic receiver ID</td>
<td>Yes</td>
</tr>
<tr>
<td>global_send_id</td>
<td>Integer</td>
<td>The global tester present diagnostic ID</td>
<td>No</td>
</tr>
<tr>
<td>connection_type</td>
<td>Enum</td>
<td>The physical connection method to talk to the ECU. See below for a list of</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>allowed data structures.</td>
<td></td>
</tr>
<tr>
<td>server_type</td>
<td>String</td>
<td>Denotes the diagnostic server type to use when talking to the ECU. Allowed</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>values are &quot;KWP2000&quot; (Keyword protocol 2000), or &quot;UDS&quot; (Unified diagnostic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>services)</td>
<td></td>
</tr>
</tbody>
</table>

Connection type

Example (LIN)

```json
1 "connection_type": { 
2   "LIN": { 
3     "max_segment_size": 254, 
4     "wake_up_method": "FiveBaudInit" 
5   } 
6 }
```

**Properties**
### APPENDIX E. OPENVEHICLEDIAG JSON SCHEMA

#### Type | Description | Required
--- | --- | ---
max_segment_size | Integer | The maximum frame size allowed to be transmitted over K-Line | Yes
wake_up_method | String | Specifies the wake up method for K-Line. Allowed values are "FastInit" (Fast initialization wake up method) or "FiveBaudInit" (Five baud initialization wake up method) | Yes

**Example (ISO-TP)**

```json
"connection_type": {
  "ISOTP": {
    "blocksize": 8,
    "st_min": 20,
    "ext_can_addr": false,
    "ext_isotp_addr": false,
  }
}
```

#### Properties

#### Type | Description | Required
--- | --- | ---
blocksize | Integer | The maximum number of CAN Frames allowed to be transmitted over ISO-TP before the ECU Must send another flow control message back to the tester. A value of 0 means Infinite block size (No flow control). | Yes
st_min | Integer | The minimum delay in milliseconds before sending consecutive CAN Frames to the ECU (Values between 0xF1-0xF9 represent 100-900 microseconds) | Yes
ext_can_addr | Boolean | Indicates if the CAN Frame’s IDs are extended (29 bits - True), or standard (11 bits - False) | Yes
ext_isotp_addr | Boolean | Indicates if the ISO-TP transport layer shall use extended ECU addressing or not. | Yes