Reverse-engineering CAN and building ECUs using Elixir

Thibault Poncelet

Background

- After 7 years building an Open Banking aggregator in Elixir, We wanted to learn something new and test if Elixir could be a good fit for an automotive use case.
- In 2024, we have built an "Open Vehicle Control System": An Elixir based devkit, allowing to upgrade any vehicle.
- "Upgrade" meaning:
  - Engine swap
  - EV retrofit
  - Infotainment system
  - Autonomous driving

EV retrofit

2007 VW Polo Diesel

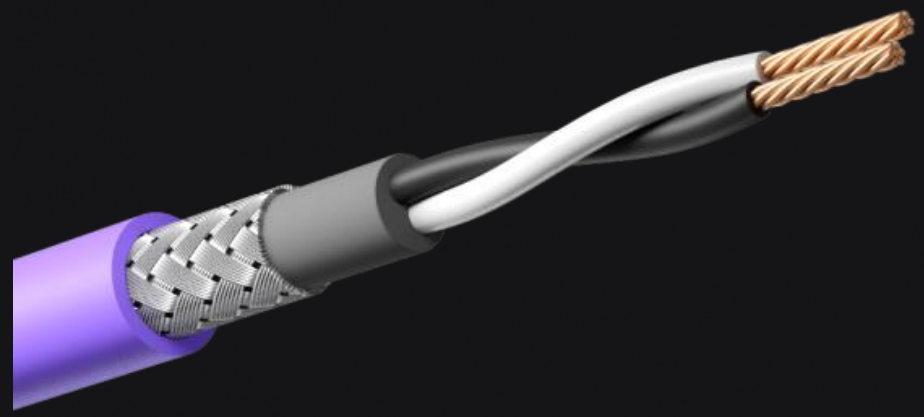
+

2013 Nissan Leaf EM57 motor

Today’s focus:

How to display the Nissan motor RPMs on the Polo’s dashboard?

CAN communication bus



CAN bus (Controller Area Network) is where all car components talk together

Standard protocol in automotive, aeronautics, industry, ...

Built-in support in the Linux kernel: libsocketcan

Although CAN is standard, the messages you transfer through it are not

CAN communication bus

Data exchanged on CAN is represented as a series of bytes

A frame with a specific ID is published periodically on the bus

Sniffer

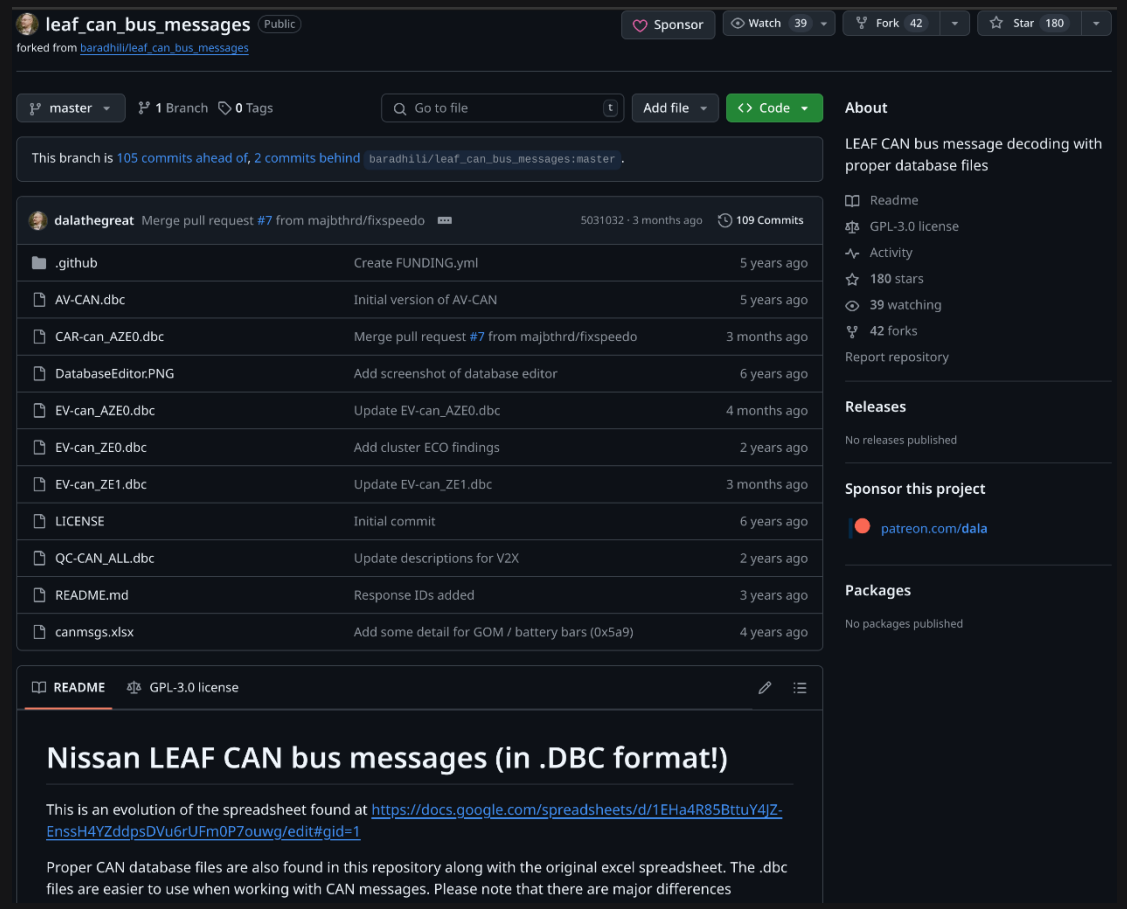
Delta	requenc	ID	0	1	2	3	4	5	6	7
0.0...	0 hz	0x00050	00	09	18	11				
0.0...	463 hz	0x00100	01	01	00					
0.0...	93 hz	0x00101	01	01	00					
0.0...	469 hz	0x00110	01							
0.0...	0 hz	0x00111	01							
0.0...	245 hz	0x0011A	04	40	00	00	C0	00	02	FD
0.0...	0 hz	0x001A0	00	05	00	00	FE	FE	00	00
0.0...	239 hz	0x001D4	6E	6E	00	00	87	44	01	23
0.0...	0 hz	0x001DA	A5	32	18	00	00	01	02	D5
0.0...	84 hz	0x00200	FF	3F	93	0A	66	05	03	
0.0...	0 hz	0x00201	00							
0.0...	0 hz	0x00280	00	00	04	00	00	00	00	00
0.0...	0 hz	0x00320	1A	00	7F	01	00	00	00	00
0.0...	0 hz	0x00388	0B	02	09					
0.0...	0 hz	0x0038A	B2	02	B0	00				
0.0...	0 hz	0x00390	24	00	30	02	00	8E	21	33
0.0...	0 hz	0x00393	00	10	00	00	20	00	00	35
0.0...	0 hz	0x00420	82	8A	89	FF	00	00	80	00
0.0...	0 hz	0x00470	00	02	00	FF	03			
0.0...	0 hz	0x004A0	00	00	00	00	00	00	00	00
0.0...	0 hz	0x0050B	00	00	06	C0	00	00	00	
0.0...	0 hz	0x00520	40	42	01	9E	2C	5E	4B	03
0.0...	0 hz	0x0055A	1E	3D	3C	00	5F	00	5A	E8
0.0...	0 hz	0x00570	87	21	FF	07				
0.0...	0 hz	0x005A0	00	00	00	42	C2	8E	19	2B
0.0...	0 hz	0x005D0	80	02	40	A0	30	41		
0.0...	0 hz	0x005D8	55	0C	00	03	10	00	00	00
0.0...	0 hz	0x005E0	00	FF	FF	00	00	00	80	00
0.0...	0 hz	0x00600	03							

CAN bus tools

- USB2CAN: An USB-to-CAN device
- SavvyCAN: a CAN bus reverse engineering and capture GUI.
- socketcand: a daemon that provides access to CAN interfaces on a machine via a network interface.

Step 1
Reverse the motor RPM frame

- Thankfully, there is a large community of Nissan Leaf tinkerers that already reverse engineered the Leaf frames and published it on the internet.



https://github.com/dalathegreat/leaf_can_bus_messages

0x1DA

Inverter Status Frame

Signal Parameters

Name: MG_OutputRevolution

Start Bit:

BYTES \ BITS ->	7	6	5	4	3	2	1	0
0	7	6	5	4	3	2	1	0
1	15	14	13	12	11	10	9	8
2	23 MG_ErrorCodes	22	21	20	19	18 MG_EffectiveTorque	17	16
3	31	30	29	28	27	26	25 MG_ErrorCodes	24
4	39 MG_OutputRevolution	38	37	36	35	34	33	32
5	47	46	45	44	43	42	41	40
6	55	54	53	52	51	50	49 MG_Clock	48
7	63 CRC_1DA	62	61	60	59	58	57	56

Bit Length:	15
Byte Order	LSB First (Little Endian)
Type:	UNSIGNED INTEGER
Scale:	1
Bias:	0
Min Value:	-16382
Max Value:	16382
Units Name:	rpm
Receiving Node:	Vector__XXX
Multiplexing	None / Multiplexed / Multiplexor / Extended
Multiplex Low Value	0
Multiplex High Value	0
Multiplex Parent	
Comment:	

Value Table:

Step 2

Reversing the Polo RPM Frame

- Pro tip: Do not remove the original engine before recording a complete CAN trace
- We could not find a DBC File for the 2007 Polo online
- VW is using similar frames on multiple cars of the same generation.

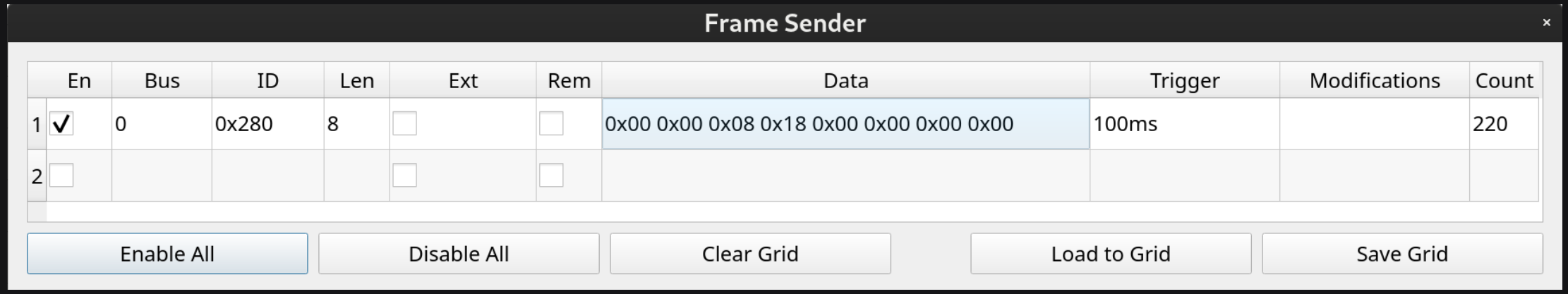
parse_can_logs / VW CAN IDs Summary.md

Preview | Code | Blame | 111 lines (103 loc) · 3.81 KB | Code 55% faster with GitHub Copilot

- 0x1AC
  - (?) `b1` - saw on 0/128 levels, ACC braking
  - (?) `b4` - noisy, correlates d(speed)
  - (?) `b5` - braking with engine, only on cruise (`bit7`)?
- 0x280
  - `b0` - clutch (`bit3`) and acceleration (`bit0`) pedals
  - `b1` = `b4` = `b7` - torque or engine load
  - `b3<<8+b2` - RPM
  - `b5` - acceleration pedal or cruise
  - (?) `b6` - some smooth graph

https://github.com/v-ivanyshyn/parse_can_logs

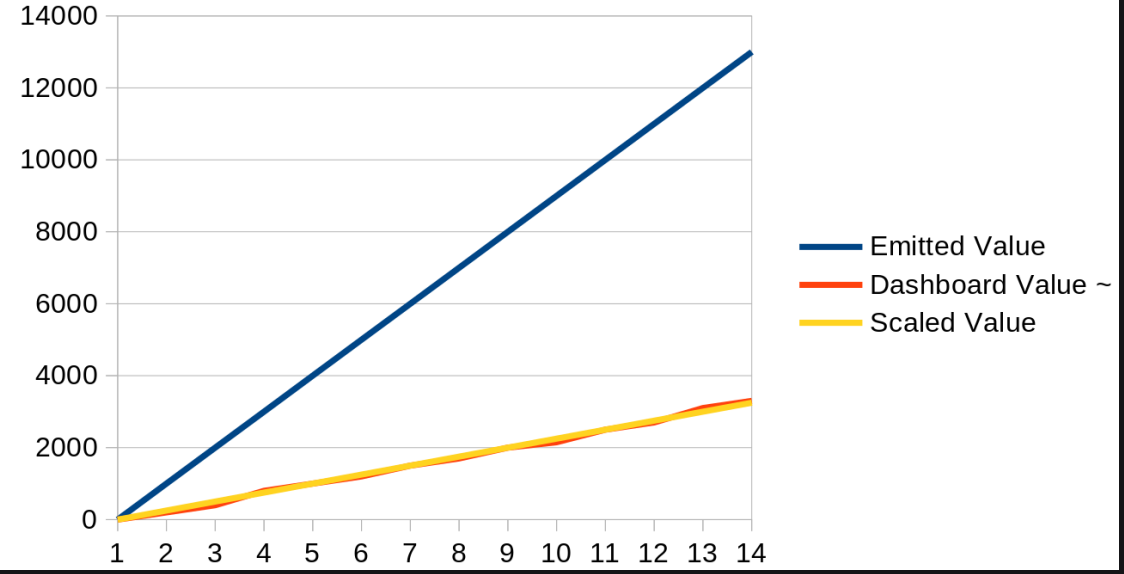
Emitting a custom frame with SavvyCAN



- Based on these findings, we tried to emit the 0x280 frame on the VW CAN bus at various frequencies.
- Some values of bytes 2 and 3 were actuating the RPM needle at 10Hz!
- Still need to translate real RPMs into the VW format
- physical value = offset + scale * raw_decimal_value

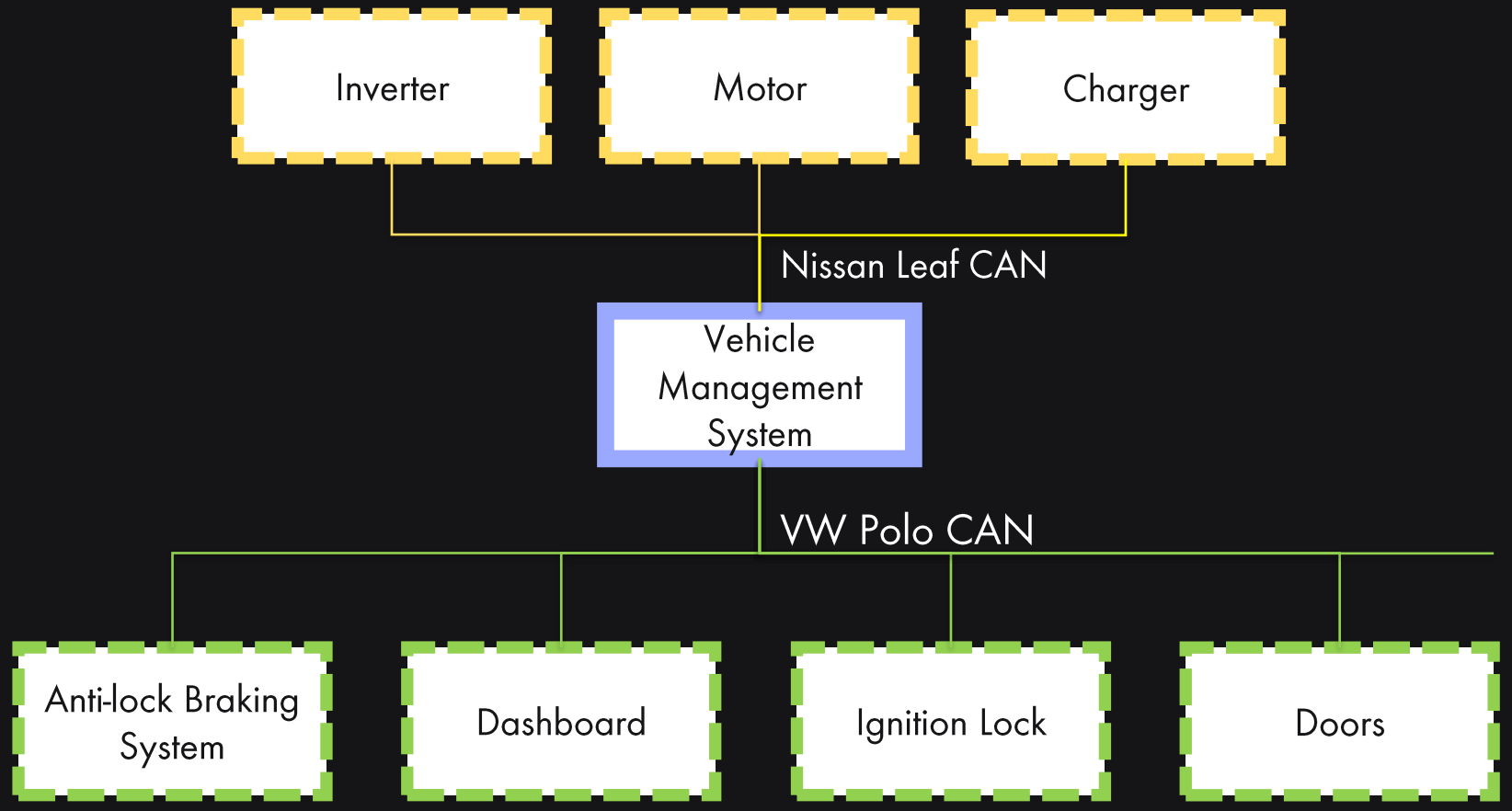
Reversing the RPM scale value

	A	B	C	D	E
1	Emitted Value	Dashboard Value ~	Scaled Value	Scale	
2	0	0	0	0.25	
3	1000	200	250		
4	2000	400	500		
5	3000	800	750		
6	4000	1000	1000		
7	5000	1200	1250		
8	6000	1500	1500		
9	7000	1700	1750		
10	8000	2000	2000		
11	9000	2150	2250		
12	10000	2500	2500		
13	11000	2700	2750		
14	12000	3100	3000		
15	13000	3300	3250		



Step 3

Concrete implementation using Elixir



CAN on Elixir

- Elixir is a dynamic, functional language running on the BEAM (aka the Erlang VM).
- The BEAM has been designed to build massively scalable soft real-time systems.
- Since Erlang was originally designed by Ericsson to build telephony switches, all the binary primitives are available out-of-the-box.
- Pattern matching is also helping a lot in parsing CAN frames.

Receiving and parsing one frame

```
with {:ok, socket}  <- :socket.open(29, :raw, 1),
     {:ok, ifindex} <- :socket.ioctl(socket, :gifindex, "can0" |> String.to_charlist()),
     address        <- <<0::size(16)-little, ifindex::size(32)-little, 0::size(32), 0::size(32), 0::size(64)>>,
     :ok            <- :socket.bind(socket, %{:family => 29, :addr => address})
do
  {:ok, raw_frame} = :socket.recv(socket)

  <<id::little-integer-size(16),
    _::binary-size(2),
    byte_number::little-integer-size(8),
    _::binary-size(3),
    raw_data::binary-size(byte_number),
    _::binary>> = raw_frame

  case id do
    0x1DA ->
      <<_::bitstring-size(32), rpm::big-signed-integer-size(16), _::bitstring>> = raw_data
      IO.inspect(rpm)
  end
else
  {:error, error} -> {:error, error}
end
```

Introducing cantastic

- An Elixir library doing all the heavy-lifting for sending and receiving CAN frames.
- Clean YAML DSL to describe your entire CAN Network
- Automatically spawns:
  - 1 receiver process (GenServer) per CAN network
  - 1 emitter process (GenServer) per emitted frame

https://github.com/open-vehicle-control-system/cantastic

Receiving the Leaf RPM value

```yaml
---
can_networks:
  leaf_drive:
    bitrate: 500000
    received_frames:
      name: inverter_status
      id: 0x1DA
      frequency: 10
      signals:
        - name: rotations_per_minute
          kind: integer
          endianness: big
          sign: signed
          value_start: 32
          value_length: 16
          unit: rpm
  polo_drive: ···
```

```elixir
defmodule Leaf.Inverter do
  use GenServer
  ...
  def init(_) do
    Cantastic.Receiver.subscribe(self(), :leaf_drive, "inverter_status")
    {:ok, %{}}
  end

  def handle_info({:handle_frame,
    %Cantastic.Frame{name: "inverter_status", signals: signals}},
    state)
  do
    %{
      "rotations_per_minute" => %Cantastic.Signal{value: rotation_per_minute}
    } = signals

    Polo.Dashboard.set_rotation_per_minute(rotation_per_minute)
    {:noreply, state}
  end
  ...
end
```

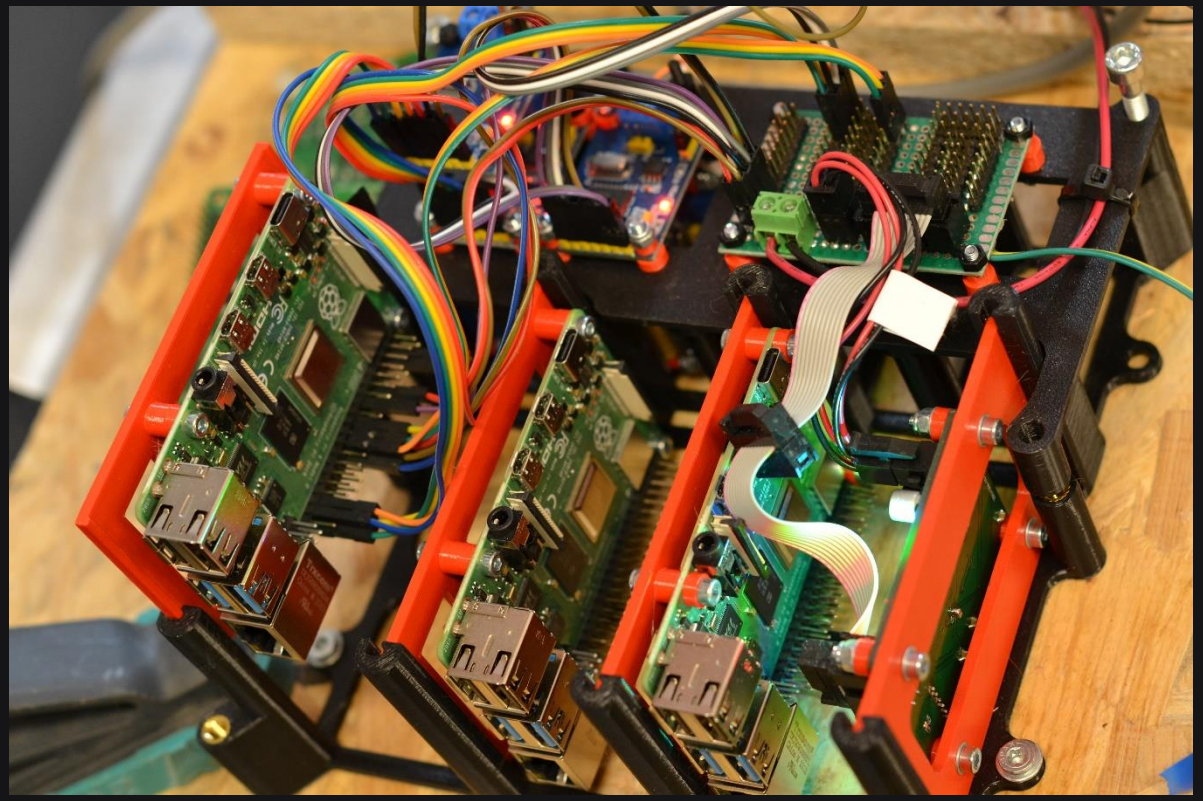
Emitting the Polo RPM value

```yaml
---
can_networks:
  leaf_drive: ...
  polo_drive:
    bitrate: 500000
    emitted_frames:
      name: engine_status
      id: 0x280
      frequency: 100
      signals:
        - name: rotations_per_minute
          kind: integer
          unit: rpm
          value_start: 16
          value_length: 16
          scale: "0.25"
```

```elixir
defmodule Polo.Dashboard do
  use GenServer
  ...
  def init(_) do
    :ok =  Cantastic.Emitter.configure(:polo_drive, "engine_status", %{
      parameters_builder_function: :default,
      enable: true,
      initial_data: %{
        "rotations_per_minute" => 0
      }
    })
    {:ok, %{}}
  end

  def set_rotation_per_minute(rotation_per_minute) do
    Cantastic.Emitter.update(:polo_drive, "engine_status", fn (data) ->
      %{data | "rotations_per_minute" => abs(rotation_per_minute)}
    end)
  end
  ...
end
```

Let’s push this on a Raspberry PI



And... It works!

Spin42

Want some more?

- Loïc will present more details about the robotic part tomorrow at 13:35 in UB2.147.
- Marc will present the OVCS project tomorrow at 16:00 in K.1.105.
- ovcs.be