

CAN Based Embedded Systems for Vehicle Applications

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Abstract - The implementation of various electronic subsystems in different kind of on-road and off-road vehicles is constantly expanding. Accordingly the new vehicles, instead of being mechanical systems, become advanced mechatronics systems which development and testing call for a new approach. Possibility of using data available on vehicles network seems to be extremely powerful tool on it.

The paper deal with new approach for service load data measurement and acquisition as a helpful tool in development and testing of different mechatronics vehicles' systems. Based on complexity of the system and different communication protocols on the vehicles' networks it was found as extremely practical solution to make approach which will be based on standards which are widely accepted by the industry. The new approach is based on the hardware and software platform oriented to the main vehicle controllers with the task to acquire data which exist on the network and which are relevant to the transmission service load. The said hardware as well as software utilities have to enable computer based monitoring of the vehicle systems behaviour and in that way to be the tool for new vehicles development.

The new system was tested in real service. It was found that system can enable significantly less time of vehicle instrumentation before testing and accurate data acquisition.

I. INTRODUCTION

The one of the most important factor which impacts the new product development, including it's testing is duration of development activities. It is of great importance to reduce the time from the initial technical specification of the new product till the moment of launching its' serial production. That task is mainly oriented to the development engineers which are under great pressure to satisfy market driven dements for fast and reliable new product design.

Many new designed vehicles' have to be in application with already installed advanced mechatronics systems. Simply speaking, if an existing vehicle would be placed in the service conditions which can be expected for the new vehicle then it can be used for service load measurement and acquisition which would be reference input for the new vehicle under development. It is of

great importance to analyse possibility for controllers which are the parts of vehicle's mechatronics systems. Simply speaking, collecting the service load based on standard electronic enables faster and more reliable new product development and validation.

The system which was developed for service load data acquisition on vehicles fitted with CAN bus is presented in the following text.

II. CAN BASED SYSTEM FOR SERVICE LOAD DATA ACQUISITION

The concept of the system is based on common situation on nowadays vehicles already fitted with electronic networks which are in use for data interchanging among different vehicle's controllers and their instruments (Fig. 1 - top). In spite of the fact that there are a few protocols which are in use on vehicles' networks it is of importance to be noted that all of them are based, mainly, on the same physical layer which is, nowadays widely accepted by all producers. That is physical layer defined through ISO 11898 or frequently named as CAN 2.0B. As it is given in Fig. 1 - bottom, all data which has to be transferred through this layer have to be organized in frames which start with SOF (Start of Frame) character, followed by 29 bits CAN identifier, RTR character, Control Field, 0 to 8 byte Data Field, CRC Field, Acknowledge Field and EOF (End Of Frame) bits.

From the message format is clear that data of interest for service load would be placed in Data Field. But, to be in position to use those data a few problems have to be solved. Those problems are mainly related to the CAN identifier (ID).

As it is defined by ISO 11898 CAN ID has to be 29 bits long. But, different protocols use that identifier in different ways. For transmission load investigation it is of importance to be oriented to the protocols which are dominant for engine and transmission controllers. As per situation in the market those controllers are mainly based on SAE J 1939 protocol. SAE J 1939 is a protocol with all 7 layers, but for the first two layers (lower two layers) it takes definition from ISO 11898 i.e. CAN 2.0B bus. Before establishing data acquisition from CAN bus it has to be analysed in which way SAE J 1939 uses CAN's identifier (Fig. 2b). In brief, in J 1939 the first 3 bits of ISO 11898 Identifier (ID) are in use for priority (000 for

the highest priority and 1111 for the lowest priority). The next 18 bits are in use for PGN or Parameter Group Number.

The PGN is the key element for understanding possibilities for service data acquisition from the existing vehicle's network. Actually, all data which have to be sent to the CAN bus are organized in the groups. For example, all data relevant for the electrical transmission controller would be placed in the data message (according to the SAE J 1939 terminology: PDU i.e. Protocol Data Unit) in which PGN would be 61442 and 61445. Data available in messages (i.e. messages Data Fields) with stated PGN(s) would be: transmission selected gear, transmission actual gear ratio, percent of clutch slip, transmission input shaft speed, etc. It is clear that lot of data significant for transmission service load are already available on the vehicle bus in the messages with appropriate PGN's.

Out of data messages with PGN(s) related to the transmission controllers, there are other messages of the interest. Those are mainly the messages from engine electronic controller, retarder controller, axle controller, etc.

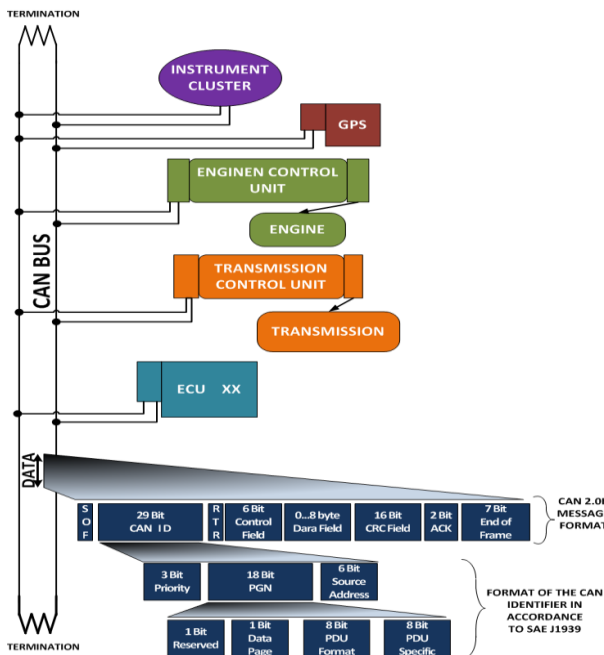


Fig. 1.: Common configuration of the vehicle's CAN bus (top) and the message format (bottom).

It is clear that for the concept of service load data acquiring is essential to be familiar with the PGN concept. Unfortunately, the concept of PGN and establishing CAN identifier is not as simple as said above. Strictly speaking, PGN has 4 parts: Reserved bit, Data Page bit, PDU Format - 8 bits and PDU Specific - 8 bits. Also, it has to be recognized that PDU Specific can be defined in two different ways based on the value of PDU Format: as the Destination Address (for PDU Format values 0 to 239) or as Group Extension (For PDU Format values 240 to 255). All of this makes approach to

the messages on the CAN bus (PDU) very complicated and can cause a lot of problems.

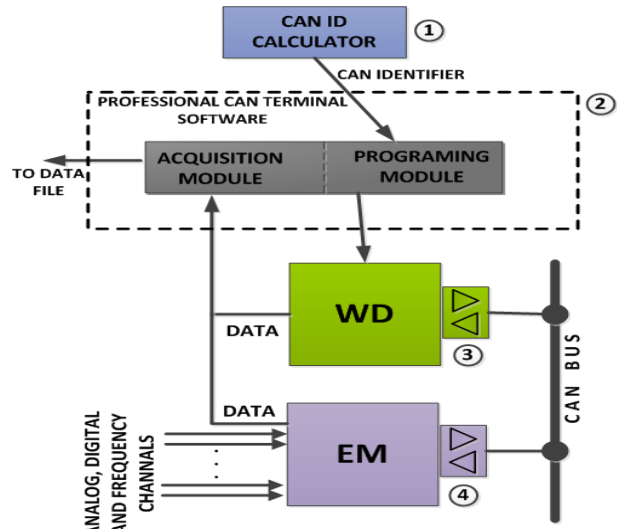


Fig. 2.: Hardware and software components developed through the project (meaning of numbers and abbreviations are given in the text).

As it was explained, defining the proper PGN is not sufficient for successful data acquisition i.e. acquiring of data of interest from the CAN bus. It is also important to know the position of the value of interest in Data Field. The Data Field is 8 bytes long and encloses different data. Their allocation in Data Field must be known for proper data extraction.

Based on explained concept of data flow through CAN bus it is obvious that first interest in establishing the system for data acquisition has to be oriented to providing of adequate software tools for PGN, CAN Identifier (ID) and Data Field evaluation.

To reduce problems i.e. to enable easier service data acquisition through CAN bus the project which results are given in this paper considered development of a few software and hardware components which are listed below.

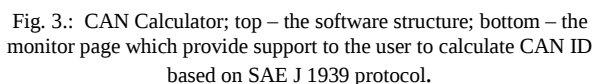
1. CAN Identifier (ID) Calculator – software component,
2. Professional CAN Terminal – software component,
3. Watch Dog (WD) – hardware component,
4. Extension Module (EM) – hardware component.

The scheme of functional interdependence of the developed components are given in the Fig. 2 where components are marked with appropriate numbers as given above.

The first of developed components is “CAN identifier (ID) Calculator”, with the structure as in the Fig. 3. Through varies data bases it provides support in defining CAN identifier from different standards including SAE J 1939. The user has to approach to the date base trough Excel (Fig. 3, path mark with 1). The data base can be searched in different ways including searching based on data of interest such as engine torque, engine rpm, etc. In that way user can find out the value

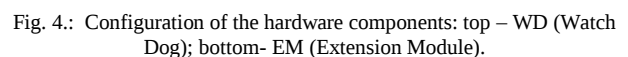
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graph TD; DB[DATA BASES] --> C[CALCULATOR]; I1898[ISO 11898 (CAN 2.0B)] --> C; C --> CID[CAN ID];
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message (i.e. from PDU).



The next part of the data acquisition system developed for the project was dedicated hardware (see Fig. 4 - top), named WD. Actually that is Watch Dog type hardware with the following basic specification:

- One Ethernet gate,
- Memory block for application programs, etc. (see Fig. 4 - top).



Once when user defines all parameters WD performs operation of grabbing data of interest from the CAN bus and places values of interest in the memory slots. The on line monitoring and data acquisition of the values are available through the Ethernet gate.

- Automatic allocation of WD within local network,
- Definition of parameters which defines data of interest from CAN bus.

- Monitoring of ongoing communication in real time and data storage,
- Possibility for sending messages to the CAN bus.

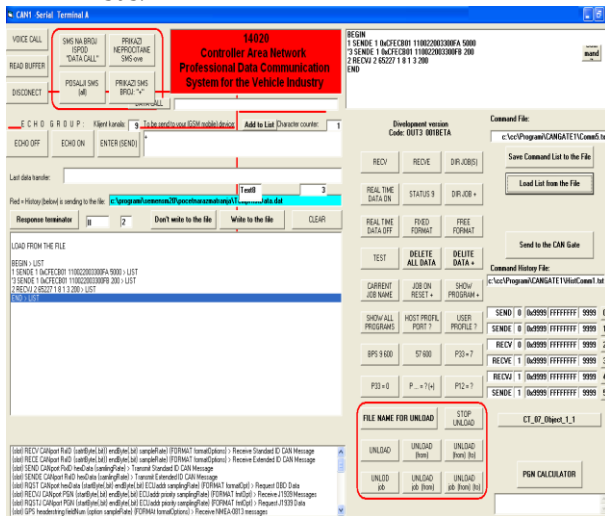


Fig. 5: “Professional CAN Terminal” software – the main monitor page.

The second hardware component which was developed in this project was “Extension Module” or EM (the configuration given in Fig. 4 – bottom). The EM, among others, performs two essential services:

- Analog to digital conversion of the analog values and
- Broadcasting CAN based messages with converted values.

The necessity for development of the module comes from the circumstance that not all values of interest were available on the CAN bus. It is common situation that there are some values of interest for acquisition which are broadcasting by no one electronic control unit connected to the vehicle’s bus. In such cases there are two possibilities for acquiring data of interest: (i) to use separate (additional) data acquisition system or (ii) to provide the system which will measure the value(s) of interest and make up the PDU(s) with Data Field in which data of interest (measured values) would be incorporated. The second noted way has some advantage. It enables utilization of the already existing data acquisition system which is oriented to the CAN bus, for acquisition of all needed data and makes needless any additional measurement and acquisition unit.

In this project the second of two stated approaches was used.

III. CAN BASED SYSTEM APPLICATION

As it is noted in the introduction, one of the important advantage of data acquisition through CAN bus is to provide accurate service load data for the system which has to be developed, by using data from already existing systems. This chapter deals with that kind of the new data acquisition system application i.e. its application in designing a tractor transmission.

For the purpose of designing the new agricultural tractor transmission it was necessary to make in detail investigation of gear box input power (actual input rpm and torque) as well as front and rear axle input torque and rpm. All those data was needed as the input for precise design calculation of the new tractor transmission.

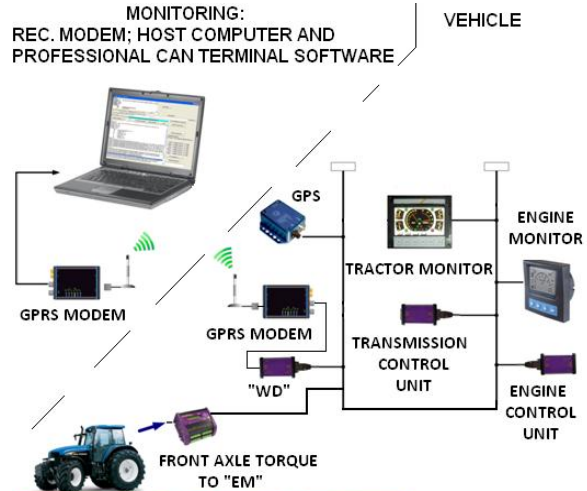


Fig.6: System for service load data acquisition trough CAN bus: top – configuration of the system, bottom left – EM built in the tractor; bottom middle – GPRS modem built in the tractor, bottom right – installation of the WD unit.

It was found that tractor with close the same specification as the new tractor which had to be developed existed on the market. Based that the existing tractor was “CAN based” it was found as cost and time effective to provide transmission service load data by utilization of CAN based data acquisition system on existing tractor. Consequently, it was brought out as possible to avoid making of the prototype of the new tractor for the purpose of service data investigation.

The existing tractor was instrumented in the way that WD was installed on its CAN bus (see Fig. 6). For real time data monitoring WD’s Ethernet port was connected to Ethernet port of GPRS modem i.e. it was establish data channel from CAN bus to GPRS network. Monitoring station was fitted on the local computer with Professional CAN Terminal software and with another GPRS modem (receiver).

For acquiring data which were of interest for this investigation and which were found as missing in CAN bus traffic (broadcasted by no one ECU on the network) the Extension Module (ED) was connected to the bus.

Since the front axle input torque was not-broadcasted value of interest the additional front axle torque measurement line was established on tractor's propeller shaft and the analog signal from the torque conditioning unit was directed to the EM.

Before data acquisition, it was necessary to find out appropriate PGN(s) part of Data Field in PDU(s) and ID for the values of interest. That was done with previously developed CAN Calculator software. The following text gives in detail explanation of that process. Given explanation is of general importance since it provides guidance for other researcher and facilitates their work on data acquisition through CAN bus.

For the engine speed which is (when the vehicle's clutch is engaged i.e. while the transmission is loaded) equal to the transmission input speed, the relevant PGN is 61444 and 2 bytes long data of engine rpm starts in 4th byte in Data Field. It was found that engine control unit on the tractor had address 0. Based on SAE J 1939 i.e. with help of CAN Calculator software it was found that corresponding CAN identifier which of interest as ID = 00DE0400_{hex}. The whole process can be visualized as it was given in Fig. 7 and represented in symbolic way as follows:

Engine speed:
Priority Level: 3 >>> ID = 011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61444_{dec} 00F004_{hex} = xxx001111000000000100xxxxxxxxx_{bin}
Source: 0_{dec} = 0_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000000_{bin}
Result ID = 217056256_{dec} = 00DE0400_{hex}
Start position in Data Field: 4th byte
Length: 2 byte
Note: "x" replaces 0 or 1 i.e. bit can be set or reset.

The next value of interest is engine torque or transmission input torque which is broadcasted by the engine electronic controller, with the same PGN. The calculated output torque of the engine is transmitted as indicated torque in percentage of reference engine torque. Consequently, from CAN calculator software it was found that the ID of the message which contents data relevant for torque was 217056256_{dec} or given in-deal:

Engine torque
Priority Level: 3 >>> ID = 011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61444_{dec} 00F004_{hex} = xxx001111000000000100xxxxxxxxx_{bin}
Source: 0_{dec} = 0_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000000_{bin}
Result ID = 217056256_{dec} = 00DE0400_{hex}
Start position in Data Field: 2nd byte
Length: 1 byte

Even the torque level is transmitted in percentage of reference engine torque one can easily find out the actual torque. That is possible based on the engine characteristic which is always defined in ECU memory as rpm/torque matrix. The matrix can be given in one of three modes. Mode 1 provides a complete curve of speed and torque points while modes 2 and 3 provide a partial curve of speed and torque points and a separate end speed governor characteristic. Data from the matrix loaded in ECU can be asked by sending the request with PGN 65251.

Here, we have to recall the part in which the Professional CAN Terminal software was described. As

one can recognize in given specification of that software it's main purpose is to help in WD programming, to enable monitoring of the traffic on the CAN bus and to support data acquisition. But, as it was given in the software specification, it also has capability to send messages to the CAN bus. Here it is clear the purpose of that (sending request with PGN 65251).

Before starting data acquisition it is essential to send request with PGN 65251 to CAN bus. That request would be served by engine control unit. The ECU will replay with message with multi-data field (total length 39 bytes) which will be matrix data. Only in that way one will be in position to find out torque value (in Nm). The actual torque level would be found based on torque value in percentage which would be transmitted with ID 00DE0400_{hex} as explained above and from the data which would be enabled through request with PGN 65251.

The next values of interest were actual or engaged gear ratio and actual transmission range. Taking together, those two values give information of overall transmission ratio. Both are defined in data field of the messages with the PGN 61445, as follows:

Transmission actual gear ratio:
Priority Level: 6 >>> ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61445_{dec} 00F005_{hex} = xxx001111000000000101xxxxxxxxx_{bin}
Source: 2_{dec} = 2_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000010_{bin}
Result ID = 418383106_{dec} = 18F00502_{hex}
Start position in Data Field: 2th byte
Length: 2 byte

Transmission current range:
Priority Level: 6 >>> ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61445_{dec} 00F005_{hex} = xxx001111000000000101xxxxxxxxx_{bin}
Source: 2_{dec} = 2_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000010_{bin}
Result ID = 418383106_{dec} = 18F00502_{hex}
Result ID = 418383106_{dec} = 18F00502_{hex}
Start position in Data Field: 7th byte
Length: 2 byte

In, addition, it was needful to provide data for real tractor speed. That is extremely important since there is no other way to find out wheel slip (and to give input do design time for development of differential locks) out of measuring the real vehicle speed and each wheel rpm.

Real vehicle speed value, in nowadays tractors, is provided based on GPS based Doppler transducer which broadcast measured value to CAN bus with PGN 65256 in according to concept as given bellow. The priority and position of the data in data field are:

Navigation-Based Vehicle Speed (real tractor speed):
Priority Level: 6
ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 65256_{dec} = 00FEE8_{hex} = xxx0011111101101000xxxxxxxxx_{bin}
Source: 10_{dec} A_{hex} = xxxxxxxxxxxxxxxxxxxxxx00001010_{bin}
Result ID = 419358730_{dec} = 18FEE80A_{hex}
Start position in Data Field: 3rd byte
Length: 2 byte

A few other values of PGN are also taken in consideration during the development but we will not discuss them here.

IV. VERIFICATION OF THE SYSTEM

This section deals with verification of the system results of measurement conducted with the previously explained system.

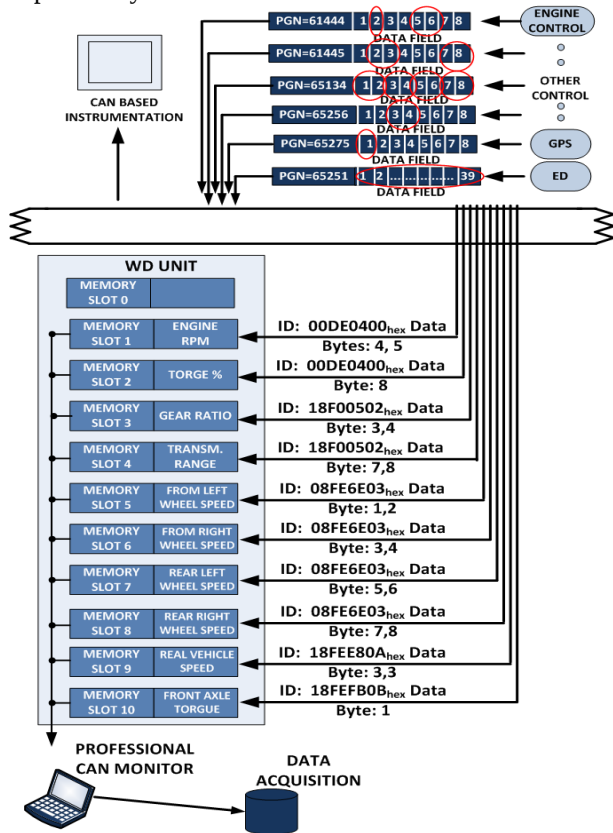


Fig.7: Concept of the measurement.

The agricultural tractor with service mass of 2850 kg, mass distribution front : 1250kg, rear: 2600 kg, rated engine power of 66 kW at 2250 rpm with transmission concept 6x2 gear ratio forward, 4 WD and with it's own CAN bus was fitted with Watch Dog (WD) hardware, Extension Module (EM) hardware and GPRS modem as given in the Fig 6. On the "receiving" side it was establish server with installed "Professional CAN Terminal" software and receiving GPRS modem.

The vehicle was submitted to the two types of tests:

- Regular service application (hauling, in field operation, etc.) as per predefined scenario and
- Non regular service application i.e. special tests created for in detail investigation of CAN based acquisition system's capability.

To enable verification of the new data acquisition system the conventional measurement (taken as a reference) of gearbox input torque and rpm was conducted simultaneously with measurement done with the new system. The reference measurement was done by implementation of full bridge strain gauge arrangement for torque measurement (at the output gearbox shaft and propeller shaft for front axle) and inductive transducers for rpm measurement (at the input gearbox shaft) as well

as multichannel signals conditioning unit (HBM's Quantum). The position of the transducers installation was selected based on available space for their installation.

The testing according to the first service condition (regular service application) was conducted with the purpose of defining the transmission input torque service load distribution. Actually, it was necessary to provide to design team information related to the percentage of particular torque level in total service life of the transmission.

It was found that the system is capable to enable accurate measurement with close to no preparation of the tractor. Thanks to GPRS connection it was possible to make no limitation on area where the tractor will operate as long as GPRS network is available.

It was found that suggested concept is extremely powerful. Without implementation of suggested concept (software and hardware developed in this project) the preparation time of the tractor was 2 weeks (because of complexity of torque measurement in the gearbox). In addition, disassembling of equipment and assembling transmission after measurement regularly took one week. With implementation of CAN based hardware and software for data acquisition the preparation time was a few hours, only.

V. CONCLUSION

The CAN based approach in monitoring of the vehicles' mechatronics systems can significantly reduce time for vehicle instrumentation and enable to development engineer to make whole testing in the already existing vehicle before making the prototype of the new vehicle or system under development.

The concept is accomplished by building up dedicated hardware and software. Totally two hardware and two software components were developed. The results of initial testing of all developed components indicate their good performances.

Trough initial testing of the development platform it was accomplished accurate monitoring.

VI. REFERENCES

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