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Original Citation

Selig, Michael, Shi, Zhanqun, Ball, Andrew and Schmidt, K. (2012) A modern diagnostic approach for automobile systems condition monitoring. Journal of Physics: Conference Series, 364. 012013. ISSN 1742-6596

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A modern diagnostic approach for automobile systems condition monitoring

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Abstract. An important topic in automotive research and development is the area of active and passive safety systems. In general, it is grouped in active safety systems to prevent accidents and passive systems to reduce the impact of a crash. An example for an active system is ABS while a seat belt tensioner represents the group of passive systems. Current developments in the automotive industry try to link active with passive system components to enable a complete event sequence, beginning with the warning of the driver about a critical situation till the automatic emergency call after an accident. The cross-linking has an impact on the current diagnostic approach, which is described in this paper. Therefore, this contribution introduces a new diagnostic approach for automotive mechatronic systems. The concept is based on monitoring the messages which are exchanged via the automotive communication systems, e.g. the CAN bus. According to the authors' assumption, the messages on the bus are changing between faultless and faulty vehicle condition. The transmitted messages of the sensors and control units are different depending on the condition of the car. First experiments are carried and in addition, the hardware design of a suitable diagnostic interface is presented. Finally, first results will be presented and discussed.

1. Introduction

Diagnostic systems in the automotive have been existing in a different state of technical complexity since the first vehicles were invented. During the last decades, fundamental changes occurred. The visual inspection as the most basic approach has been improved through the introduction of electrical measuring systems, which enhanced the scope of the diagnostic procedure. This implies effective tools allow e.g. an inspection of the ignition system. The implementation of electronic systems including communication interfaces caused an even more drastic change. Beside the state-of-the-art requirements of latest control units, permanent failure storage and standard diagnostic interfaces are realized.

In general, it has to be differentiated between two different diagnostic methods, the onboard (OBD) and offboard diagnosis. The control units are permanently checking their own condition and the condition of the controllers' surrounding in self diagnosis mode. This is carried out either when a corresponding boundary condition is exceeded, hence when a problem has appeared or periodically in a program loop. The OBD is a representative example of the self diagnosis, which has its origins in the U.S. Thereby, the OBD continuously analyses the cars' emission data. All measured information needs to be checked for a specific threshold value. The operating condition and the specification define the threshold values. Exceeding the thresholds will be indicated via a warning lamp (MIL) in the dashboard of the car. The control units also store the

malfunctions permanently to allow an investigation of the problem at the garage. To access the stored trouble code a tester is needed, which is an example for offboard diagnosis [1].

The matter of offboard diagnosis is analyzing the trouble code of the control units. Early diagnostic systems used a light, either as internal warning lamp, e.g. the engine control unit lamp in the vehicles' dashboard, or as an external device. Blinking codes indicated the malfunction and isolated the fault location. Advanced automobiles with different sensors, actuators and several control units need a more precise diagnostic approach. The method of fault isolation is no more effective and an option with a better fault description is needed. For that reason a trouble code entry in the fault memory is defined by explicit rules and symptoms. A high voltage condition on the controllers' signal input is an example. The trouble code is represented in the tester. State of the art safety- and comfort systems using multiple control units which are divided into sub-networks, distributed over the entire vehicle. Thereby, the control units using different bus systems, e.g. CAN, FlexRay, LIN or MOST to communicate with each other. An example of the in-vehicle cross-linking with the sub-networks 'Powertrain', 'Comfort' and 'Infotainment' is shown in Figure 1.
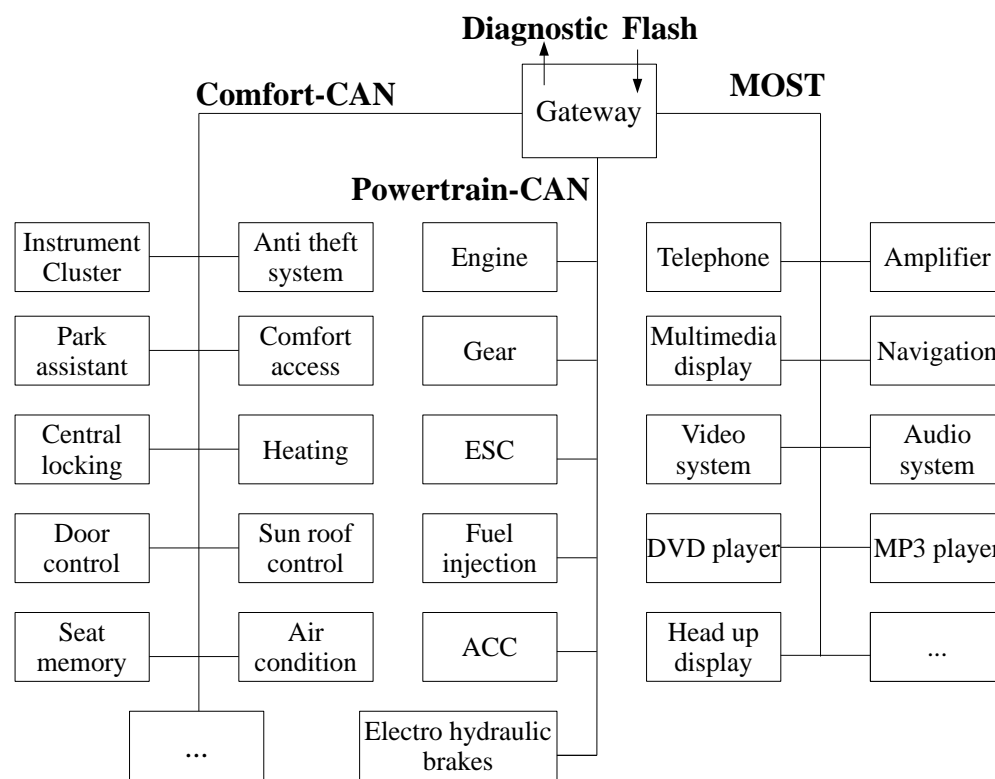
Figure 1. Example of automotive cross-linking.

The functions are distributed over several control units and the systems are developed and produced by different manufactures. Considering these difficulties provides high demands on an accurate diagnosis. A single fault can affect several control units due to the in-vehicle cross-linking, which will be illustrated in the following theoretical example: A sensor fault is detected by a control unit. The monitor program of the sensor generates trouble codes in the fault memory. Simultaneous further controllers rely on the messages of the concerned control unit. But the messages of this controller are no longer correct or transmitted on the bus. Thereby, further control units will generate different trouble codes in their fault memory or will turn into fall back mode. Beside the actual fault the offboard diagnostic tool will read further trouble code, caused by different monitoring procedures. These procedures neither correlate in content nor in time. The task of the diagnostic tool is the inference of the actual fault from the trouble codes [1].

Conditioned by safety requirements only a small part of the controllers' diagnostic services can be accessed during regular driving. This is a disadvantage of the current approach in term of diagnostic requirements. Accessing the fault memory of the control units is not possible or very limited while the vehicle is driving [2]. This means the driver does not obtain explicit

information about the cars' condition and if a malfunction appears, the fault information is or only very limited available. To evaluate the seriousness of the present fault is only partly possible for the driver and the safeness of driving is restricted.

In the current applied diagnostic approach each single control unit detects the faults of the integrated sensors and their own. However the quantity of control units have steadily increased and new functions are shared over several controllers over the past years [3]. Recapitulatory the present diagnostic approach has the following disadvantages:

- Different standards are used over the past years.
- During the vehicle is driving only limited diagnostic services are available.
- Different control units can be affected by a single fault, caused by the network.

2. The modern diagnostic approach

Till now the transmission of messages between the different control units and the cross-linking is not considered to detect vehicle malfunctions. The advantage of the new diagnostic approach is the usage of the transmitted messages on the bus as fault detection method. According to the authors' conception, the transmitted messages change between faultless and faulty vehicle status. Depending on the condition of the car, the transmitted messages of sensors and control units are different. Hence, the onboard diagnostic approach is improved by using a function of analysing the bus level, which has the following advantages over the current offboard diagnostic method:

- Through a precise presentation of trouble code no components of the car are replaced on suspicion, which decreases repairing costs and time.
- An embedded fault memory in the control units is unnecessary. Hence, the purchases of cost intensive offboard diagnostic tools are no longer necessary for the MOT and garages.
- An advanced onboard diagnostic approach supplies more precise information about malfunctions and therefore, the improvement of vehicles.
- Precise malfunction information exists for the driver at any time. Malfunctions are indicated as soon as a fault occurs. Driving with a faultless car is possible.

The advanced fault detection method uses the transmitted bus messages as fault indicator. The developed onboard diagnostic tool is able to communicate with each bus member. This means:

- Smart sensor data are checked for plausibility by monitoring the transmitted messages on the in-vehicle bus network.
- The controller and actuator condition can be enquired by sending status messages over the in-vehicle bus network.
- Incorrect commands from the control units for actuator or other control units can be detected by monitoring the transmitted messages on the in-vehicle bus network.

A detected fault can be presented as trouble code on a display by the diagnostic tool. [4].

3. The hardware design of the diagnostic tool

For the implementation of the new diagnostic method, it is necessary to develop an interface to the in-vehicle bus system. The designated data flow chart is shown in Figure 2.
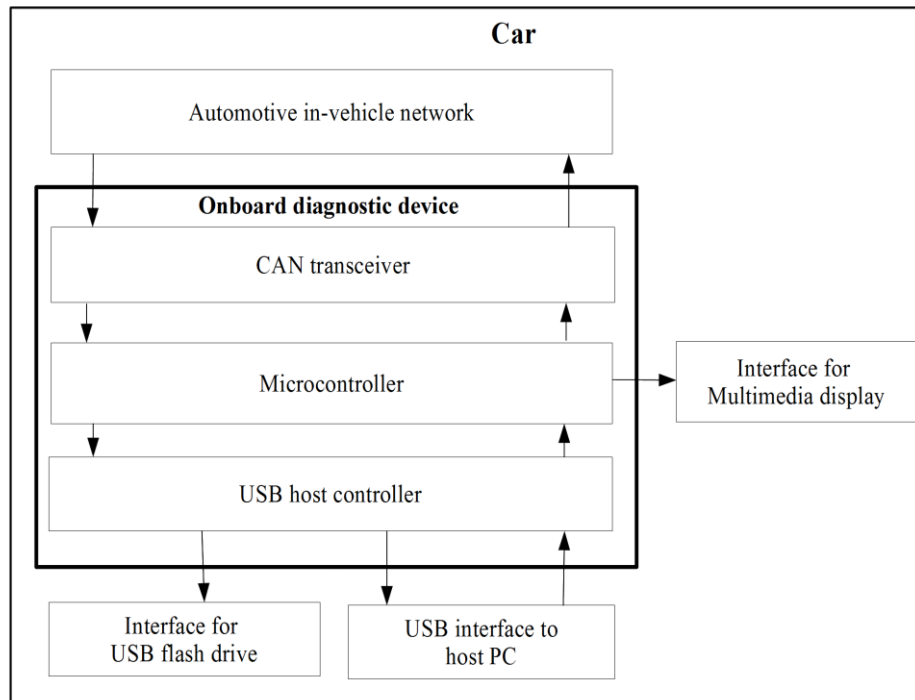
Figure 2. Diagnostic tool data flow.

A CAN bus monitor is used as basis and extended with features and functions for the hardware layout of a prototype diagnostic tool. The schematic is shown in Figure 3.
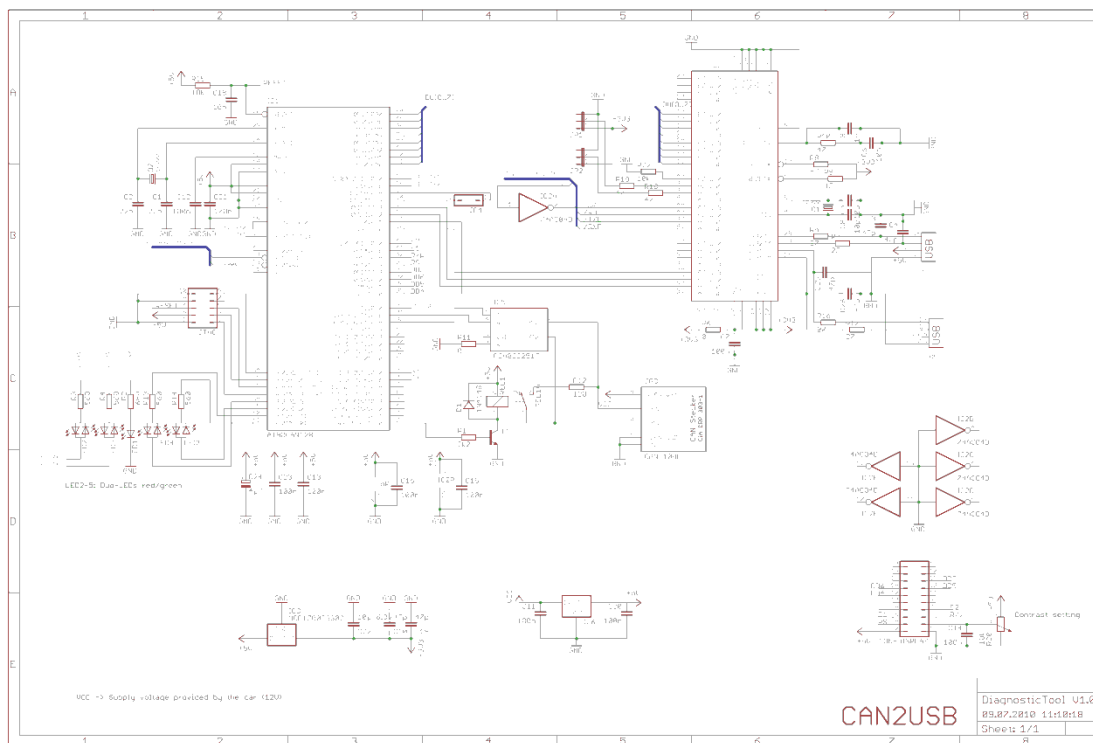
Figure 3. Diagnostic tool hardware layout.

The used components are listed in the following:

- The Atmel AT90CAN128 is an 8-bit low power microcontroller and includes a CAN controller [6].
- The port 'C' is used as display interface to indicate detected faults.
- The Philips CAN transceiver PCA82C251 provides an interface between the physical bus and the CAN protocol controller. It is mainly implemented in cars, trucks and buses for applications up to 1Mbaud. Differential transmit capability is provided by the device to the physical bus and differential receive capability to the CAN controller [7].
- The FTDI USB host controller VNC1L is an embedded single chip. In the layout are two USB ports wired. One port serves as USB slave and the other one as USB host. The USB slave provides an interface, a virtual RS232 port, between a personal computer and the diagnostic device to monitor the CAN bus in real time, which is especially helpful to implement a characteristic look up table with indicative fault messages. Thereby, the data are transmitted over the parallel FIFO interface [8]. The USB host allows connecting a USB flash drive to the diagnostic device. Hence trouble codes can be stored on a memory stick if a specific message is transmitted. Thereby, the data are transmitted over the SPI interface of the AT90CAN128 microcontroller.
- The cars' battery is used as power supply for the designed hardware. As the hardware components AT90CAN128 and the CAN transceiver need 5V supply voltage, a voltage regulator 7805 is used. The maximum input voltage of the 7805 is 35V, the output is the needed 5V. Usually the car provides an input voltage of 12V. The voltage regulator MCP1700T3302 is needed as the VNC1L needs a supply voltage of 3.3V.

4. Experimental Results
The designed CAN hardware has been connected to a test car provided by the University of Huddersfield using the OBD interface. Figure 4 shows the experimental setup.
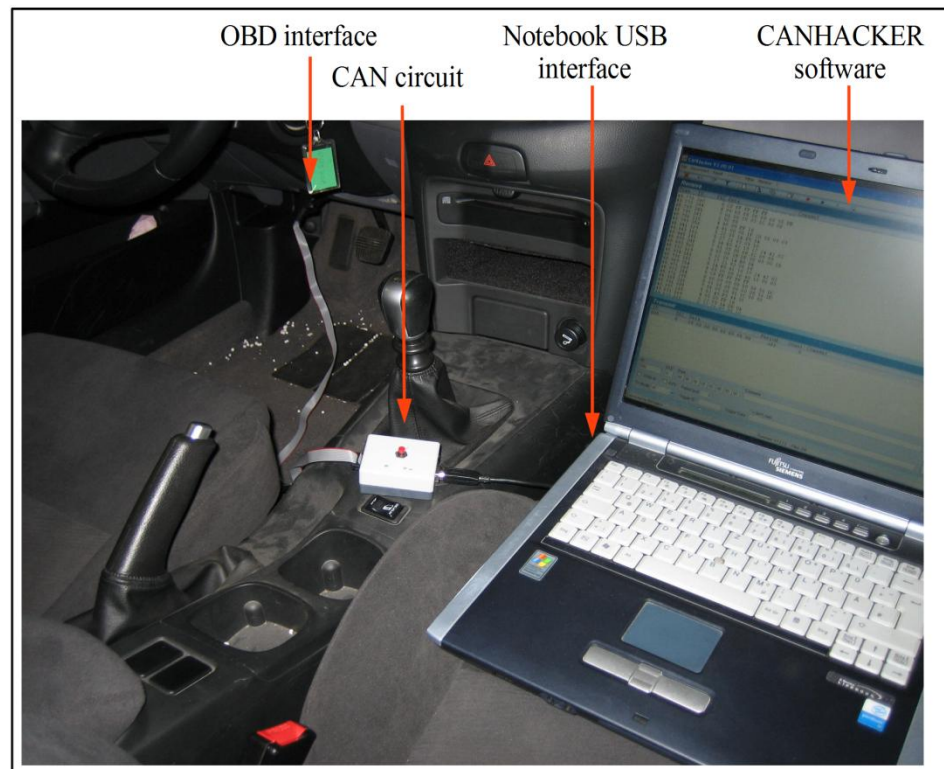

Figure 4. Recording of CAN bus messages.

The freeware software tool CANHACKER [9] is used as CAN monitor. The CAN messages was recorded and verified with a professional industrial tool, the National Instrument PCMCIA-CAN for monitoring the CAN bus. The sampled messages with the self designed CAN hardware and the NI tool are showing the same message IDs. This means the designed hardware is working correctly.

The connection between the USB memory flash drive and the microcontroller AT90CAN 128 and a display was tested using the experimental setup shown in Figure 5. The AT90CAN128 was successfully writing three test files on a memory flash drive and a test message was shown on display. Blackouts of sensors with a CAN bus interface, e.g. smart wheel speed encoder, can be detected with the analysing tool till this end.
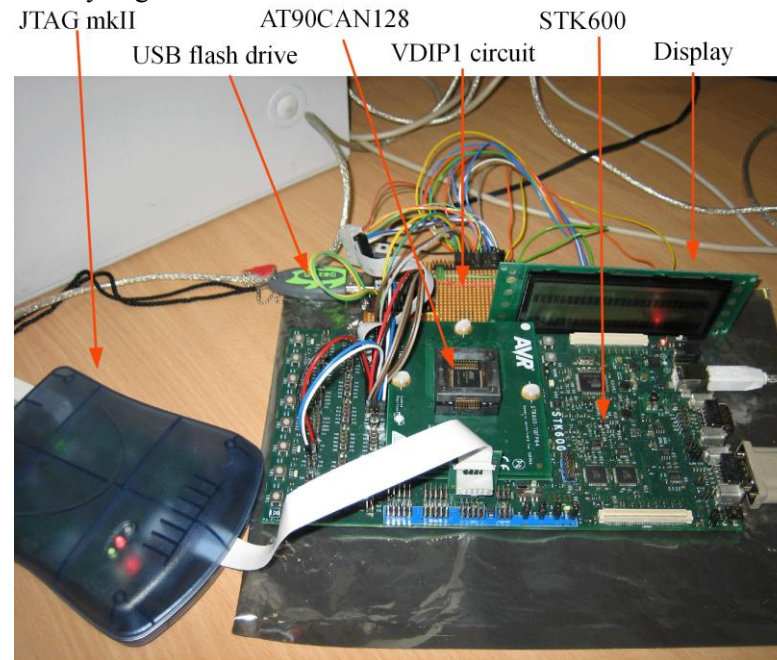
Figure 5. Assembling of the USB and display interface.

5. Conclusion

In this contribution is the hardware design for a new diagnostic approach presented. First experimental tests are carried out and the fault detection algorithm is under development. For the detection of more complex malfunctions cooperation with well-known companies in the vehicle area are in discussion.

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