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SENSOR NETWORK FOR VEHICLES TRANSPORTING DANGEROUS GOODS

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ABSTRACT: The described sensor network has been designed to enable real-time monitoring of dangerous goods status during transport. The network is based on well known CAN bus which is widely used in automotive industry. The sensors measure temperature, LPG concentration, vehicle inclination and pressure. Status of the sensor is transferred via OBU into monitoring centre by GSM network.

KEYWORDS: Sensor, LPG, inclination, temperature, pressure, CAN bus, on-board unit

❖ INTRODUCTION

The dangerous good transport by road network is everyday threat for population and environment close roads which are being used for these transports. Despite of respecting of all regulations there always exists possibility of technical failures, crashes and malfunctions. For elimination of these risks an information system for the monitoring of the dangerous good transport has been developed. This system uses standard communication technologies GPS, GSM/GPRS and CAN (Controller Area Network). The whole project of dangerous goods transport monitoring was solved as a part of the project CONNECT [1] which was funded by the European Commission.

The sensor network for vehicles transporting dangerous goods has been designed to monitor selected parameters of the dangerous goods during transport. Conception of the sensor network is open to enable flexible selection of number and types of the sensor units. For connection to the vehicle OBU (On Board Unit) a standard industrial CAN bus has been selected. CAN bus is often being used in automotive industry for its robustness, resistance against the external environment and fault management [7]. Topology of designed sensor network is shown in Fig. 1.

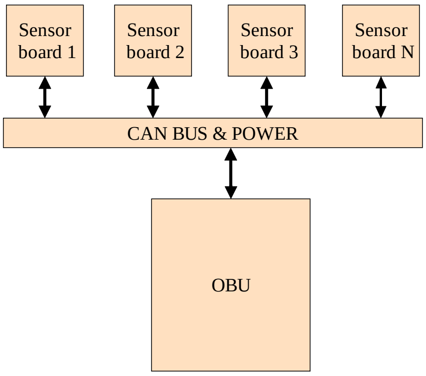


Figure 1. Interconnection of the sensor network

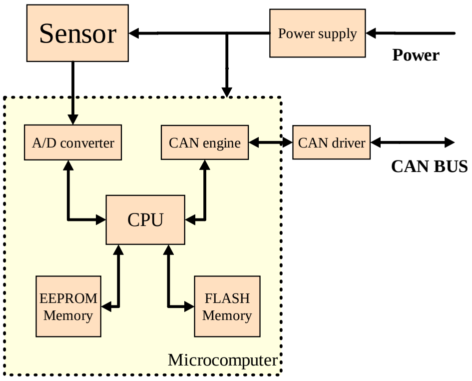


Figure 2. Block diagram of sensor unit

❖ CONCEPTION OF THE SENSOR UNITS

Because standard types of analog or digital sensor elements have not direct CAN bus interface the conception of intelligent sensor units has been selected. Every sensor is equipped with its own microcomputer which performs several functions: communication, diagnostic and data processing. During the design steps of sensor network the reliability and autodiagnostic properties have been emphasized [6]. The microcomputer of sensor unit periodically checks the checksums of program memory and configuration memory. Next diagnostic mechanism built in sensor unit is self test of used sensor elements. The simple sensor elements (contacts, temperature sensor etc.) are doubled and the microcomputer compares if both elements give similar data in the predefined tolerance field. All sensor units have the same block diagram which is in Fig. 2. Except for the sensor element the unit contains microcomputer with CAN bus support and driver of CAN physical layer. The sensor unit has linear DC stabilizer for supplying of electronic circuits. The current consumption is from 50 to 80 mA in dependence on the sensor type.

For verification of selected conception these functional samples of sensor units have been designed and produced:

- Temperature sensor unit
- Gas detector unit (LPG)
- Unit for measurement of vehicle inclination and detection of overturning
- Unit for measurement of absolute or relative pressure of transported medium.

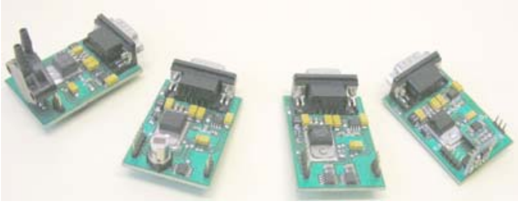


Figure 3. Functional samples of sensor units

All four samples of sensor units are shown in Fig. 3, detailed schematic diagram of LPG concentration sensor is shown in Fig. 4 and detail of the vehicle inclination sensor is in Fig. 5.

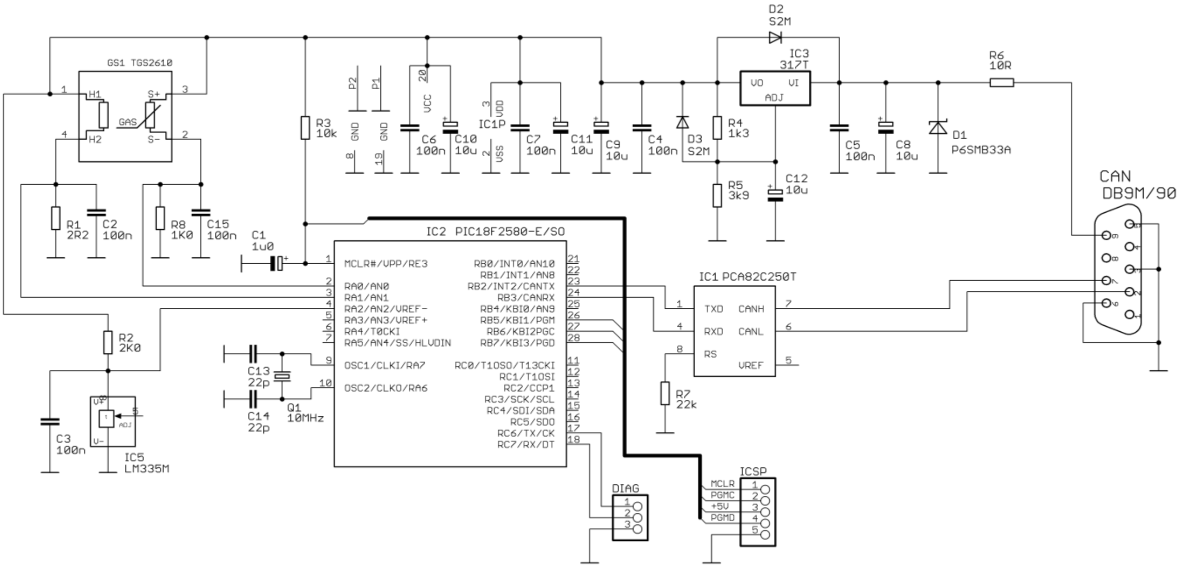


Figure 4. Schematic diagram of LPG sensor unit

Physical communication medium of vehicle sensor network is created by STP cable of category 5e which is mostly being used in local area networks. The cable has suitable impedance and wire cross section. One pair is used for data communication and next pair is used for powering of sensor elements. Other two pairs are not used. Connectors used in functional samples and their pinning are compliant with specification [2]. In case of real usage in vehicle environment more suitable cable and connectors will be chosen.

FIRMWARE OF THE SENSOR UNITS

Firmware of the sensor unit consists of several key parts which enable to perform all required functions. These functions are defined as follows:

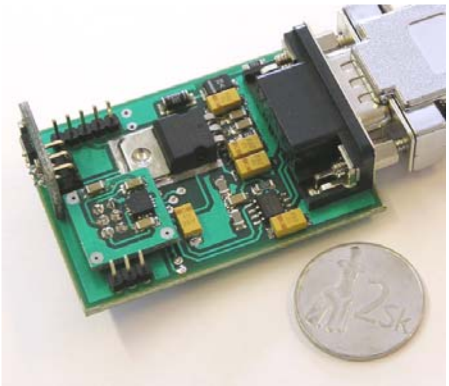


Figure 5. Detail of vehicle inclination sensor unit

- Initialization of sensor unit i. e. definition of input and output ports of microcomputer, initialization of A/D converter, CAN engine, interrupt system and loading of calibration constants.
- Autodiagnostic of the sensor unit consists from test of microcomputer [4] and test of sensor elements. The test of microcomputer is the same for all kinds of sensor units. During this test the checksums of program (FLASH) memory and configuration (EEPROM) memory are computed and compared with predefined values which are stored at the last addresses of program memory and configuration memory. The test of sensor element depends on the type of sensors. Temperature sensors are tested by comparison of values from two identical sensors placed close together. The test result is positive if absolute value of difference of both temperatures is less than predefined

constant. Accelerometers and pressure sensors have self test mechanisms integrated and they can be activated by a logical signal from microcomputer. After activation of self test known value is added to sensor output voltage and the test result is positive if this voltage increase is registered by microcomputer. The LPG sensor is tested by monitoring of heating DC current which must be in predefined interval.

❖ Data processing - the sensor elements provide analog signals which are digitalized by 10 bit A/D converter built in the microcomputer. The sampling rate in all sensor units has been set to 8 kHz. This value is sufficient for processing signal spectrum generated by used sensors. In the next step the sampled signals are digitally filtered by averaging filter with length of 8 samples and decimated by ratio 1:8 because the computational power of used microcomputer is limited. From preprocessed signal the value of observed quantity is calculated in accordance with mathematical formulae given for sensor elements. For example, gas concentration (in ppm) can be calculated from these equations:

$$C = 10^{-\frac{\log \frac{R_{S20}}{R_0 \cdot K}}{a}} \tag{1}$$

$$R_{S20} = \frac{R_S}{T_{C1} \cdot T_{MEAS} - T_{C2}} \tag{2}$$

$$R_S = R_8 \cdot \frac{1024 - RES_{AD}}{RES_{AD}} \tag{3}$$

where *a*, *K*, T_{C1}, T_{C2} are specific constants for given type of gas sensor (Table 1), R_0 is sensor resistance at gas concentration 1800 ppm and temperature 20 °C, R_S is sensor resistance before temperature compensation, R_{S20} is sensor resistance after temperature compensation (2), R_8 is 1 kΩ resistor in series with the sensor (see Fig. 4) and RES_{AD} is the result of A/D conversion. The calculations are performed in the space of integer numbers. In the calculation process the compensation and calibration data are taken into account. If the result values exceed the boundary values an alarm message is sent into the OBU.

Table 1. The Constants
for LPG Sensor FIGARO TGS2610

α	K	T_{C1}	T_{C2}	R_0
0.5413	57.82	-0.02	1.4	1.46 kΩ

❖ The communication with the OBU is on the physical and data link layers performed by the CAN bus controller which is integrated into the microcomputer. The CAN controller after proper configuration performs all needed communication functions without CPU intervention. For communication on the application layer a simple protocol has been designed. The role of the CPU is to read and write data and configuration registers of the CAN controller, evaluation of its status, receiving of commands from the OBU and sending responses or alarms to the OBU.

❖ COMMUNICATION PROTOCOL ON THE APPLICATION LAYER

A simple communication protocol has been designed for communication between sensor units and the OBU. Standardized application protocols working on the CAN bus (CANOpen, DeviceNet) have not been used for their complexity. The protocol is based on command – answer principle. Protocol data units are transferred by using standard data frames with 8 octet data field in accordance to CAN 2.0A specification [3]. The PDU structure is given in the Table 2. The CAN message identifier (11 bits) is used to address group of sensor units which measure the same quantity (000H – OBU, 010H – inclination sensors, 020H - pressure sensors, 030H - gas sensors, 040H - temperature sensors). The sensor unit uses CAN filter to select only the messages relevant for its group. The whole sensor network is addressed by message with identifier 000H. Individual sensors can be addressed on the application layer by the 16 bits sensor unit number SENS_NBR.

Table 2. Structure of The PDU

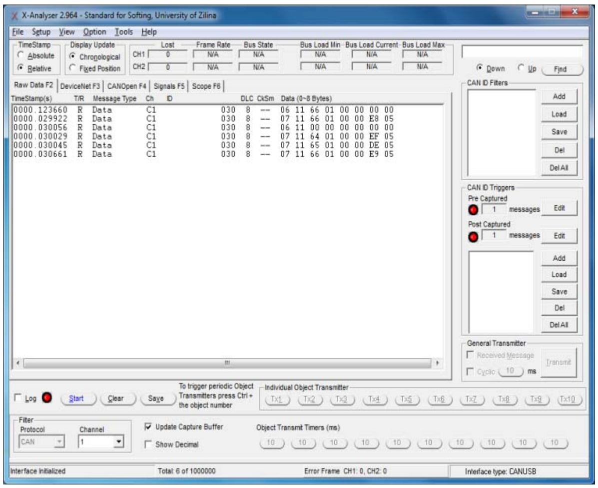
ID	D0	D1	D2	D3	D4	D5	D6	D7
SENS_ID	CMD_ID/ ANS_ID	MES_NBR	SENS_NBR_L	SENS_NBR_H	VAL_1_L	VAL_1_H	VAL_0_L	VAL_0_H

The command, answer or alarm is identified by the CMD_ID/ANS_ID field (Table 3). Command parameters or measured values are transferred in the fields VAL1_L – VAL0_H. If longer message must be fragmented the field MES_NBR gives number of fragments (4 bits) and fragment order (4 bits). An example of communication shows Fig. 6.

Example of communication among the OBU and he sensor units shows the measurement of LPG concentration. Three gas sensors with identification numbers SENS_NBR 0164H, 0165H and 0166H respectively have been used and they have been placed into environment with LPG concentration approximately 1500 ppm. The first two lines in Fig. 6 show communication between the OBU and the sensor with number 0166H which returned value 05E8H (1512 ppm), the third line shows multicast communication from the OBU to the sensors (SENS_NBR=0000H). Last three lines are answers from all three sensor units, respectively.

Table 3. Definition of Commands, Answers and Alarms

CMD_ID/ ANS_ID	TYPE	Description
00H	CMD	Get sensor unique identifier
01H	ANS	Number of sensor unit
02H	CMD	Set number of sensor unit
04H	CMD	Get sensor unit status
05H	ANS	Sensor unit status
06H	CMD	Get actual sensor data
07H	ANS	Actual sensor data
08H	CMD	Set sensor limit value
0AH	CMD	Get sensor limit value
0BH	ANS	Sensor limit value
0DH	ALM	Upper limit exceeded
0FH	ALM	Lower limit exceeded
11H	ALM	Sensor error
12H	CMD	Sensor reset
13H	ANS	OK
15H	ANS	Error



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Lost        Frame Rate  Bus State   Bus Load Min  Bus Load Current  Bus Load Max
CH1  0      N/A         N/A         N/A           N/A               N/A
CH2  0      N/A         N/A         N/A           N/A               N/A

TimeStamp(s)  T/R  Message Type  Ch   ID    DLC  CkSm  Data (0~8 Bytes)
0000.123660   R    Data          C1   030   8    --    06 11 66 01 00 00 00 00
0000.029922   R    Data          C1   030   8    --    07 11 66 01 00 00 E8 05
0000.030056   R    Data          C1   030   8    --    06 11 00 00 00 00 00 00
0000.030029   R    Data          C1   030   8    --    07 11 64 01 00 00 EF 05
0000.030045   R    Data          C1   030   8    --    07 11 65 01 00 00 DE 05
0000.030661   R    Data          C1   030   8    --    07 11 66 01 00 00 E9 05

Interface initialized   Total: 6 of 1000000   Error Frame CH1: 0, CH2: 0   Interface type: CANUSB
```

Figure 6. Snapshot of CAN protocol analyzer

❖ CONCLUSION

The project CONNECT [1] solved in domain 4 (Traveler Information Services) and in its subdomain 4.9 problems of creation “Dangerous goods monitoring and information system.” At present a new project EasyWay [5] continues in solving of similar themes focused on intelligent transport systems.

The described design of the sensor network is an integral part of the subdomain 4.9 system solution. For the test purposes three sets of OBUs and sensor networks have been manufactured. The tests have been performed on the territory of north Slovakia by staff of Transport Research Institute, Inc. and University of Žilina. Results of the tests prove full functionality of manufactured OBU prototypes, sensor networks and real time data transfer into the monitoring centre. Next development will be focused on design of new sensor units, for example “black box” for road traffic accident analysis. In addition to the technical development of the information system for dangerous good transport monitoring the questions about standardization and legislative are interested, for example the standardization of sensors in vehicles, integration of the various functions into the OBU, the international cooperation on dangerous good monitoring etc.

❖ ACKNOWLEDGMENT

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