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Electric Vehicle Data Recorder

Streszczenie. *W pracy przedstawiono konstrukcję oraz właściwości urządzenia rejestrującego parametry eksploatacyjne pojazdu z napędem elektrycznym. Zaprezentowano możliwości i funkcje urządzenia skonstruowanego w oparciu o mikrokontroler ATMEL ATMEGA 2560. W oparciu o zarejestrowane dane podczas eksploatacji pojazdów, przedstawiono przebiegi przykładowych parametrów pojazdów elektrycznych. Omówiono możliwości zastosowania urządzenia oraz korzyści wynikające z jego użycia.*

Abstract*. The paper describes the design and properties of an data recording device for registering electric vehicle operation parameters. The capabilities and functions of the device, built around and Atmel ATMEGA 2560 microcontroller are presented. Basing on the recorded data on the operated electric vehicles, the example traces of registered parameters are shown. The possibilities of device's applications and the advantages of using the device are discussed. (****Rejestrator parametrów pojazdu z napędem elektrycznym****).*

Słowa kluczowe: monitoring pojazdów elektrycznych, EVDR, rejestrator zdarzeń (EDR), system monitoringu pojazdów
Keywords: electric vehicle monitoring, EVDR, Event Data Recorder (EDR), Open Vehicle Monitoring System (OVMS).

Introduction

The progress in vehicle technology, including the electric vehicles, requires the engineers to test their designed prototypes in real driving conditions. Simultaneously, the number of road accidents happening each year is the incentive to create devices which can continuously record the vehicle parameters allowing the analysis of what happened before, and at the moment of accident, which should allow to pinpoint its cause and perhaps prevent the cause from creating further interference.

There are three types of vehicle data recorders:

- recorders which store the vehicle's parameters regarding forensic accident analysis (ADR – Accident Data Recorder, EDR – Event Data Recorder), along with function of notification of emergency services (eCall, E911, VEDR - Video Event Data Recorder) [1, 2, 3, 4, 5]
- recorders which store the data on the driver's working hours and vehicle speed and distance travelled (Tachograph , EOBR – Electronic On-Board Recorder) [6, 7, 8, 9, 10]
- recorders gathering the data on vehicle components operation, in order to optimize the components' settings or the operator's driving style. [11, 12, 13, 14, 15, 16]

The recorders belonging to the last group, have recently found application in the research of properties and energy consumption of electric vehicles such as: battery energy storage vehicles (EV, BEV, PEV, EVC), hybrid vehicles (HEV, PHEV) and fuel cell powered vehicles(FCEV).

The research conducted due to development of vehicle powertrain system, require verification after being installed in the prototype vehicle. When the testing is being done on a dyno, there is no problem in surrounding the vehicle with test equipment. The situation changes when the prototype is running in the traffic. In this case, the best solution would be to take advantage of the data already present on the CAN bus of the vehicle [17, 18, 19, 20]. Additionally, the information can be transmitted in real-time via the GSM module and network, to a base station. As an additional benefit from the data recording systems presence to the vehicle's driver, is the possibility to track and analyze the gathered data including the statistics on the vehicle use costs. Unfortunately, not all vehicles support the data collection from the CAN bus. This was the reason for creating the digital Electric Vehicle Data Recorder - EVDR. The goal of the EVDR is to register in real-time the electric vehicle parameters regarding the motion of the vehicle with respect to ambient temperature, as well as the parameters of each of the electric powertrain components. The analysis of registered data allows to investigate the energy consumption, user driving style, or behavior of various vehicle components in different operational and weather conditions.

EVDR structure

The EVDR device has been built using the Atmel AVR ATMEGA2560 microcontroller. The recorder can be powered by two independent power sources, the external power fed via the USB type-B port, or from the internal lithium-ion type battery, with 4400mAh capacity and voltage of 3.7V. In case of using the external power, plugging the USB cable connected to e.g. a 12/5V cigar plug converter will power on the system, regardless the ON/OFF switch position. With the power on the USB port present, the internal Li-ION battery charger will begin charging the battery.

The charger is a commercial charger module based on a TP4056 chip, with a max. charging current of 1000mA and charge end voltage of 4.2V. The energy from the internal battery will power the recorder after turning on the ON/OFF switch, which will power the DC/DC converter based on a commercial module with a LM2577 chip.

The source of power to the EVDR is selected automatically by the diode switch built on Schottky 1N5822 type diodes, and is protected by a 0.5A rated polymer fuse. The output voltage of the converter is set to 5.0V.

Fig.1. Electric Vehicle Data Recorder with assortment of probes.

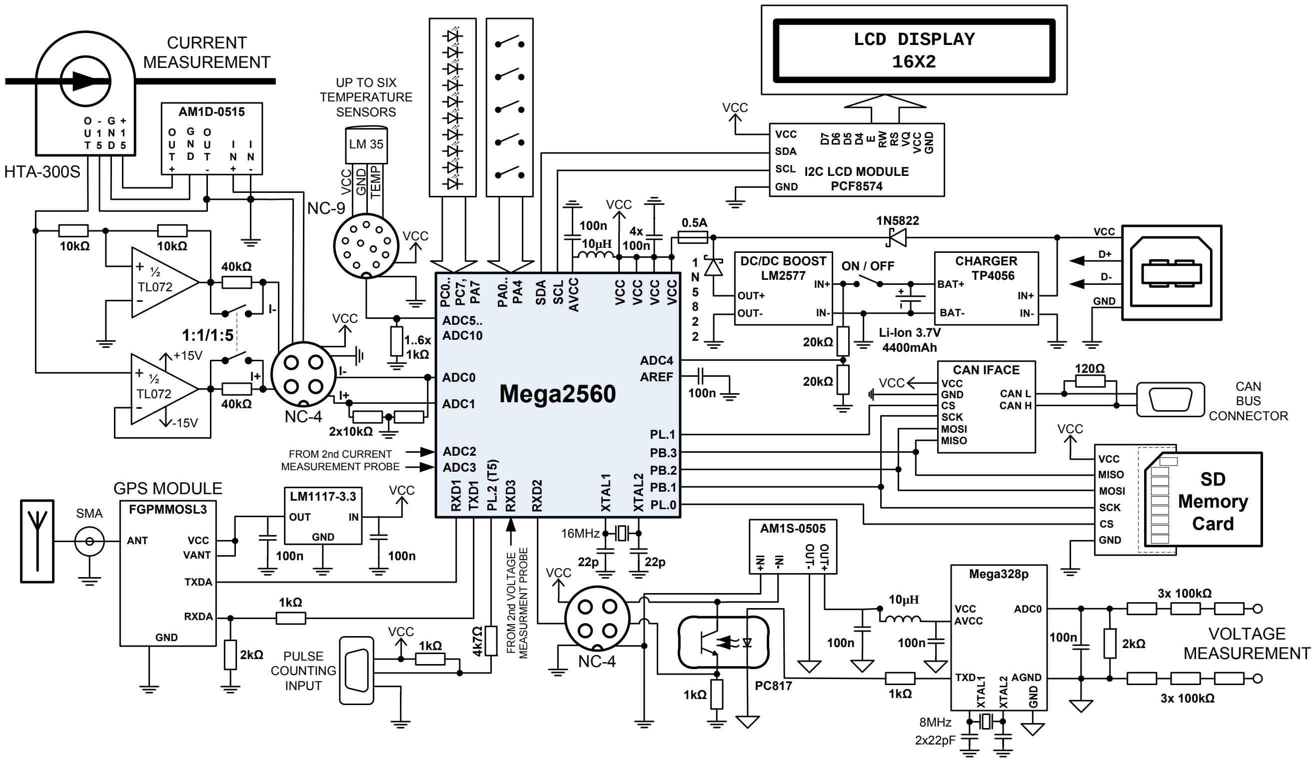

Fig.2. Electric Vehicle Data Recorder schematic diagram

The Atmel ATMEGA2560 microcontroller [21] allows the monitoring of internal battery voltage using a 1:2 voltage divider which output is connected to the fourth ADC channel pin (ADC4). The constant voltage measurement allows the recorder to react to low battery state of charge. When the measured voltage drops below 3.55V, the LCD backlight is automatically turned off and an indicator LED titled "LOW BATT" is lit.

The EVDR allows:

- registration of temperatures, currents and voltages in the powertrain, using galvanically isolated probes,
- registration of ambient temperature,
- registration of GPS data - velocity, MASL, geographic position.

Fig.3. The EVDR enclosure with SD card socket, ON/OFF switch and USB power cable

The gathered information is stored on a Secure Digital (SD) type memory card. The card is connected to the microcontroller by a commercial module containing a card socket, 3.3/5V logic level converter and a 3.3V voltage regulator. The microcontroller communicates with the memory card via a hardware SPI interface and a CS line connected to PL.0 microcontroller pin

The recorder uses an LCD display with 2 rows and 16 columns, and a HD44780 compatible interface. The display is driven using microcontroller's hardware two wire interface (TWI) port, and a commercial LCD-I^{2}C module using a PCF8574 port expander chip. The port expander allows control of LCD's D4-D7, RS and E data lines as well as control of display backlighting.

The configuration of the EVDR can be accomplished by five user buttons connected to the microcontroller ports PA.0 through PA.4, activated with a low logic state. Next to the user buttons, there are 10 status LEDs used to report the operational states of the EVDR. Nine of the diodes are connected to PORTC of the microcontroller (pins PC.0 through PC.7), and one PORTA pin - PA.7. The last diode marked "POWER" is tied to the 5V supply line and functions as a power on indicator. The LED titled "GPS" indicates reception of accurate time and location from the GPS module. The lit "RECORD" LED indicates that the EVDR is in the data recording mode and is periodically writing the data to the SD card. The mode can be turned on and off by pressing the "RECORD" button. After turning the record mode on, the actual date from GPS is stored, and the main directory "/" of the SD card is checked for presence of a directory matching the pattern "DDMMYY", where DD - day, MM - month, YY - year. In case the directory does not exist, it will be created automatically, and it will be made the current working directory. In the next step, the EVDR creates in the working directory a file with a name matching the pattern "HH_MM_SS.txt", where HH - actual hour, MM - actual minute, SS - actual second. Data is periodically written to this file, with the user selected period, which can be set in the MENU. Depending on the requirements of the conducted research, the possible selections of period are as follows: 100ms, 200ms, 500ms, 1s, 2s, 5s, 10s and 60s. The first line of the file contains a header - which is simultaneously a description of every field in the file. After each period, a new line is written to the file, each line contains a number of data fields, separated by a semicolon sign ";". The sequence of fields is: sequential number (line number), date using format DDMMYY, time using format HHMMSS.S, geographic latitude in decimal format DD.dddddd (where DD - degrees, dddddd - decimal fraction of a degree), geographic longitude using format DD.dddddd, height in meters ASL, speed over ground (SOG) in kilometers per hour, voltage as measured by the voltage probe in volts, current as measured by the current probe in amperes, six fields of temperatures from temperature probes in Celsius degrees, number of impulses per second on the pulse counting input.

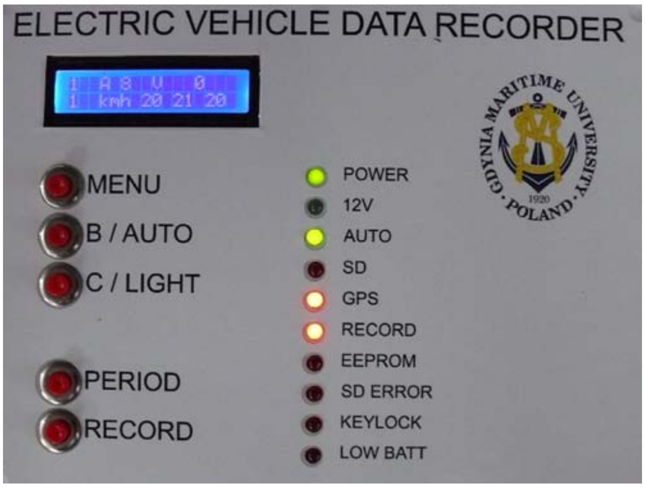

Fig.4. The EVDR front panel

The user keyboard consists of five buttons marked: MENU, B/AUTO, C/LIGHT, PERIOD and RECORD. The operation of MENU requires pressing and holding the MENU button and a second button - B/AUTO for AUTO function, C/LIGHT for FIXWAIT function, PERIOD for setting the recording period and RECORD for activation/deactivation of keyboard lock. The AUTO function allows for automatic, maintenance-free operation of the EVDR in the examined vehicle. It requires an external 5V power source with an USB type B plug, e.g. a 12/5V converter powered from the vehicle's ignition circuit. It allows powering on the recorder along with the vehicle. The state of AUTO function is persistent (stored in the non-volatile EEPROM memory) and can be set from the MENU.

The recorder with the AUTO function turned on, after powering up: checks the EEPROM memory for the saved persistent function states, after determining that the AUTO function is active turns on the RECORD function, it checks the state of FIXWAIT function. Active FIXWAIT halts the beginning of the recording process (including creation of directory/file) until the GPS reports correct position, date and time. Operation during waiting for GPS data is indicated by a pulsing RECORD diode. When the GPS sends the correct values, the cyclic writes begin and the RECORD diode is constantly lit. With inactive FIXWAIT function, the automatic data gathering proceeds immediately after powering up the recorder. In case of detection of any problem with the SD card (e.g. no card present in the socket, card full or not formatted) the "SD ERROR" LED will be lit.

In order to secure the data recording process from inadvertent interruption, the EVDR allows the user to lock the keyboard. It can be accomplished by pressing and holding the MENU button and pressing the RECORD button. Activation of lock is acknowledged by lighting the LED titled "KEYLOCK". The lock state is persistent - saved in the EEPROM memory, it allows safe operation of the recorder in automatic mode with a protected keyboard.

The alphanumeric LCD display with 2 rows and 16 columns is used to display the values of measured parameters in order to e.g. verify that the sensors and probes are connected and they report correct values. The main LCD screen, which is shown by default after powering up the recorder, displays the following information - in the first line: measured current, measured voltage, number of pulses per second on the pulse counting input. In the second line: velocity in km/h, and first three (1-3) temperature channel values in degrees Celsius. Additional screens can be displayed by pressing the B/AUTO button. They include information on: geographic latitude and longitude, time and date, voltage of the internal lithium battery.

The EVDR has 6 temperature measurement channels. Each uses an analog LM35 type sensor, with a scale factor of voltage output of +10mV/°C. The sensors have an accuracy of 0.5°C and are connected to the recorder by a NC-9 type connector. In order to reduce interference, the output of every temperature sensor is loaded with a 1kΩ resistor connected to the signal ground inside the recorder enclosure. The temperature measurement channels 1...6 use the microcontroller's analog to digital channels ADC5 through ADC10.

The recorder has two current measurement channels. The current measurement probe uses an Hall-effect based, open loop, LEM HTA-300S type current transducer. This transducer allows to measure the DC current in the range -950A to +950A, uses a symmetric ±15V power supply and has a voltage output with a scaling factor of 4V at the nominal (300A) current. The transducer is powered by an integrated AIMTEC AM1D-0515 dc/dc converter, with 1W power, 5V input and a symmetric ±15V output. The same converter also supplies power to the measurement amplifier with two operational amplifiers in the form of TL072 chip. The first amplifier is used in the voltage follower configuration with unity gain, and allows the microcontroller to measure the positive magnitude of current flowing through the transducer (0A to +950A range, I+ signal). The second amplifier works in the inverting amplifier configuration with a gain of -1 and allows the microcontroller to measure the negative magnitude current (-950A to 0A range, I- signal). The current probe is connected to the recorder with a NC-9 type connector, which carries the power supply signals (+5V, GND) and current signals I+ and I-. The amplifier outputs are loaded with 10kΩ resistors, connected to the signal ground inside the EVDR enclosure. In line with the amplifier outputs there are two 40kΩ resistors, with the possibility of shunting them through a switch marked "1:1/1:5". With the switch closed, the resistors are shunted which causes the output signals not to be attenuated and the probe works in the ±190A range. Opening the switch turns on the 1:5 attenuation using the 40 and 10kΩ as voltage dividers and extends the measurement range to ±950A. The I- signal is connected to the ADC0 channel of the analog-digital converter and is the inversion of the I+ signal, which is connected to the ADC1 channel of the analog-digital converter. The microcontroller samples both signals and chooses the value with the greater absolute magnitude as the measured current value, while the number of selected channel determines the sign of the measured value. When the greater signal is detected on the ADC0 the measured current is deemed negative, while on the ADC1 - positive. The optional second current probe uses the ADC channels ADC2 for the I_2- signal, and ADC3 for the I_2+ signal.

The voltage probe is galvanically isolated due to possibly high measured voltages as well as the fact that the high voltage circuit in the examined vehicle is universally isolated from the vehicle body ground. The probe is built around an ATMEL ATMEGA328P microcontroller, and has a measuring range of 0-150 VDC. The measured voltage enters the 1:50 voltage divider, for safety reasons consisting of several resistors. The attenuated voltage is converted by the microcontroller analog-digital converter and then is transmitted to the EVDR through an optocoupler isolated serial interface. The voltage probe is connected to the recorder by a NC-4 type connector with ground signal (GND), power supply signal (+5V) and optocoupler isolated return serial signal, which is connected to the RXD2 microcontroller input. In order to maintain correct serial signal polarity, the optocoupler is connected in a follower configuration, with the output resistor connected to the signal ground. Voltage sampling and result transmission is performed 10 times per second. The probe's power is supplied through an isolated AIMTEC AM1S-0505 dc/dc converter, with 1W of power and 5V input and output voltages. An optional, second voltage probe can be connected to the RXD3 serial microcontroller input.

The geographic position and time acquisition is performed using a GPS receiver, using a FGPMMOSL3 integrated receiver with an external, active GPS antenna, connected with an SMA connector. The GPS module and the antenna are powered by 3.3V voltage, supplied from a LM1117-3.3 linear type voltage regulator. Higher logic voltage level of the microcontroller (5V) is shifted to the 3.3V required by the GPS module's RXDA input by a resistor voltage divider. The GPS module sends its data in the standard NMEA 0183 format five times per second. In order to lower the microcontroller load, after each power-up, the GPS module is programmed to send only the VTG, GGA and RMC sentences. The EVDR is equipped with a pulse counting input, which can count the number of raising or falling signal edges per second. The source of the pulses can be the vehicle speed signal generated by the ABS system (e.g. Graduated Audio Level Adjustment - GALA), or the signal from the chassis dyno rollers speed encoder, or any similar signal. The pulse counter connector contains +5V power supply signal, which allows direct powering of a sensor e.g. a Hall-effect sensor, or an inductive NPN sensor.

The EVDR contains a commercial Controller Area Network (CAN) bus module, with an integrated Microchip MCP2515 CAN controller and MCP2551 CAN transceiver. The CAN module allows the data collection from the CAN bus present in the tested vehicle. Simultaneous gathering of data from up to 5 CAN addresses is possible. The CAN controller communicates with the microcontroller using the hardware SPI bus. Connection of CAN signals is possible using the DB-9 type connector with the supplied CAN_L and CAN_H signals.

Results

The verification of Electric Vehicle Data Recorder operation was conducted by testing the electric powertrain of a Fiat Panda EV car [22]. The tested vehicle is powered by a Permanent Magnet Synchronous Motor (PMSM) with a rated power of 50kW (and maximum power of 85kW). The flow of energy from a battery of 36 LiFePO4 lithium cells with a capacity of 160Ah each, is controlled by an IGBT inverter which allows top speed of 170km/h without active field weakening, and 220km/h with active field weakening algorithm. In the first phase of the test, the car was driven on a chassis dyno rollers (fig.5., time index: 0÷470s), in the second phase it was driven in the real traffic conditions (fig.5., time index 500÷1450s). The result plots of registered parameters are shown in the figure 5.

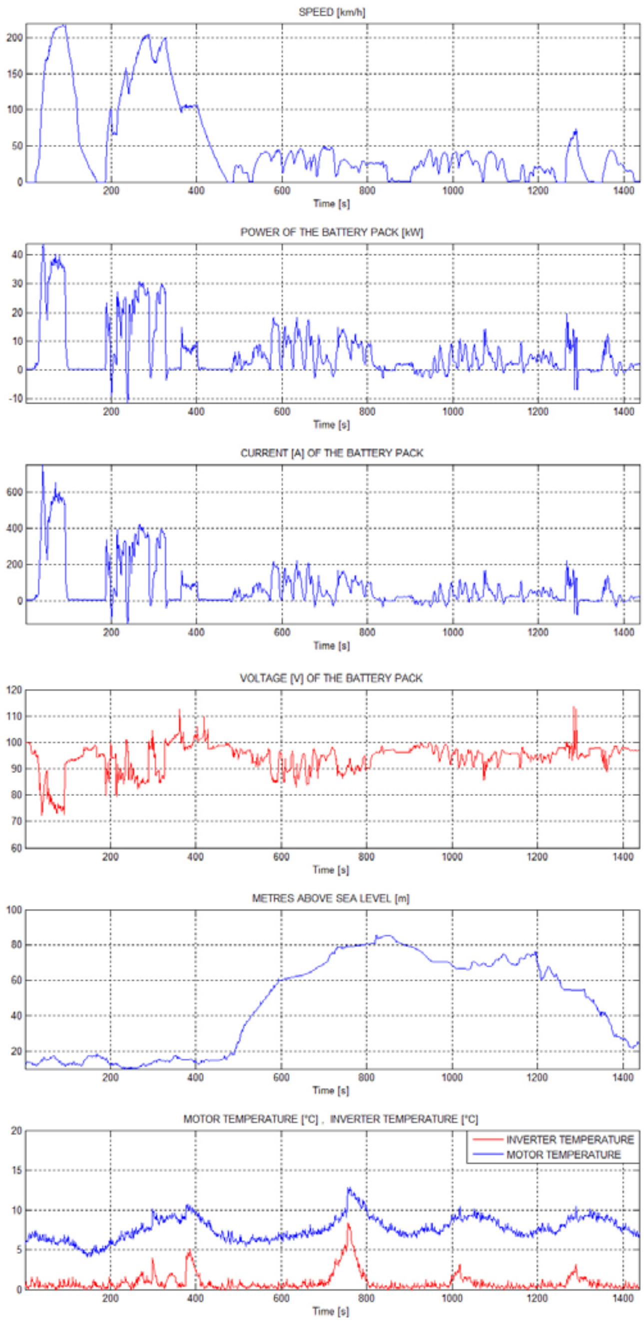

Fig.5. Example parameter plots registered during the traction tests of the Fiat Panda EV car.

Basing on the recorded information, the following plots were drawn: vehicle speed, power and current consumed form the battery, power and current regenerated and returned to the battery, the battery voltage, the vehicle's height in meters ASL, the motor and regulator temperatures. The recorded data allow one to estimate the efficiency of the powertrain components in the vehicle, which is driven in the various road conditions (hilly or flat terrain, urban or extra-urban driving), and in different ambient temperature conditions, which mostly impact the performance of the vehicle's battery. On the basis of recorded data for this particular Fiat Panda EV, it can be stated, that the used powertrain offers much more power than is really needed in real road conditions. An optimal power for A-segment and B-segment cars would be in the range of 10÷25kW rated (16÷40kW maximum), and the average specific power consumption should not be in excess of 150Wh/km.

Conclusions

The article presents an actual device EVDR which allows the acquisition and recording of an electric vehicle operational parameters, driven in various road conditions and at different ambient temperature values.

The described device can be used in many vehicle types, both purely electric and hybrid powered, beginning from bicycles, scooters, mopeds, motorbikes, through cars, trucks, buses, and finally in boats, small ships and even electric planes. In the extreme situations, the EVDR can be used as a Event Data Recorder - EDR, which allows forensic analysis of the possible causes of an accident.

Fig.6. Some of electric vehicles built in Gdynia Maritime University on which the EVDR operation was verified

The registration of vehicle operational parameters, including parameters from the on-board CAN bus, allows the analysis of this information and optimization of various settings of the electric powertrain in order to achieve optimal performance of the vehicle and as low as possible energy consumption.

The possibility of data recording period selection allows the EVDR device to be used to test the powertrain in an electric vehicle on a chassis dyno which is not adapted for testing electric vehicles, especially in the low rotation speed regions of the motor in the range not exceeding 1000 RPM.

Thanks to universal architecture of the device it allows interoperability with other types of sensors (such as accelerometric sensors), and modules (e.g. GSM module which could be used to send the collected data to a remote location for analysis).

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