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VERSATILE SENSOR PLATFORM FOR AUTONOMOUS SENSING IN AUTOMOTIVE APPLICATIONS

M. Lieschnegg, B. Lechner, A. Fuchs, O. Mariani
Virtual Vehicle Competence Center
Inffeldgasse 21a, 8010 Graz, Austria
Emails: michael.lieschnegg@v2c2.at

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Abstract- This paper presents the development of a versatile sensor platform used for autonomous data acquisition. The key advantages of the platform are its compact design, implemented onboard sensors, standard interfaces to connect application specific sensors and subsequently simple installation and low costs for the preparation of a measurement task. The paper provides details of the platform design and key characteristics. Practical exemplary applications in the field of automotive sensing, covering thermal management related and passenger comfort related measurement tasks, are presented.

Index terms: sensor platform, onboard sensing, autonomous sensing, automotive application.

I. INTRODUCTION

Modern vehicles are complex systems that host a variety of electrical and mechanical sub-systems designed to improve safety, efficiency, reliability, comfort, and further demands of drivers and passengers. To evaluate taken measures for a prototype or production car during a test drive or to analyze the potential for optimization on a test rig, a multitude of parameters have to be determined from sensor signals.

A variety of specific sensors measuring quantities such as acceleration, temperature, gas concentration or tire slip are available in automotive industry. A reliable and versatile data acquisition system capable of synchronizing, coordinating, and storing measurement data is required to efficiently evaluate sensor signals and allow real-time or a-posteriori analysis of the behavior of single parameters and their mutual impact.

For automotive applications, various data acquisition systems have been designed for test rigs [1]. They typically have little or no restriction in terms of energy consumption, cabling or size and weight.

For a mobile onboard measurement system, which is taken in a test car on a track to record measurement data, both sensor front-end and data acquisition system have to be:

- of small dimension to be operated in limited space environment (e.g. engine compartment),
- easy to configure and install at any required place in and on the vehicle to save time and costs while preparing for tests,
- highly flexible and versatile to allow determination of sensor data with different amplitudes, sampling rates, and nature (digital as well as analogue data),
- highly reliable to ensure synchronized and seamless recording and tracking of measurement data and their further processing.

Commercial data acquisition systems for onboard measurement exist but are typically not optimized for the particular field of application [2] and they are most often expensive and require costly cabling.

A novel versatile data acquisition platform for autonomous sensing applications, such as demanded in automotive industry, has been developed at the Virtual Vehicle Competence Center in Graz, Austria. This data acquisition platform is called ViFDAQ and features several advantages with significant relevance for automotive testing, among others small dimensions, onboard sensors, standardized interfaces, and the ability to transfer measurement data wirelessly.

This paper is structured as follows:
In Chapter II the design of the sensor platform is presented, providing details of the functional modules of the system. The results of exemplary automotive onboard measurements carried out with ViFDAQ are presented in Chapter III.

II. SENSOR PLATFORM DESIGN

The main aim for the sensor platform was to design a versatile, easy to operate measurement system that is capable of recording measurement data for various measurement tasks simultaneously and synchronizing the input of multiple sensors connected. At the Virtual Vehicle Competence Center the sensor platform is mainly used for automotive R&D applications. Due to the versatile hardware and software design, the possible field of application is diversified and not limited to automotive or technical applications.

Apart from demands of high sampling rate and reliable, high-resolution data acquisition, one of the most important demands for the sensor platform is its small size and the ability to work without external power supply, since many measuring points are difficult to access. The hardware is optimized to have minimum energy consumption and a small housing size. For several standard measurement tasks the platform is already equipped with onboard sensor (e.g. 3-axes acceleration sensor and temperature sensor). Additional external sensors can easily be connected with the sensor platform using standard interfaces or wireless communication. It is possible to operate a measurement or control task completely independent from a host (PC, notebook, mobile phone, etc.), ViFDAQ is hence able to work completely stand-alone. Fig. 1 shows a functional block diagram of ViFDAQ.

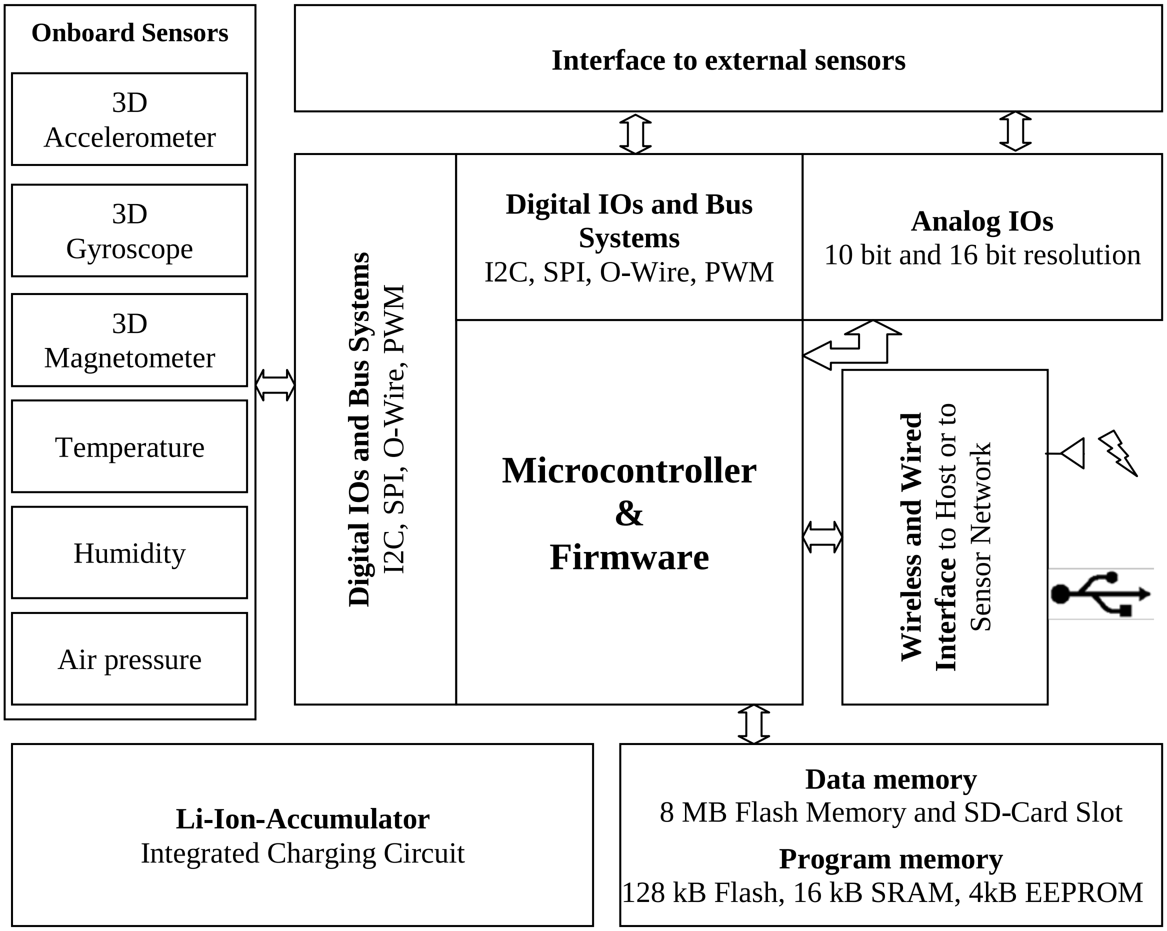

Fig. 1: Functional block diagram of ViFDAQ showing the microcontroller and firmware core, digital and analog IOs, onboard data and program memory, onboard sensors, and interfaces to external sensors, host or sensor networks.

To achieve the small housing size, most of the sensors are based on micro-electro-mechanical systems (MEMS) technology [3]. Other advantages of this MEMS technology are that a wide range of those sensors have low energy consumption and they are inexpensive due to the mass production for e.g. smartphones or automotive assistance systems. Table 1 lists all integrated sensors and its most important technical parameters.

The entire measurement circuitry, the connectors for external sensors and actuators, and the integrated sensors are encapsulated in a housing with the dimension of only 30 mm length, 20 mm width, and 15 mm height (compare Fig. 2).

Table 1: Onboard sensors implemented in ViFDAQ and their specifications

Measurement Parameter	Measurement Range	Resolution, Noise Density, Accuracy	Sensor Output Rate
3D Accelerometer	±2,±4,±8,±16 g	Res.: 1 mg, Noise Density:	1 Hz - 5 kHz
3D Magnetometer	±1.3,±1.9, ±2. ±4.0, ±4.7, ±5.6, ±8.1 Gauss	Res.: 8 mGauss	0.75 - 75 Hz
3D Gyroscope	±250,±500, ±2000 dps	Res.: 0.00875 dps, Noise Density:	100 - 800 Hz
Temperature	-40 bis 125 °C	Res.: 0.01 °C Accuracy ±0.3 °C	max. 100 Hz
Humidity	0 bis 100%	Up to 0.04% Accuracy ±2 %	max. 250 Hz
Air Pressure	300 bis 1100 hPa	Res.: typ. 1 hPa	max. 300 Hz

The complete system consists of two independent printed circuit boards (PCB). The entire data acquisition system comprising onboard sensors and external connectors are integrated on a four layer PCB. The internal accumulator, charging unit, and USB-to-serial interface is assembled on a two layer PCB.

The housing also includes a Lithium-Polymere (LiPo) accumulator with a charge capacity of 100 mAh, which enables ViFDAQ to work stand-alone for several hours. To achieve a higher lifetime of the system, the internal accumulator can be replaced by an accumulator with a higher capacity. Both, an external or the internal accumulator can be charged by the integrated charging circuitry of ViFDAQ (see Fig. 1) or by means of other power sources such as a micro USB, a car battery or a photovoltaic cell via 2.5 mm power connector. The supply voltage is between 3.3 V and 17 V. Due to this wide input voltage range, the system can use a variety of external energy sources to be loaded.

One of the main features of ViFDAQ is wireless communication. Therefore, two independent radio frequency (RF)-transceivers have been included in the design of the communication structure of the sensor platform. For the direct communication to a host a Bluetooth transceiver has been implemented (according to IEEE 802.15.1 standard) [5]. The Bluetooth interface is specified by the Bluetooth standard V2.0 with Enhanced Data Rate (EDR).

In addition to the Bluetooth transceiver, a second transceiver for wireless communication according to IEEE 802.15.4 standard is implemented, that allows transfer rate of up to 2 Mbit/s. Among others, the ZigBee protocol can be used with this IEEE standard [6]. ZigBee is designed

for data transfers with a transfer rate of 250 kbit/s. The receiver sensitivity of the transceiver is -100 dBm and its maximum transmission power is 3.5 dBm. Due to this technology, transmission ranges between the transmitter and the receiver of up to 200 m are possible. Compared to Bluetooth communication mode, the transceiver operates more energy-efficient (maximum current 14.5 mA) and it is possible to combine multiple ViFDAQ sensor platforms to a network.
Data is stored primarily on an integrated high speed 64 Mbit flash memory or on an additional MicroSD card.

Fig. 2 shows the entire stand-alone sensor platform in side- and bottom view. To show the compact design of the system, a 2 EURO coin is placed next to the sensor platform for the photo.

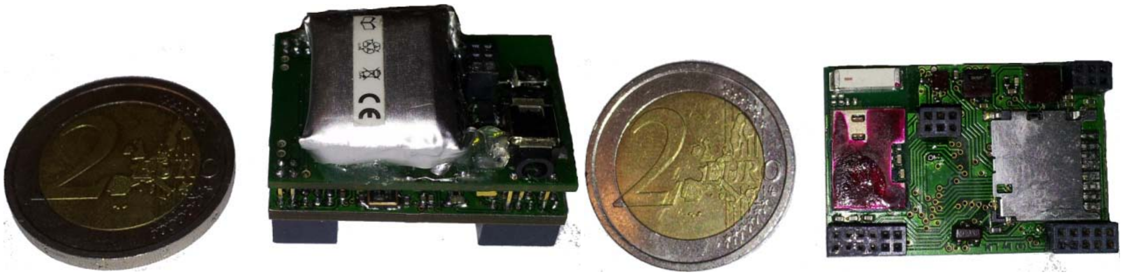

Fig. 2: Stand-alone data acquisition system ViFDAQ including power supply (side- and bottom view). Dimensions: 30 mm length, 20 mm width, and 15 mm height

III. AUTOMOTIVE SENSING APPLICATION

As shown in Chapters II and III, the sensor platform ViFDAQ features a highly flexible and versatile design. The fields of application for this sensor platform are not limited to specific applications in industry and science – the deployment of the sensor platform for measurement tasks in healthcare, security, environment protection or in predominantly technical fields such as automation, aviation, energy production or transportation is well-suited and can be very beneficial.
In this paper we evaluate the applicability of the developed sensor platform for automotive engineering as a representative field of application. Therefore, two exemplary measurement tasks automotive engineers are interested in have been defined:

- Thermal management: What temperatures in the engine compartment can be expected for a given driving cycle?

- Passenger comfort: What accelerations (angular velocity) are the passengers exposed to in a passenger compartment on a given test track?

A test drive with a BMW X3 has been performed using ViFDAQ as a data acquisition system for the defined measurement tasks.

a. Preparation

For the two measurement tasks defined above, two ViFDAQ units have been used:

ViFDAQ 1 was placed in the engine compartment immediately behind the radiator fan. An external GPS module was used to provide GPS position information for track recording. No further preparations were necessary since the sensor platform was operated stand-alone. Measurement data was recorded for:

- Accelerations in 3 axes by means of the on-board sensor (sampling rate 100 Hz)
- Orientation in 3 axes by means of the on-board gyroscope (sampling rate 100 Hz)
- Humidity by means of the on-board sensor (sampling rate 1 Hz)
- Temperature by means of the on-board sensor (sampling rate 10 Hz)
- Air pressure by means of the on-board sensor (sampling rate 10 Hz)
- GPS position using an external Wintec WBT-202 Bluetooth GPS connected to ViFDAQ via Bluetooth connection (SPP Serial Port Profile) and National Marine Electronics Association (NMEA) Protocol [8, 9]

ViFDAQ 2 was placed in the passenger compartment on the dashboard. This sensor platform was only used to record accelerations in the passenger compartment in 3 axes by means of the onboard acceleration and gyroscope sensor (sampling rate 250 Hz).

Measurement data was stored as binary data on the microSD card.

b. Test Track

For the test drive a federal highway between the Austrian provinces Styria and Carinthia has been chosen since this highway shows significant variations in altitude and bends and is frequently used for vehicle testing in automotive industry. Fig. 3 shows a relevant section of the test track with the most important bends numbered from 1 to 14. The test drive started east of bend 14 (right in map) and followed the highway westward. West of bend 1, the vehicle turned, the driver changed, and the car drove back to the end position east of bend 14.

Fig. 3: Recorded GPS track of a relevant section of the test drive. Numbers indicate relevant bends of the track (Map source Google Earth)

c. Measurement Results for the Thermal Management

Measurement data for ViFDAQ 1 placed in the engine compartment has been recorded during the test drive described in III.a. Fig. 4 shows three parameters recorded by the sensor platform during the test drive that are of relevance for understanding and validating the thermal management of the test vehicle and demonstrate the potential of ViFDAQ for automotive testing at the same time:

- The vehicle velocity in Fig. 4 (top) is acquired by means of the external GPS and data is transferred to the data acquisition unit via Bluetooth.
- The air temperature in the engine compartment in Fig. 4 (middle) is acquired by means of the ViFDAQ onboard sensor.
- The altitude in Fig. 4 (bottom) is also acquired by means of the ViFDAQ onboard sensor.

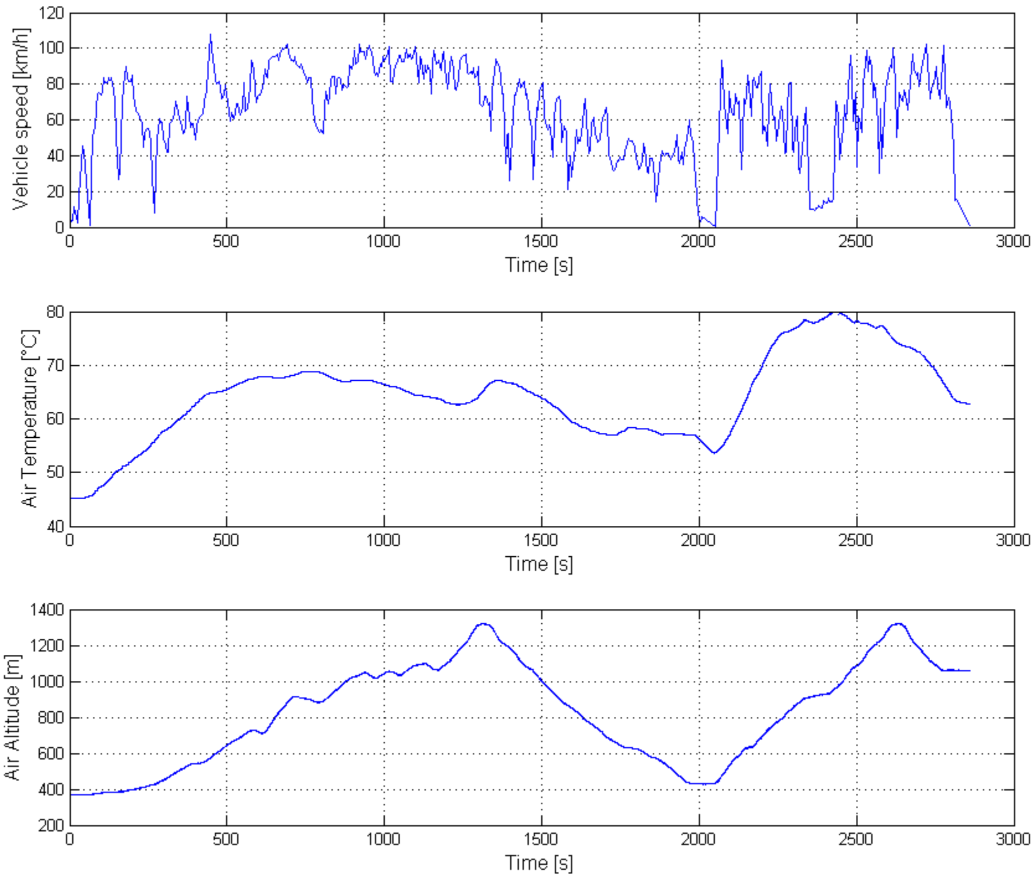

Fig. 4: Measurement data recorded with ViFDAQ 1 placed behind the radiator fan during the test drive. The figure shows the vehicle velocity (top), the air temperature in the engine compartment (middle), and the altitude (bottom).

From the start of the recorded test series until time step 1.300 s the test vehicle was driven uphill and from time steps 1.300 s until 2.000 s downhill. The downhill section was steeper than the uphill section. During a short stop at time step 2.000 s (compare Fig. 4 top: velocity is zero), the driver changed and the same track was driven back – first steep uphill and then downhill with less inclination. Even though the same track was driven forward and backward, neither the altitude profile over time nor the temperature profile is symmetrical. One reason therefore is that the velocity was lower after driving behind a tractor at time steps 2.300 s (compare Fig. 4: top, velocity is below 20 km/h). The steeper uphill section (2.000 s until 2.650 s) causes higher air temperatures in the engine compartment (up to 80 °C) than the flatter uphill section (0 s until 1.350 s, temperatures below 70 °C), even though the vehicle velocity is comparable for both sections.

d. Measurement Results for Passenger Comfort Assessment

For the exemplary measurement tasks to assess the passenger comfort, the angular speed and the vibrations are considered. Fig. 5 shows the measured angular velocity along the test track in Fig. 3 when the car was driven from bend 1 eastward to bend 14. The measurement signal has been low-pass filtered (f_g=1 Hz) to remove artifacts of higher frequencies that result from local vibrations in the engine compartment. It can be seen that bend 1 is a sharp right turn (about 35 degrees per second, dps, with a narrow peak) and bend 2 is a sharp left turn (about -22 dps, again with a narrow peak). The typical angular velocity acquired on the test track section shown in Fig. 3 is between +15 dps and -15dps, the passenger has the impression of a rather twisty road. Bend 14 is in fact the driving into a parking area and hence features two sharp left turns.

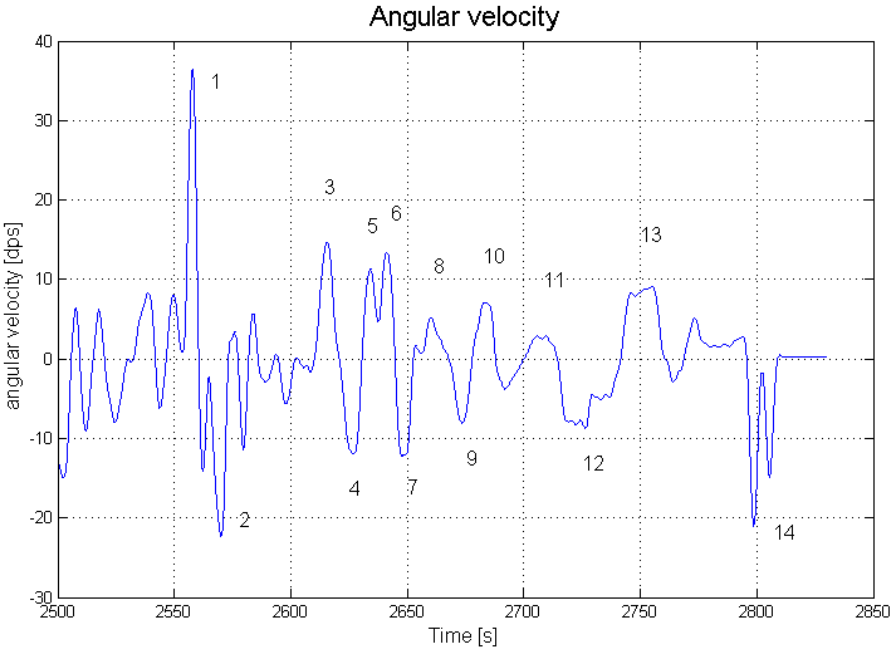

Fig. 5: Angular velocity obtained for the test drive section shown in Fig. 3. Numbers of bends correspond to Fig. 3.

Fig. 6 shows the high-pass filtered (f_g=10 Hz, 2nd order Bessel filter) accelerations acquired in the three axes with ViFDAQ 1 and ViFDAQ 2 during the entire test drive. Directions of the axes are according to Fig. 6 (bottom right). It can be seen that higher accelerations (i.e. vibrations) are present in the engine compartment (ViFDAQ 1, blue signal) and that the passenger is exposed to vibrations that are in the same order for accelerations in y-axis but much lower for x- and z-axis (ViFDAQ 2, green signal).

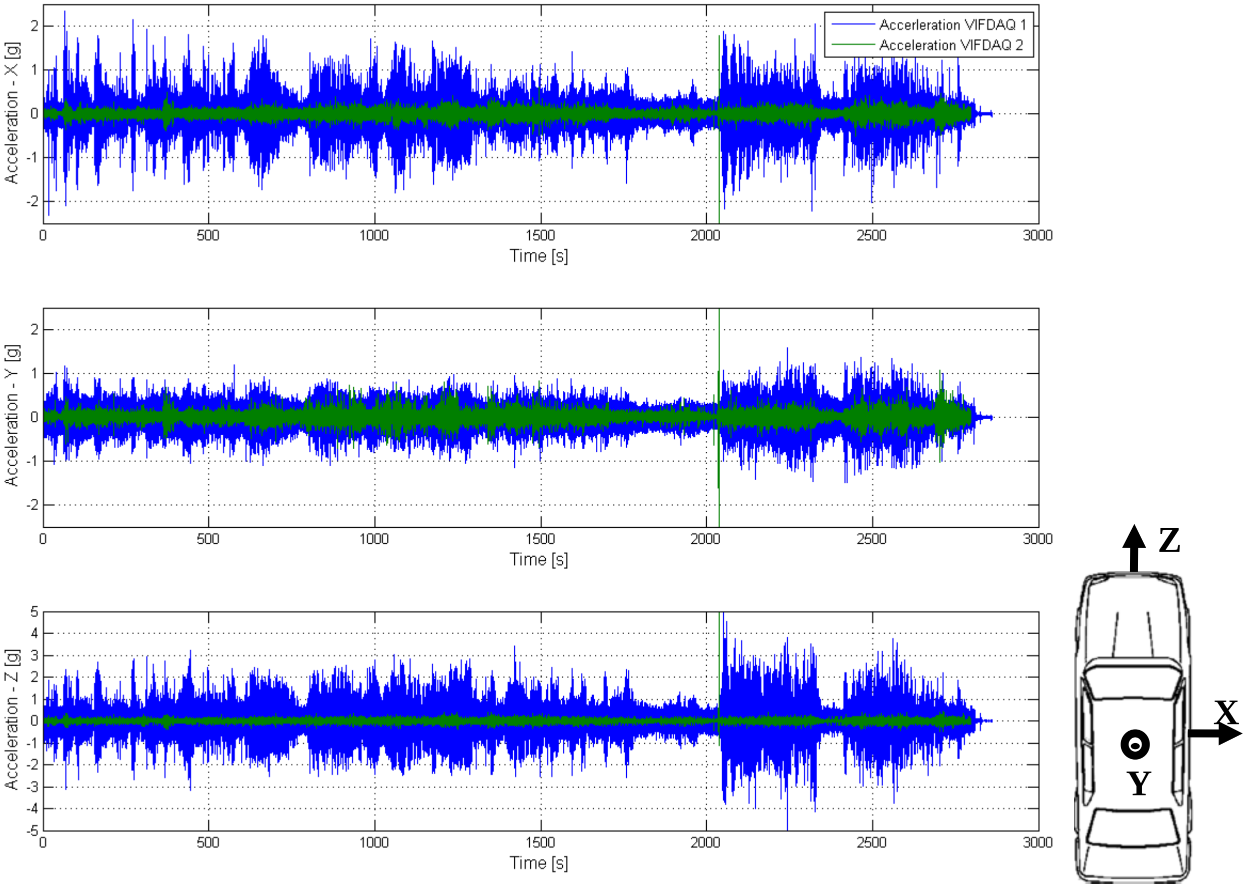

Fig. 6: Accelerations acquired with ViFDAQ 1in the engine compartment (blue signal) and ViFDAQ 2 in the passenger compartment (green signal) for all three axes. The accelerations in the passenger compartment are typically lower than in the engine compartment.

IV. CONCLUSIONS

In this paper, a novel versatile sensor platform is presented that meets important requirements for mobile sensing and testing such as autonomous operation, small dimensions, onboard sensors, and standard interfaces to augment the system with additional sensors. The sensor platform design and data acquisition by means of the system are described in detail. Exemplary measurement tasks in the field of automotive engineering are presented.

The sensor platform is well-suited for data acquisition with multi-sensor input and can hence be used for a variety of measurement tasks in science and industry. Its applicability in automotive testing is shown.

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