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Belgrade, 15-16, October 2020

PROCEEDINGS

TOPICS

AERODYNAMICS AND FLIGHT DYNAMICS
AIRCRAFT
WEAPON SYSTEMS AND COMBAT VEHICLES
AMMUNITION AND ENERGETIC MATERIALS
INTEGRATED SENSOR SYSTEMS AND ROBOTIC SYSTEMS
TELECOMMUNICATION AND INFORMATION SYSTEMS
MATERIALS AND TECHNOLOGIES
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PREFACE

Military Technical Institute, the first and the largest military scientific-research institution in the Republic of Serbia with over 70 years long tradition, has been traditionally organizing the OTEH scientific conference, devoted to defense technologies. The Conference is supported by the Ministry of Defense and it takes place every second year.

Its aim is to gather scientists and engineers, researchers and designers, manufactures and university professors in order to exchange ideas and to develop new relationships.

The ninth International Scientific Conference OTEH 2020 is scheduled as follows: lecture on the occasion of “Mihailo Petrovic Alas”, given by Prof. Žarko Mijajlović, PhD, and plenary lecture on “Electromagnetic Pulsed Weapon Treat Hmp and Hemp“, given by Prof. Momčilo Milinović, PhD Eng, and working sessions according to the Conference topics.

The papers which will be presented at the Conference have been classified into the following topics:

− Aerodynamics and Flight Dynamics
− Aircraft
− Weapon Systems and Combat Vehicles
− Ammunition and Energetic Materials
− Integrated Sensor Systems and Robotic Systems
− Telecommunication and Information Systems
− Materials and Technologies
− Quality, Standardization, Metrology, Maintenance and Exploitation.

The Proceedings contain 97 reviewed papers which have been submitted by the authors from 13 different countries. I would also like to emphasize that 23 papers are from abroad. The quality of papers accepted for publication achieved very high standard. I expect stimulated discussion on many topics that will be presented online, during two days of the Conference.

On behalf of the organizer I would like to thank all the authors and participants from abroad, as well as from Serbia, for their contribution and efforts which made this Conference possible and successful.

I would also like to thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for its financial support.

Finally, dear guests and participants of the Conference, I would like to wish you a pleasant and successful work during the Conference. I am looking forward to see you again at the tenth Conference in Belgrade. All the best and stay healthy.

Belgrade, October, 2020

Col. Miodrag Lisov PhD Eng
President of the Scientific Committee
OTEH 2020

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THE CONCEPT OF PORTABLE MULTIFUNCTIONAL MEASUREMENT INSTRUMENT BASED ON ICTM SENSORS

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Abstract: *Several types of MEMS and thin-film based sensors have been developed at the Institute of Chemistry, Technology and Metallurgy (ICTM), including piezoresistive pressure sensors, a multipurpose thermal sensor, and an adsorption-based mercury vapor sensor. In this paper, we present the concept of a portable electronic instrument that can be used with different combinations of pressure, thermal and/or mercury sensors. Such an instrument is highly configurable, thus enabling various measurements to be performed in different applications, from industrial plants to environmental monitoring. Since the mentioned sensors have different requirements in terms of sensor excitation, as well as different ranges of their output signals, the design of the instrument is a demanding task. Additional design requirements are related to the portability of the instrument, including the overall dimensions, power source and consumption, and communication methods. One of the possible directions of further development is the design of a rugged version of the instrument, intended for harsh environments.*

Keywords: *pressure sensor, thermal sensor, mercury sensor, instrument.*

1. INTRODUCTION

Various silicon micro-electro-mechanical (MEMS) and thin-film based sensors have been developed at the Department for Microelectronic Technologies (ICTM, Belgrade). Several types of piezoresistive pressure sensors have been successfully commercialized, as well as industrial pressure and liquid level transmitters based on them. The mercury vapor sensor, and the multipurpose thermal sensor (it can be used as a gas flow sensor, vacuum sensor, thermal converter and gas type sensor), have been developed and characterized, and are now ready for various applications. In order to develop modern measurement instruments based on them, some efforts have already been undertaken [1, 2]. The chosen approach was to design two separate instruments: one based on the thermal sensor and another one based on the mercury sensor. In this paper, a concept will be presented of a more universal portable instrument, which will incorporate all the necessary circuitry in order to accommodate the piezoresistive MEMS pressure sensor, the multipurpose thermal sensor and/or the mercury vapor sensor. Thus, the instrument will be capable of measuring different physical parameters, depending on the chosen sensor configuration and the instrument's firmware.

1.1. Piezoresistive MEMS pressure sensor

ICTM manufactures silicon piezoresistive MEMS pressure sensors for several pressure ranges up to 400 bar [3]. Electrically, they consist of four pressure sensitive resistors (piezoresistors) connected in a Wheatstone bridge. Two of the resistors whose resistance increases with the applied pressure are located in one diagonal of the bridge, while the two resistors whose resistance decreases with the increase of the applied pressure are in the other diagonal. ICTM pressure sensors are optimized for constant current excitation, and the typical value of their nominal output signal is 100 mV with the excitation of 2 mA applied. The resistance of the resistors without the pressure applied is in the range from 2500 Ω to 3000 Ω at 22°C, and the typical value of their temperature coefficient of resistance is 0.13%/°C. Since the output signal of all semiconductor-based piezoresisitve pressure sensors exhibit significant parasitic temperature dependence, a temperature compensation technique must be used in almost all applications.

1.2. Multipurpose thermal MEMS sensor

A detailed description of the multipurpose thermopile-based MEMS sensor chip is given in [4]. Its main elements are a heater made of Al (A-type sensor) or p^+Si (P-type sensor), and two thermopiles, each consisting of 30 multilayer p^+Si/Al thermocouples, located on both sides of the heater. The heater and the hot junctions of both the thermopiles are placed on a thermally isolating membrane that consists of SiO_2 and a residual n-Si layer. The cold thermopile junctions are located on the outer, unetched part of the chip (the rim). The sensor has two output signals in the millivolt range, generated by the two thermopiles. Constant current sensor excitation is needed in order to supply 50 mW of power to the heater.

1.3. Mercury vapor sensor

The principle of operation of the mercury vapor sensor is described in detail elsewhere [5]. The sensor consists of four thin film resistors made of gold on a silicon substrate. The resistors constitute a Wheatstone bridge. Two resistors placed in one diagonal of the bridge are exposed to the surrounding atmosphere, while the remaining two resistors are covered by a layer of photoresist. Mercury vapor is adsorbed on the surface of the exposed resistors, which results in the change of their resistance, while the resistance of the covered resistors remains unchanged. This produces the output signal up to 1.6 mV with the bridge excitation current of 10 mA. When the sensor saturates with mercury, it must be heated in order for the mercury to desorb, thus enabling a new measurement cycle. For this purpose, the built-in heater must be supplied with 1 W of power.

2. METHOD

In order to develop the portable multifunctional instrument, specific requirements of the sensors that will be used must be properly addressed.

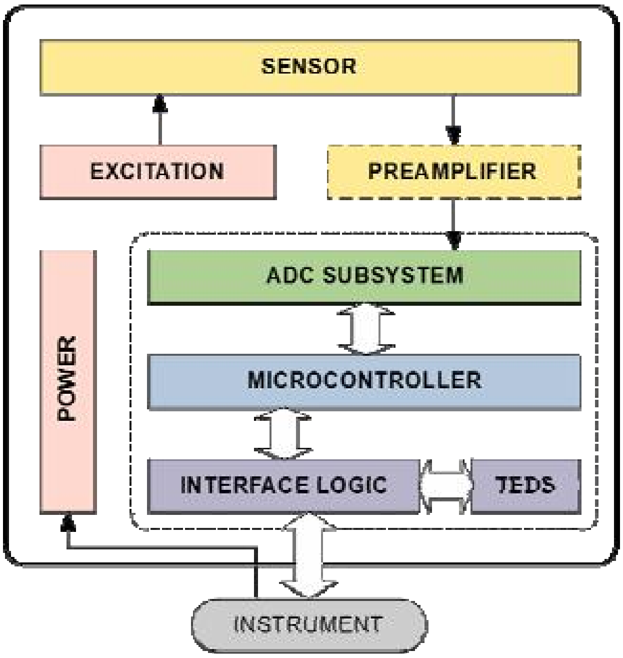
First, the output signals of the three sensor types are significantly different. The order of magnitude of the pressure sensor differential output signal is typically from 10 mV to 100 mV, with the offset lower than the nominal signal. In the case of the multipurpose thermal MEMS sensor, the output signal is extracted according to the desired application as a sum or difference of Seebeck voltages of the two thermopiles present on the chip [4]. Therefore, value of the output signal can vary from several mV only, up to around 140 mV, in the current design. This results in high offset compared with low signal variation, around 100 μV. Finally, the mercury vapor sensor with the constant current excitation of 10 mA has a differential output signal up to 1.6 mV, and the offset voltage within ±3 mV. The differential signal from the pressure sensor can be connected directly to the differential input of a modern, highly integrated high-resolution analog-to-digital converter (ADC), such as the AD7124-8, which has a differential multiplexer, programmable gain amplifier, digital filter, voltage reference, and other circuitry built-in. However, a low-noise, zero-drift preamplifier, such as the one described in [1], is needed in the case of the multipurpose thermal sensor and the mercury vapor sensor, in order to optimally utilize the ADC's dynamic range.

Second, all of the mentioned sensors need a constant current excitation, but with different current values, and in different modes of operation. The excitation current of the piezoresistive MEMS pressure sensor can be up to 4 mA; however, lower values, typically up to 2 mA, are often used for practical reasons. The two types of multipurpose thermal sensors developed at ICTM both have a built-in heater that produces about 50 mW of heat. A 100 mA constant current source is needed for the low resistance heater of the A-type sensor. The high resistance heater of the P-type sensor needs only 3 mA of current, but with a voltage compliance of 18 V. The mercury vapor sensor needs the excitation current of 10 mA during its normal operation. Additionally, a much higher current must be supplied to the heating element built into the mercury sensor, since it must produce 1 W of heat for about 1 minute in each cleaning cycle. In order to fulfill all of these requirements, two types of constant current sources are needed: one for the current range of 10 mA, and the other for the higher current range (up to 100 mA).

After a detailed consideration of the above-mentioned facts, it became obvious that different signal conditioning and sensor excitation requirements of the sensors lead to a significant amount of switching circuitry and preamplifier stages, although they may not be needed in all sensor configurations. In order to reduce the complexity and cost of the instrument, a different approach was chosen, that relies on a high level of modularity. Instead of using the sensors as passive devices, a specific sensor module will be designed for each of the sensor types. The module will contain as much of the sensor-specific circuitry as possible, and will be connected to the rest of the system via power connections and a digital interface. This concept is largely influenced by the IEEE 1451 family of standards [6]. According to the IEEE 1451.2 standard, the system consists of the Network Capable Application

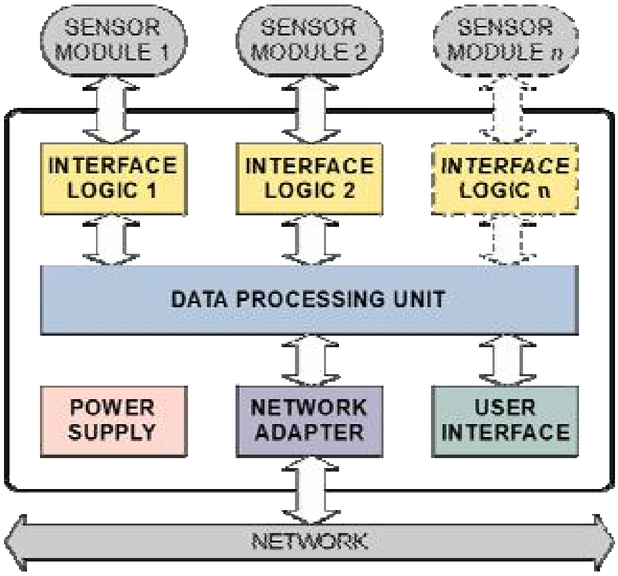
Processor (NCAP), one or more Smart Transducer Interface Modules (STIM), as well as the Transducer Independent Interface (TII), which is a point-to-point digital interface between each of the STIMs and the NCAP. The standard also defines the Transducer Electronic Datasheet (TEDS), which is a data structure that contains all the information needed by the NCAP to properly identify and use the transducer(s) within a STIM. It is stored in a non-volatile memory of the STIM. In this work, the sensor module is to be designed as a STIM, and the instrument as an NCAP. In addition to the standardized power and signal lines that constitute the TII, a higher voltage necessary for sensor excitation must be supplied to the modules.

A generalized block diagram of the sensor module is shown in Picture 1. The Sensor excitation block and the Preamplifier block are optional, and specific for the given sensor type. The ADC subsystem, TEDS and Interface logic blocks are required in every implementation, as they enable the sensor module operation. The functions of the blocks surrounded by a dashed line can be performed by a highly integrated mixed-signal microcontroller, such as the ADuCM360. In general, the module is not limited to a single sensor. It can be expanded in order to include several transducers (sensors and/or actuators).



Picture 1. Block diagram of the sensor module

A generalized block diagram of the portable multifunctional instrument is shown in Picture 2. It can operate with several sensor modules, each connected via a separate Interface logic block. The Power supply block supplies all the necessary voltages to the system, and charges the built-in battery when an external power source is available. The Digital processing block is a single board computer. It performs all the calculations, communicates with the sensor modules, serves the user interface, and enables the access from remote computer systems via the Networking block. The User interface block provides the measurement readout and status indication, and enables the user to access the instrument's settings.



Picture 2. Block diagram of the portable multifunctional instrument

A conceptual rendering of the instrument is given in Picture 3. In this case, the instrument can accommodate up to two sensor modules. The two module slots are located on the top of the instrument's enclosure. The user interface is on the front, while the power supply and network connections are on the back. The overall dimensions of the instrument (excluding the electrical and other connections) are expected to be within 110 mm × 60 mm × 160 mm. The instrument can be equipped with a shoulder strap, and is expected to be compact and lightweight enough to be carried for longer periods of time. The built-in rechargeable battery should ensure several hours of autonomous operation.

Depending on the intended use of the instrument, the user can have several sensor modules, and install them as needed. Since each of the modules contains the memory element (TEDS) with all the necessary data, the instrument can identify the modules, and reconfigure itself in order to operate with the installed sensors. This includes setting of the sensor excitation voltage, interpretation of sensor-specific parameters, receiving and processing of sensor signals, implementation of calibration procedures, and user interface configuration.

Picture 3. Conceptual rendering of the portable multifunctional instrument with two sensor modules installed

The described approach is not limited to the three sensor types mentioned in this paper (the piezoresistive MEMS pressure sensor, the multipurpose thermal MEMS sensor, and the mercury vapor sensor). As a result of the development of new sensors at ICTM, or optimization of the design of the existing devices, new sensor modules can be expected in the future. The instrument can be made compatible with them by means of firmware upgrades, which can also be used to add some new functionality.

3. CONCLUSION

In this paper, the concept of a portable multifunctional measurement instrument is proposed, that enables the use of different combinations of pressure sensors, multipurpose thermal sensors, mercury sensors, and some other sensors that will be developed at ICTM. The instrument should be highly configurable in order to enable various measurements to be performed in different applications, from industrial plants to environmental monitoring. Since the mentioned sensors have different requirements in terms of sensor excitation, and different ranges of output signals, the design of the instrument is a demanding task. In order to avoid unnecessary complexity, and to achieve a high level of modularity, we have chosen the approach based on sensor modules that incorporate as much of the sensor-specific circuitry as possible. The instrument automatically identifies the installed sensor modules, and reconfigures itself accordingly.

One of the possible directions of the further development is the design of a rugged version of the instrument, intended for harsh environments. That would require a robust metal enclosure, the power and network connectors, as well as the user interface, to have a suitable ingress protection rating. A sealing plate with gaskets would have to be installed over the sensor modules, allowing only the sensor input ports to be accessed externally. Due to their principle of operation, and the nature of the measured quantity, some sensors must be additionally protected from dust and water ingress, which is likely to occur in harsh environments.

ACKNOWLEDGMENT

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