A Device for Monitoring Physiological Parameters and Electrotactile Stimulation

Bojan Jorgovanović, Matija Štrbac, Miloš Kostić, Vojin Ilić, Nikola Jorgovanović

***Abstract* — This work stems from a research and innovation action financed under Secure societies programme of the European Union's Horizon 2020 framework. Specifically, the aim is to develop an easy-to-use wearable system for enhancing situational awareness of first responders deployed in extreme environments by providing tactile feedback on the risk factors that can lead to rapid deterioration of their health or operation capabilities. For this purpose, an unobtrusive system was designed to acquire, process, and analyse the data from a battery of novel biosensors and generate actionable information about assessed health risks, in real-time. Aptly named SIXTHSENSE, it leverages electrotactile stimulation to continually convey this information to the first responder wearing it, leveraging the sense of touch. It effectively expands first responders' sensory bandwidth to include the "feeling" of changes in critical parameters that are not within the reach of human senses, like the ionic imbalance, the lactate level or physiological strain, much before they manifest through symptoms of exhaustion, heatstroke or hypothermia. The developed system further incorporates means for transmitting information to the command centre, where it can be analysed and visualised through a mission specific decision support system, allowing for a more efficient and safer data-driven team management.**

***Index Terms*—Electrotactile stimulation; First responders; Wearable acquisition unit**

I. Introduction

SIXTHSENSE is a multidisciplinary innovation and research action with the overall aim to significantly improve efficacy and safety of first responders' deployment in hazardous environments by optimising on-site team coordination and mission execution.

Bojan Jorgovanović is with the Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Global Electronic Solutions doo, Cara Dušana 75, 21000 Novi Sad, Serbia (e-mail: bojan.jorgovanovic@uns.ac.rs).

Matija Štrbac is with Tecnalia Serbia doo, Deligradska 9, 11000 Belgrade, Serbia (e-mail: matija.strbac@tecnalia.com).

Miloš Kostić is with Tecnalia Serbia doo, Deligradska 9, 11000 Belgrade, Serbia (e-mail: milos.kostic@tecnalia.com).

Vojin Ilić is with the Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Global Electronic Solutions doo, Cara Dušana 75, 21000 Novi Sad, Serbia (e-mail: vojin@uns.ac.rs).

Nikola Jorgovanović is with the Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia and Global Electronic Solutions doo, Cara Dušana 75, 21000 Novi Sad, Serbia (e-mail: nikolaj@uns.ac.rs).

Between the booming EU economy and the climate change, the number and consequences of disasters occurring in inaccessible rural areas is on a constant rise. First responder deployments in extreme conditions such as fighting wildfires or alpine search and rescue missions have gone from exceptional to regular events in only a couple of decades. As this trend is likely to continue, the risks for wellbeing of the engaged first responders continue to grow. To avoid the loss of life or lasting consequences on the first responders' health, it is important that the key physiological parameters of deployed operatives are monitored in a way that provides timely and actionable information, without hindering their operational capacity [1]. One way to achieve gathering such data and providing feedback is to use a device which could monitor the first responder's physiological parameters and use electrotactile stimulation as a way of conveying a message [2, 3].

At this point, a device that could do both data acquisition and analysis and give feedback to the first responder via stimulation is not available on the market, so it was necessary to develop one. The device presented in this paper is named the Alpha Mobile Device (AMD). The AMD is a system for multimodal data acquisition and control of electrotactile feedback stimulation. The aim of the AMD design was to enable synchronised electrotactile stimulation and acquisition from multiple sensors in a modular and scalable way that enables the inclusion of existing, developed and emerging sensors. The AMD design provides compactness, low power consumption, small overall dimensions and robustness with a main goal to develop a real mobile and wearable system.

II. Architecture of the AMD

The AMD was based on the STM32H743VIT6 microcontroller by ST Microelectronics. This ARM microcontroller has plenty of integrated peripheral modules which can work with very little or no processor core supervision. Furthermore, the STM32H743VIT6 microcontroller includes enhanced power management which provided all necessary power down or sleep operating modes in order to reduce power consumption.

The AMD needed to encompass 3 functionalities - data acquisition, electrotactile stimulation and communication. A block diagram of the AMD is shown in Figure 1.

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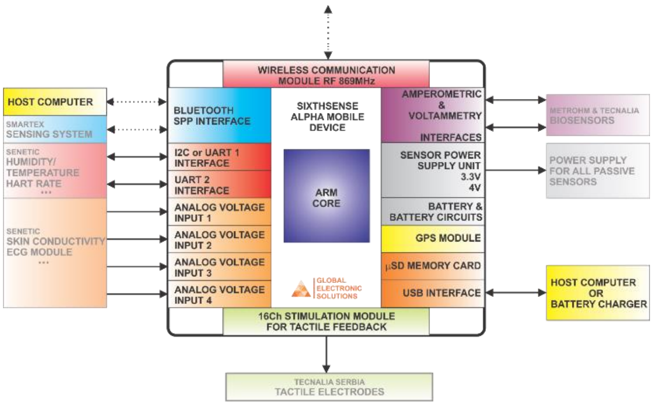

Figure 1. Block diagram of the AMD

A. Data acquisition

The AMD is equipped with interfaces for acquisition data from following type of sensors:

- Analog sensors with voltage output
- NTC thermistor sensor for temperature measurement
- Electrochemical sensors – Biosensors
- Digital wired sensors with USART interfaces
- Digital wired sensor with I2C interface
- Wireless connected sensor system with Bluetooth SPP interface
- GNSS sensor

The AMD is equipped with four voltage analogue inputs. Analogue voltage input 1 is also equipped with a precise current source which provides a constant current flow of 100µA to pin 13 of the sensor connector. This construction allows temperature measurement using the precise 10kΩ NTC thermistor connected between analogue ground and AIN_0. The other three analogue inputs are standard voltage inputs. By default, all four analogue inputs are connected to the internal 16-bit ADC of the microcontroller with a sampling rate of 1KSPS. If it turns out that the accuracy of the internal ADC is not satisfactory each input can be independently rerouted to a high speed and high accuracy ADC of the AD5941 by SMD jumpers on the PCB.

The AMD is equipped with two inputs for electrochemical sensors (biosensors). This interface is based on the single channel electrochemical front end circuit, AD5941, by Analog Devices. The electrochemical sensor interface can be set to operate in the following modes:

- Amperometric
- Chronoamperometric
- Cyclic Voltammetry

B. Electrotactile stimulation

This functionality is intended for conveying messages to the first responder wearing the device through electrotactile stimulation. The device is designed to be compatible with multi-pad electrodes [4] designed and produced by Tecnalia Serbia doo. The AMD stimulation unit consists of the following blocks:

- DC/DC step-up voltage converter
- Biphasic current source
- Switch area (output demultiplexer)
- Control unit
- Battery and interfaces

The purpose of the DC/DC step-up converter is to provide voltage which is high enough to enable current flow through relatively high electrode-skin interface impedance. The manufactured DC/DC converter for the AMD is capable to boost battery voltage to voltage a level of up to 150V. This converter is based on a modified boost topology with coupled coils, and this design is confirmed in a number of different electrical stimulators previously developed by Global Electronic Solutions. The converter output voltage can be pre-set by the programme of the control unit. This flexibility is very important especially for the Alpha system in order to find the optimal voltage level in real life tests.

Biphasic Current source is based on current controlled H-bridge topology which is capable to create an either monophasic or biphasic current pulse. The amplitude of the current pulse is controlled by a control loop which is integrated into the H-bridge. This approach reduces the number of components and overall module dimensions. The set-point of the pulse amplitude is set by the control unit via a 16-bit D/A converter with standard SPI interface.

The Switch area includes a high-voltage switching circuit that allows multiplexing a signal from the H-bridge and driving it to one or more of the 16 output channels. Only one pole of the current source (cathode) can be distributed to any of the 16 electrode pads while the other pole (anode) is connected to a single predefined electrode pad, known as the unipolar stimulation topology.

The Alpha prototype will be based on ST Electronics' high performance ARM microcontroller (MCU). Only a small part of this microcontroller's resources are intended for the operation of the stimulator subsystem, while a bigger part will be used for the sensor data acquisition module. According to that, the part of the MCU which acts as the Stimulator control unit has the following important functionalities:

- Stimulation pulses waveform timing control
- Stimulation pulses amplitude control
- Stimulation pulse distribution to the pads of the multi-pad electrode
- Execution of the predefined electrotactile stimulation schemes

Beside the subsystems intended exclusively for the stimulator subsystem, there are two other common parts of the Alpha prototype which are necessary for the functioning of the stimulator subsystem and those parts are also integrated in the realized stimulator prototype:

- Battery and a battery electronic circuit
- Communication interfaces

The manufactured prototype is powered by Li-poly rechargeable battery. Battery charging, battery protection and battery monitoring electronic circuits are an integral part of the stimulator prototype. The manufactured device has Bluetooth

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and isolated USB interfaces. The following functionalities are realized via both communication channels:

- Setting all stimulation parameters (pulse width, pulse rate, pulse amplitude, active output channels)
- Starting/Stopping the stimulation
- Creating stimulation schemes
- Programming via a bootloader application

The device is also equipped with two multicolour LEDs indicating battery status, communication and stimulator activity. A block diagram of the stimulator is shown in Figure 2.

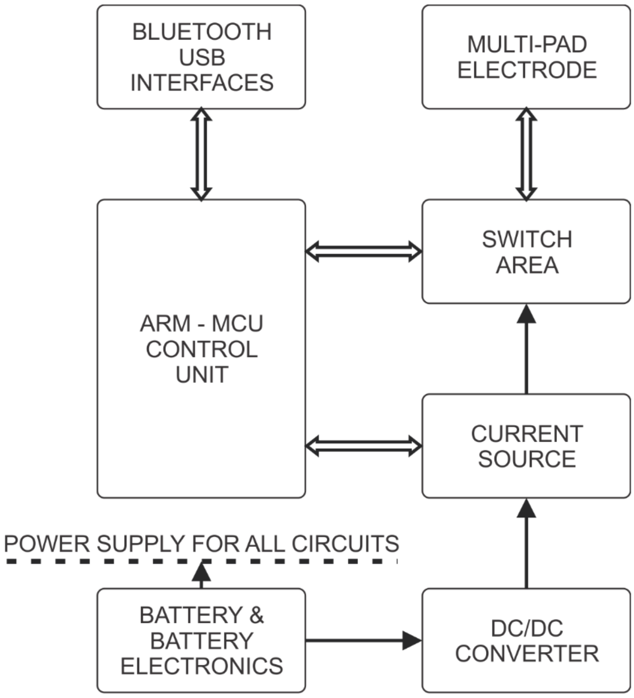

Figure 2. Block diagram of the AMD stimulator

C. Communication

The AMD is equipped with a narrow band RF communication channel for duplex communication between the first responder and the command centre. The communication is based on the GES-RF869 communication module produced by Global Electronic Solutions. The GES-RF869 is a radio module which is in compliance with ETSI EN 300 220-1. This module provides the possibility of exchanging small packets of data, up to 100 Bytes, with low speeds, in a relatively simple way. It works on an operational frequency band ranging from 869,400MHz-869,650MHz which enables it to have radiated power of up to 27dBm (500mW). It provides duty cycle control and obeys the 10% duty cycle restrictions for the 869,400MHz-869,650MHz frequency band. It offers multiple radio communication channels inside the operational frequency band and the possibility of configuring the transmit power. In order to optimize power consumption and communication range the transmit power can be set between 10mW and 500mW. The ISM standalone antenna by Molex is integrated inside of the AMD enclosure.

III. Results

The stimulator was tested on a circuit which resembles the electronic properties of the electrode-tissue interface and the signals were recorded using an oscilloscope. The waveform of the stimulation current is recorded at the serial resistor R_S by voltage input of the oscilloscope. The resistance of R_S is 1kΩ, so 1V at the recorded waveform corresponds to 1mA of measured current. A block diagram of the equipment used for testing the stimulator is shown in Figure 3.

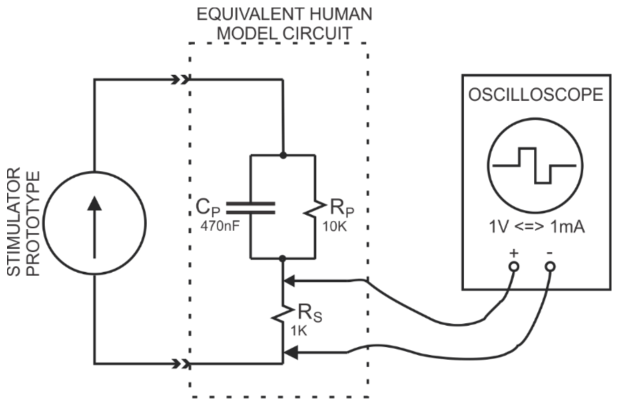

Figure 3. Block diagram of the test equipment

The waveform of a biphasic pulse generated by the AMD stimulator is shown in Figure 4. The pulse width of the generated stimulation pulse is 250µs, and the amplitude is 5mA.

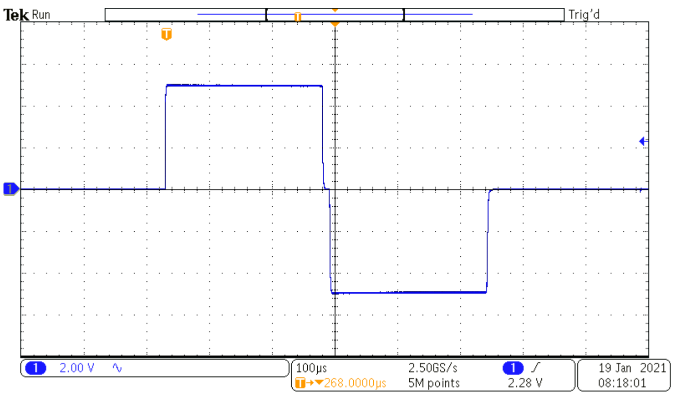

Figure 4. Stimulation pulse biphasic charge compensated test

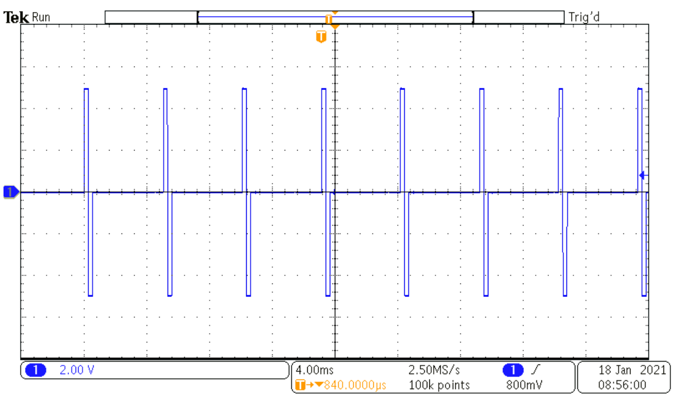

Figure 5. Stimulation pulse train

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A stimulation pulse train generated by the AMD stimulator is shown in Figure 5. The frequency of the pulse train is 200pps and each pulse has the same stimulation parameters as the pulse shown in Figure 4.

IV. Conclusion

The AMD device was designed and produced for the purposes of the SIXTHSENSE project. It has since been successfully tested in two field trials performed by first responders. The functionality of acquiring data was used for collecting physiological data about the first responders from various sensors. These data were both logged on an integrated µSD card and transmitted to a command centre which was realised through the communication functionality. Through electrotactile stimulation, the first responders were notified if certain parameters were out of regular boundaries. Feasibility tests in the field trials proved that the realized specifications of the voltage converter and the current source provided a sufficient range of stimulation levels for the tactile communication over multi-array electrodes placed on the torso of the user during physical activity, i.e. skiing and walking. The accuracy of the stimulation pulses shown in Figures 4 and 5 is satisfactory for electrotactile stimulation and the pulse amplitude error with respect to the set point value is negligible. Furthermore, initial tests proved that flexibility provided through the creation of stimulation patterns, which consider change of the active electrode pad and stimulation frequency, allow the generation of a large number of feedback messages. Given the number of different interfaces integrated in the device, it can also be used outside the scopes of the SIXTHSENSE project. The mentioned interfaces allow the device to communicate with both analogue and digital sensors of many types which makes it suitable for different kinds of tests and experiments. Furthermore, the powerful STM32H743VIT6 microcontroller used as the core of the device can even be used for certain signal processing applications or for running more complex algorithms than the ones used in this project.

Acknowledgment

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