Minutes of SP4LIFE Workshop #4

Bratislava, February 21-24, 20232 (in person, partially on-line in ZOOM)

Place on-line: https://zoom.us/j/98096100711?pwd=UStLV0tpbUJyaVVUK3FHb3Y5WXJoQT09

Participants:

From Slovakia:	Dr. Milan Tysler, Dr. Daniel Gogola, Richard Bagín, Dr. Jana Švehlíková, Pavel Krakovský
From Belgium:	Prof. Carlo Iorio, Christophe Minetti
From N. Macedonia:	Prof. Ana Madevska Bogdanova, Assoc. Prof. Bojana Koteska, Prof. Nevena Ackovska, Assoc. Prof. Magdalena Kostoska
From Serbia:	Dr. Marko Spasenović, Teodora Vićentić, Stefan Ilić, Miona Tomić

The goal of the workshop was to review current achievements of the Milestone 3, and precise methodological, hardware and software solutions and define tasks for the next six months until Milestone 4.

Program (see detailed program in separate document)

1. Tuesday, February 21:
- WP1, WP2 (lab.506): HW (electronics) preparation and testing
- WP3 (lab.507): SW applications implementation and testing

2. Wednesday, February 22:

morning:
- WP1, WP2 (lab.506) materials and mechanics integration. Setting the patch parameters
- WP3 (lab.507): SW applications implementation and testing

afternoon:
- Welcome by IMS SAS director
- Visits of IMS SAS laboratories
- Partners presentations of results of the third milestone
- Discussion to WP1, WP2, WP3, WP4 results

3. Thursday, February 23:

morning:
- Demonstration of experiments in labs, discussion to future tasks.

afternoon
- WP1, WP2, WP3 (lab.506, 507): HW and SW integration, results, and conclusions
- Co-directors: Milestone 3 reports preparation: deliverables, budgetary issues, personnel
- Preparation of the Milestone 3 reports – common discussion
- Future workshops and conferences planning

4. Friday, February 24:

morning:
- Discussing and summarizing the expected results and future tasks.
- Workshop Closing

Minutes

Day 1

At the beginning of the workshop, Dr. Tysler welcomed the workshop attendees and shortly introduced the schedule of the meeting.

The workshop started its morning and afternoon activities in laboratories in two groups. The first group (Daniel, Teodora, Stefan, Miona, Christophe) was related to WP1 and WP2 and the aims were to test the function of the new laser induced graphene (LIG) sensor samples, to test the functionality of the uP unit of the patch with the ECG/PPG sensor using different sensor settings and to check the ECG/PPG signal quality recorded from different positions on the anterior chest surface.

In the group oriented to WP3 (Richard, Bojana, Magdalena, Nevena), the SW application for HR estimation from the ECG signal based on the Pan-Tomkins algorithm was debugged (optimized data format and memory management) and tested in off-line mode using previously recorded ECG data.

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Day 2, morning

The workshop continued with activities in laboratories. In WP1-WP2 group, signals from ECG/PPG sensor and graphene sensor were recorded in parallel. Measurements were repeated with several PPG parameter settings in three different positions on the chest (upper, medium and lower left anterior chest). The obtained data will be used for possible simultaneous processing of ECG, PPG and LIG signals.

In the WP3 group, development of an application for RR extraction from ECG continued and its implementation in the patch HW model was started.

Day 2, afternoon

The workshop continued with a formal opening. The director of the hosting Institute of Measurement Science SAS, Assoc.prof. Viktor Witkovsky welcomed the participants of the workshop and in a short presentation introduced the departments and research topics of the Institute. Then the participants, according to their wishes, visited selected laboratories of the Institute (oriented to MR tomography, micro CT-tomography, magnetometry, interaction of EM fields with living organisms and surface ECG mapping and modeling).

The afternoon program continued by presentation of individual partners. They reported the activities of their groups during the M3 period, focused on results from September 2022 (since Workshop 3). Most presentations are in the private part of the project web site https://www.um.sav.sk/SP4LIFE/.

The first presentation was given by Milan Tysler (also on behalf of Daniel Gogola and Richard Bagín). He focused on the results in IMS within WP2 and WP3 and concluded that the planned tasks are in a good position. In correspondence with the project plan, within WP2 the patch model hardware (uP module, sensor module and battery) was prepared and its functionality with the ECG/PPG sensor MAX86150 was tested. Selected recorded ECG and PPG signals that were partially evaluated in FCSE were presented. In the second part of his talk he presented the status of the patch SW development within WP3: libraries for the sensor control were developed and tested, library for Bluetooth module is under development. It will serve for communication between the patch and controlling PC/tablet (with Bluetooth LE long range USB dongle) in advertising and paired mode. Suggested software framework is arm Mbed-os6 and the programming language is C. During the workshop, this HW and SW was tested in measurement experiments. In this way also deliverables D1.1, D1.4 (with ICTM), D2.2 (with ULB, ICTM) and partially D3.1 (with FCSE) were prepared.

Marko Spasenovic presented the progress of the robust laser induced graphene (LIG) sensor development in ICTM within WP1. Sensor samples were evaluated also during the workshop. As an alternative, also a commercial piezoelectric sensor was tested last year. The deliverables D1.1 and D1.4 were obtained. He also summarized the dissemination of results within WP5. In next presentation Teodora Vicentic presented latest results of the robust LIG sensor from biocompatible materials, its implementation in experiments and evaluation of its performance in different positions on the chest. She also reported on possible HR and RR estimation from LIG signals and attempts of model-based estimation of SPO2 from LIG signal.

Ana Madevska-Bogdanova presented a summary of the FCSE activities from March 2022 to March 2023. Most activities were within WP3 and WP4. Within WP3, models for SPO2 estimation from ECG+PPG, for BP classification from ECG+PPG and for HR and RR estimation from graphene sensor (with ICTM) were developed. Within WP4, building of own databases of vital parameters was finished and project support for Big Data continued. Also modules for BP and SPO2 estimation using Python modules HeartPy and Neurokit were built and first version of the software for HR and RR on the patch was prepared. In this way the D3.1, D3.2 and D4.1, D4.2, D4.3 were completed. Current activities are oriented to software modules for the patch (with IMS), estimation of SPO2 from LIG and to transformers for BP estimation. Bojana Koteska presented the common research with ICTM to predict oxygen saturation from LIG signal using a deep learning network and a database of ECG, PPG, and impedance pneumography signals that contains also HR, RR and SpO2. Also a review of selected 78 articles (out of 5327 screened) on critical SPO2 level estimation from PPG was presented. Magdalena Kostoska reported more in detail on BP estimation from ECG and PPG features,

including data cleaning, feature extraction and different used models. Obtained results currently do not fulfill required precision standards. She also summarized the activities for IT infrastructure usage and management.

Carlo Iorio and Christophe Minetti reported about the achievements (with Stefan and Teodora from ICTM) during the three-week training in ULB on wearable biocompatible materials and their testing. Christophe also presented the idea of packing the patch electronics in PDMS shell and possibly a biocompatible layer of alginate on the patch bottom (to skin). He also demonstrated conceptual design of the mould for electronics and sensors packing. He also proposed to select the power supply for the patch from those used for cardio-stimulators.

In the presentations, also activities within WP5 (LinkedIn and web page, conferences and workshops) were reviewed and invitations to coming conferences and planned workshops were presented.

The presentations were followed by common discussion where some of the obtained results were treated in detail and the patch functions that should be implemented in the proof-of-concept, proposed HW and SW architecture with possible technical solutions were discussed. The discussion continued on Day 3 with specification of future tasks.

Day 3, morning

In the WP1-WP2 group, the functionality of the patch model with ECG and PPG sensors was demonstrated to workshop participants. The possible integration of the LIG sensor to the patch was discussed. For this reason, additional experiments were performed with LIG sensor glued to the foam strip of the ECG electrode (not directly to the skin). The sensor could record the LIG signal with quality similar to that when glued to the skin what gives the possibility to integrate the sensor with the strip of ECG electrodes.
In the WP3 group, the SW development continued with implementation and testing of the Bluetooth transmission between the patch HW model (development kit) and a notebook with Bluetooth dongle in the Low Energy Long Range (BT LE LR) mode. Basic transmission of simulated data was successful.

Day 3, afternoon

The work in HW and SW laboratories was finished and obtained results can be summarized:
WP1-WP2 group:

- The LIG sensors were able to sense breathing signal with quality sufficient for RR estimation in all tested positions, better signals were on the lower chest surface. The heart beat signals could be visually recognized in most records what gives the possibility to extract and estimate also the HR.
- As one possibility, the LIG sensor can be integrated with the sticky foam strip of the ECG electrodes.
- The uP unit of the patch co-worked with the ECG/PPG sensor using the commercial SW and BT transmission to PC, as well as with the own developed software and recording on local SD card. In both cases different sensor parameters could be set and their influence on signal quality evaluated. Lower currents to PPG sensor resulted in more noise in IR and Red signal channels, with higher currents the pulsating PPG signal was slightly better.
- ECG signal quality with disposable ECG electrodes was sufficient for HR estimation in all tested positions on the chest.
- Breathing signals (changes of R amplitude and baseline) were visible in most ECG signals what gives the possibility to extract from ECG also the RR.
- The PPG signals were able to record breathing but the pulsating part of the signal was hardly visible what makes him probably good enough for HR estimation but not for direct SPO2 computation.
- Additional testing data (ECG+PPG+parallel LIG signals) were recorded and can be used for testing the applications for HR and RR extraction, as well as for testing for extraction of other vital parameters (SpO2 and BP).

WP3 group:

- The application for HR extraction from ECG was successfully implemented in the patch HW model (development kit) and tested on previously measured ECG signals (not in real time).
- The application for RR estimation from ECG was implemented and tested on previously recorded ECG signals and can be further tested and optimized.
- Basic transmission of data from the patch to a monitoring PC/tablet via Bluetooth in Low Energy Long Range (BT LE LR) mode using simulated data was successfully implemented.

In the meeting room, the co-directors discussed the Milestone 3 progress report preparation (deliverables description, definition of future tasks). The structure of the document will be the same as in previous milestones. Milan Tysler will prepare and send a form-like document where the partners will insert their contributions. Best if it can be a shared document on the net.
Additional discussion was devoted to the financial report, namely how the individual items in Financial record should be organized. It is desirable to have individual item for each invoice, several items can be substantiated by a single PDF document signed by the co-director. The document filename should clearly define to which items it belongs. Milan Tysler will send the initial M3 XLSX file and short instructions how to prepare the inputs.

The participants were invited to following workshops and conferences, where contributions from the project are expected:
- Papers for CIIT conference, Krusevo, N. Macedonia, May 5-6, 2023
- Special session on wearable systems within the Measurement 2023 conference, Smolenice, Slovakia, May 28-31, 2023
- SP4LIFE 5th Workshop during ICT Innovations conference, Ohrid, N. Macedonia, September 24-26, 2023

The contents of the discussions during the workshop and the conclusions can be summarized as follows:

Functions of the patch (proof-of-concept)

- The patch should be used after primary START triage for yellow patients (and green patients, if more patches are available)
- All three sensors (ECG, PPG, LIG) should be integrated – EPG sensor will be created.
- The patch should locally evaluate HR and RR and start sound and light alarm if the parameters are out of limits (G-to-Y and Y-to-R alarms),

Track A:
- Single patch will transmit ECG and PPG data over BT to a PC/tablet for processing and model-based BP and SPO2 estimation in the vehicle. All 4 parameters will be available on the PC/tablet (FCSE)

Track A is applicable if the PPG or LIG signals from the chest are good enough to be used for the estimation of SPO2 and BP (to be verified until June 2023 by FCSE).

Track B:
- Single patch will transmit via Bluetooth the HR, RR to the PC/tablet in the vehicle, BP and SPO2 will be obtained from separate devices in the vehicle, all 4 parameters will be available on the PC/tablet (FCSE)

Track B is applicable if Track A cannot be finished by September 2023.

Optional additional steps (if enough time):
- Multiuser mode with transferring HR and RR data from several patches on the field to central tablet in the vehicle via Bluetooth.
- WiFi transfer of the data from the tablet to cloud or hospital server during the transport to the hospital.

Idea for next projet:

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- Development of a smart glove version of the patch: with the PPG sensor on the finger or wrist and separate second ECG electrode + LIG sensor on the chest to get better PPG signal.

Tasks for the next milestone:

- Mechanical design of disposable ECG and LIG sensors: make use of ECG electrode strip,
- Development of EPG patch model for simultaneous collection of data from ECG, PPG and LIG sensors,
- Programing of alarms according START triage,
- Development of SW for streaming ECG, PPG, LIG data via BT to tablet,
- Evaluation of each sensor's performance for RR, HR, and possibly SpO2 evaluation,
- Decision which sensors to use for which parameters and Implement C code on microcontroller,
- Development of the patch electronics and PCB,
- Development of the patch packaging,
- Implementation of basic functionality on tablet application.

See also table in enclosure.

Day 4, morning

In the morning, free discussion on details of the above shown patch functions and planned tasks continued. Among other things, possible mechanical design of the disposable patch sensors using ECG electrode strips was proposed.

Milan Tysler thanked all participants for their active contributions to the workshop that moved the project forward and expressed his belief that the project will be successfully completed.

The next 5th project workshop, according to the schedule established during the meeting, will be hosted by FCSE and will take place in Ohrid, Macedonia, during ICT Innovations conference, on September 24-26, 2023. Additional project meetings will be organized if needed using the video-conference platform ZOOM.

The minutes were taken by Milan Tyšler and amended by Ana Madevska Bogdanova.

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Enclosure: Basic project requirements – Single user module
Product status and basic scenario March to September 2023

Actor	Result	Description	HW	Current and status	When to finish	Partner	WP
First responders	Manual START triage	Putting the patches on Yellow, Green		As Is			
Stefan, Daniel, Pavel, Christophe	Integration of sensors	Basic mechanical patch design with disposable ECG and LIG sensors	ECG, LIG sensors	Partially done	March	ICTM, IMS, ULB	WP1, WP2
Stefan, Richard, Daniel	Patch model with ECG+PPG+LIG calculating RR and RR	The fourth channel on the patch, HW and SE implementation	Patch model	Not started	End of March	LIG sensor - ICTM, connect - IMS	WP2
Richard, Bojana	Alarms According START - G to Y - Y to R	C programming, according START Alarms LED light, sound	Patch model	Not started Must	Middle of April	HW- IMS, ULB SW – IMS, FCSE Method - FM	WP2 T2.2 M3
Richard, Bojana,	Red patients taken in medical vehicle	Bluetooth transfer of ECG, PPG and LIG from patch to tablet in the vehicle	Patch model Tablet	Partially done	April	patch - IMS tablet - FCSE	WP3, T3.4, M4
Bojana, Richard, Magdalena	Patch model with ECG+PPG+LIG calculating HR and RR	C programming and evaluation of apps for ECG, PPG and LIG processing	Patch model	Partially done	May	IMS, FCSE	WP3
Teodora, Magdalena, Bojana	Graphene Signals	Gathering to a data base, processing the data for HR, RR, SPO2 with HeartPy	…	Partially done	June	ICTM, FCSE	WP3
Daniel, Pavel, Christophe	Complete electronics: uP+sensors+BT+battery	mechanics, electronics and PCB development and manufacturing	Patch electronics	Not started Must	August	electronics – IMS LIG sensor – ICTM Battery - ULB	WP2
Christophe, Teodora	Patch packaging	Selection of materials, moulds, technology	Patch prototype	Started	September	package - ULB	WP1
Magdalena	Tablet application	Reading HR, RR from patch, estimation of BP and SPO2	Tablet/PC	Not started	September	Methods – FCSE BT connect - IMS	