Wireless Transmission of Vital Signs of entrapped victims during Search and Rescue Operations in collapsed buildings

George C. Pallis
T4i Engineering Ltd
40 Gracechurch Str. EC3V 0BT
London, United Kingdom
gpallis@t4i.co.uk

Lars Hildebrand
Technical University of Dortmund
Computer Science Department
Otto-Hahn-Str. 12
44221 Dortmund, Germany
lars.hildebrand@tu-dortmund.de

Nuno Ferreira
onCaring
Parque Industrial de Lote 49,
3045-504 Taveiro, Portugal
nunof@oncaring.com

Geert Seynaeve
ECOMED bvba
Huart-Hamoirlaan 68
B-1030 Brussel, Belgium
geert.seynaeve@attentia.be

Abstract—**During Urban Search and Rescue (USaR) operations in collapsed buildings, once the entrapped victims are located the extrication starts. The latter is always time consuming whilst in most cases medical monitoring and support of the victim is needed. Monitoring vital signs of victim is quite important but due to the particular post-collapse conditions of the building (fires, gas leaks, tremors/instability), the preferred method would be remote medical monitoring. In this work a commercial off-the-shelf system for victim's vital signs wireless transmission is tested as part of a feasibility study in which non-invasive methods such as breath or sweat analysis can be used for medical monitoring. The capabilities and the limitations of the tested technology are presented and discussed.**

Wireless transmission, vital signs, entrapped victims, search and rescue, collapsed buildings

I. INTRODUCTION

It is known that following a victim location in Urban Search and Rescue (USaR) operations in collapsed buildings, it actually takes time to access and extricate the victim. During that time, there is a need for continuous monitoring of victim medical status.

Structural failure has been identified as the prime cause of death in earthquake disasters. Survival of entrapped persons (requiring the assistance of others to escape) rapidly diminishes with time. It is obvious that there is a major difference in the rescue difficulties between non-structural entrapment, void entrapment and entombed persons. The morbidity and lethality rate of structural entrapment is influenced by many factors, including the type and quality of the built structure; the day, time and the occupant's location and behavior at the moment of collapse. Known health risks diminishing the change of survival include suffocation, major blood loss, crush syndrome, exposure to low temperatures, uninjured persons without water.

Apart from search and rescue, best practice in Urban Search and Rescue (USaR) requires a third core activity of USaR, namely field critical care. Traditionally the medical staff of USaR focused on first aid and occupational health issues for the members of the team. However, the health challenges associated with structural collapse, entrapment, and the difficult rescue process requires specialized knowledge, skills and equipment and a general approach which is fundamentally different from disaster health and mass emergency methods. [1-5]

During USaR operations, one significant ICT application becomes quite challenging over time; telemedicine/field critical care both for medical support during rescue but also after victim recovery and for on-site, field, pre-hospital treatment and stabilization. Developing sensors for near-real time monitoring of vital signs of victims, adapting them so that they can be easily applied in human body during entrapment, capability of these sensors to work in harsh environments (high temperature, humidity, dust, smoke) and equipped with wireless transmission, are central in making telemedicine perform effectively during USaR operation. Research for developing non-invasive methods for monitoring the medical status of victims during extrication is essential for telemedicine applications. However, examples of successful applications do exist [6-9] and future research can make it more accessible to first responders whilst enhancing their safety.

The aim of the present work was to test commercial off-the-shelf solutions that can be combined with methods (e.g. breath analysis) at a later stage in order to provide additional, innovative solutions. Thus, COTS technology [10] was tested as a first step. The main challenge of this technology for human

MOBIHEALTH 2014, November 03-05, Athens, Greece

DOI 10.4108/icst.mobihealth.2014.257378

vital signs transmission to a remote healthcare system, is that in order to acquire such signs (e.g. heart beat, body temperature, blood pressure, etc.), one needs first to find ways to strap the belt-like probe on victim body parts. Vital parameters include among others heart rate, respiration rate, skin temperature and full ECG. These parameters when related with vital signs of entrapped victim are important and can provide information on victims physiological state. Clinical tools exist for measuring these parameters accurately with long-established procedures for operation and calibration, whereas field-portable devices also exist with equivalent performance. However, extrication conditions impose a strong barrier in the performance of these devices.

It should be emphasized that due to unexpected events (further tremor, fires, gas leaks), the situation during extrication may turn unsafe for both the rescuer and the victim. This is true even when the access to the victim has been established. Therefore, wireless transmission of vital signs outside the rubble is a solution. Wired transmission is not fully excluded though, but due to the harsh conditions in the ruins of a collapsed structure (broken glass, iron bars and other building materials), wireless communication seems to be the method of choice. Nevertheless, wireless transmission is also not problem-free, especially when taking into consideration the communication shadows that may occur in a collapsed building. [11 – 21]

II. EXPERIMENTAL

For the transmission of vital parameters of an entrapped victim one needs lightweight sensors, flexibility in attaching these sensors to victims' body parts, field calibration of the sensors and power supply until extrication and medical stabilization after rescue. Exploring transmission of vital parameters in USaR operations demands resolving all these issues. For the purpose of this study, Zephyr BioHarness was used (http://www.zephyr-technology.com/bioharness-bt), a technology based on wearable sensors that can be attached to the patient's chest using a strap.

Victim vital signs that should be monitored during entrapment include electrocardiogram (ECG), heart rate, breathing rate, skin temperature, posture, activity, blood pressure and pulse oximetry. These signs can be related with the following conditions: stress, anxiety, fatigue, malnourishment, heart stress, hypothermia and hypoxia. It can also correlate with other health problems.

A. *The hardware*

Zephyr BioHarness technology consists of a wireless, portable bio-monitoring system used to measure physiological conditions. The system comprises an electronic module and a smart fabric garment that is worn on the torso. Data may be transmitted to a PC and viewed in real time or logged on the device and later uploaded for view and analysis.

The following sensors are embedded in Zephyr device:

a) heart rate: full 32bit microprocessor analysis of EKG (optionally: EKG, heart rate, R-R, HRV, EKG noise, EKG amplitude)

b) breathing rate: analysis of breathing waveform

c) temperature: using a medical grade pyrometer

d) posture: using 3 axis accelerometer, the device is giving important information of what that person is doing.

e) activity: it makes energy expenditure (calorie) calculations.

f) logging: logs for up to 21 days to internal memory

g) radio: it comes in several radio transmission options; custom ISM 880/921 MHz, Bluetooth etc.

h) testing: designed physiological and biomechanical test protocols to test the limits of vital sign monitoring in the laboratory and the field

B. *The software*

The software that was developed for supporting Zephyr device wireless communication employed the data packets shown in Table I.

TABLE I. DATA TRANSMITTED FROM ZEPHYR DEVICE

Packet name	Data Type	Number of bytes	Comment
HEART_RATE	longint	4 bytes	Beats per minute
BREATHING_RATE	longint	4 bytes	Breaths per minute
SKIN_TEMP	Float	4 bytes	10°-60°, res. +/- 0.1°C
SKIN_CONDUCTANCE	Float	4 bytes	Conductance of skin
POSTURE	longint	4 bytes	+/- 180°
ACTIVITY_LEVEL	Float	4 bytes	Based on acceleration
PEAK_ACCELERATION	Float	4 bytes	Max acc. Of last second
BREATHING_AMP	Float	4 bytes	Ampl. of breath. wave
ACC_X_MIN	Float	4 bytes	
ACC_X_PEAK	Float	4 bytes	
ACC_Y_MIN	Float	4 bytes	
ACC_Y_PEAK	Float	4 bytes	
ACC_Z_MIN	Float	4 bytes	
ACC_Z_PEAK	Float	4 bytes	
WORN	Longint	4 bytes	Status, if device is worn
BUTTON	Longint	4 bytes	Status, if button pressed

C. *Description of the testing*

The Zephyr technology was strapped on the chest of a volunteer that moved inside a building walking up and down the stairs.

1) *Technical data*

The following list shows the Zephyr technical data that were sent via Bluetooth protocol.

1. General parameter
2. Breathing parameter
3. ECG
4. Heart rate R-R data
5. Accelerometer

The device was integrated in the graphical user interface of an existing network of sensors developed in the framework of "SGL for USaR" EC FP7 project (www.sgl-eu.org). Data recorded were processed and visualized on specially developed software for wireless data acquisition.

III. RESULTS

In Fig. 1 and 2 the output of a resting person tested is presented on the Zephyr GUI, whereas in Fig. 3 the output of a person just after activity is presented. In Fig. 4 and 5 the corresponding screenshots of the network of sensors GUI are shown.

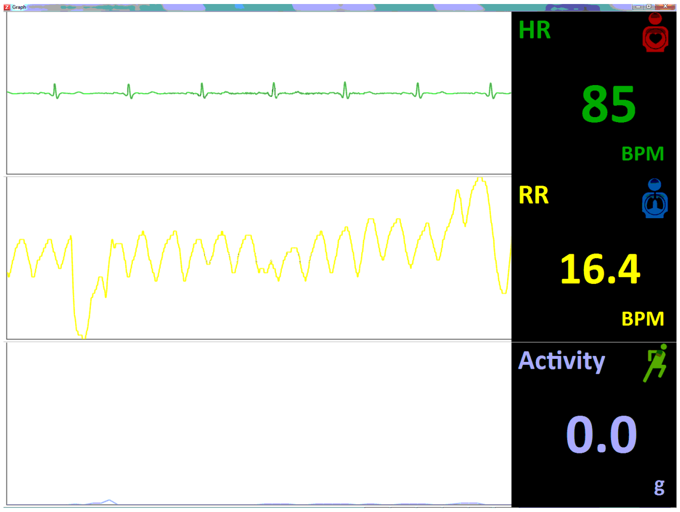
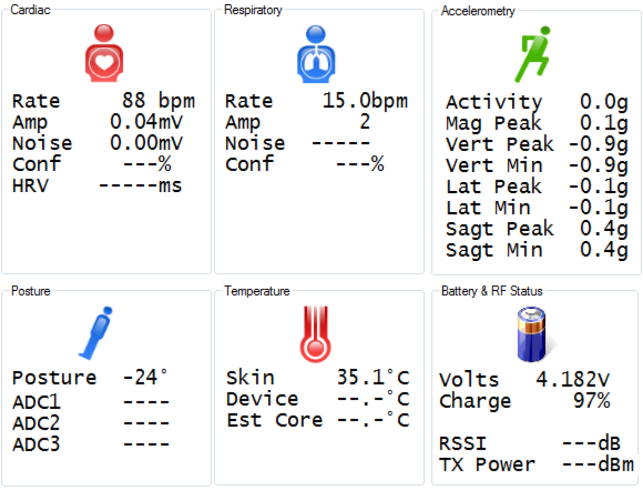


Figure 1. Testing data (resting person) presented over time in Zephyr GUI



Cardiac
Rate 88 bpm
Amp 0.04mV
Noise 0.00mV
Conf ---%
HRV -----ms

Respiratory
Rate 15.0bpm
Amp 2
Noise -----
Conf ---%

Accelerometry
Activity 0.0g
Mag Peak 0.1g
Vert Peak -0.9g
Vert Min -0.9g
Lat Peak -0.1g
Lat Min -0.1g
Sagt Peak 0.4g
Sagt Min 0.4g

Posture
Posture -24°
ADC1 ----
ADC2 ----
ADC3 ----

Temperature
Skin 35.1°C
Device --.-°C
Est Core --.-°C

Battery & RF Status
Volts 4.182V
Charge 97%
RSSI ---dB
TX Power ---dBm

Figure 2. Testing data (resting person) presented in Zephyr GUI

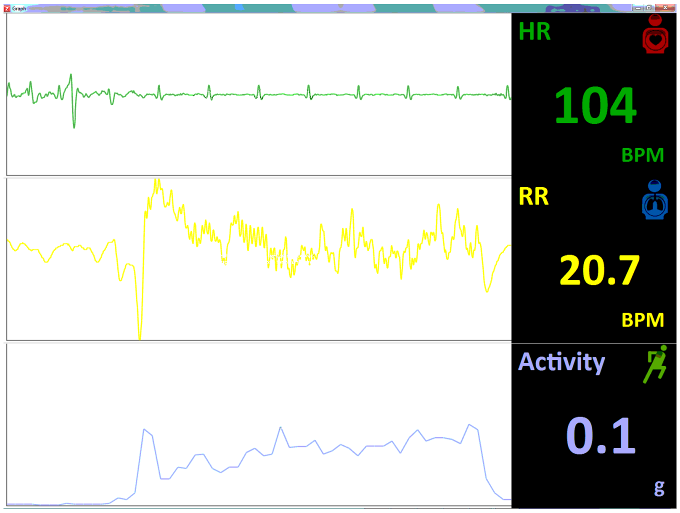
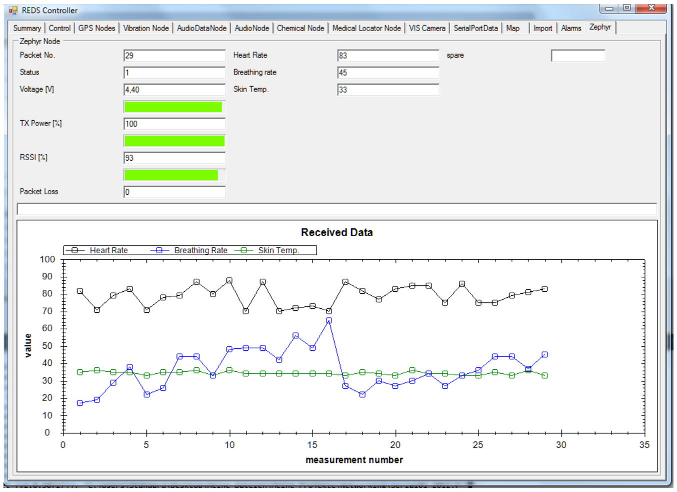
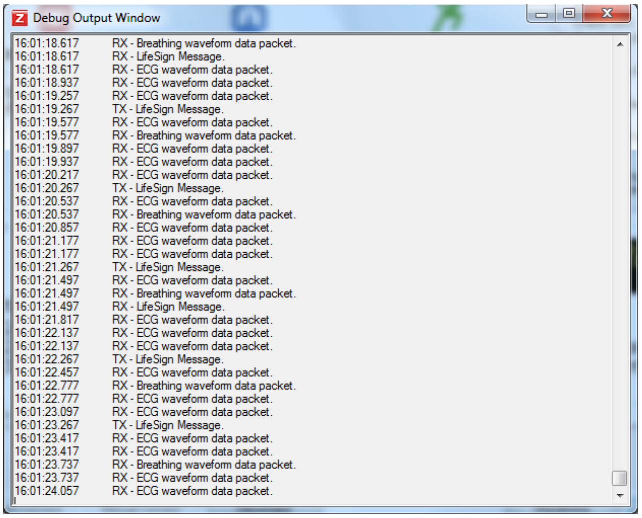


Figure 3. Testing data (person after activity) presented in Zephyr GUI



Packet No. 29
Status 1
Voltage [V] 4,40
TX Power [%] 100
RSSI [%] 93
Packet Loss 0
Heart Rate 83
Breathing rate 45
Skin Temp. 33
spare

Figure 4. Integration with network of sensors



```
16:01:18.617    RX - Breathing waveform data packet.
16:01:18.617    RX - LifeSign Message.
16:01:18.617    RX - ECG waveform data packet.
16:01:18.937    RX - ECG waveform data packet.
16:01:19.257    RX - ECG waveform data packet.
16:01:19.267    TX - LifeSign Message.
16:01:19.577    RX - ECG waveform data packet.
16:01:19.577    RX - Breathing waveform data packet.
16:01:19.897    RX - ECG waveform data packet.
16:01:19.937    RX - ECG waveform data packet.
16:01:20.217    RX - ECG waveform data packet.
16:01:20.267    TX - LifeSign Message.
16:01:20.537    RX - ECG waveform data packet.
16:01:20.537    RX - Breathing waveform data packet.
16:01:20.857    RX - ECG waveform data packet.
16:01:21.177    RX - ECG waveform data packet.
16:01:21.177    RX - ECG waveform data packet.
16:01:21.267    TX - LifeSign Message.
16:01:21.497    RX - ECG waveform data packet.
16:01:21.497    RX - Breathing waveform data packet.
16:01:21.497    RX - LifeSign Message.
16:01:21.817    RX - ECG waveform data packet.
16:01:22.137    RX - ECG waveform data packet.
16:01:22.137    RX - ECG waveform data packet.
16:01:22.267    TX - LifeSign Message.
16:01:22.457    RX - ECG waveform data packet.
16:01:22.777    RX - Breathing waveform data packet.
16:01:22.777    RX - ECG waveform data packet.
16:01:23.097    RX - ECG waveform data packet.
16:01:23.267    TX - LifeSign Message.
16:01:23.417    RX - ECG waveform data packet.
16:01:23.417    RX - ECG waveform data packet.
16:01:23.737    RX - Breathing waveform data packet.
16:01:23.737    RX - ECG waveform data packet.
16:01:24.057    RX - ECG waveform data packet.
```

Figure 5. Data transmission test

IV. CONCLUSIONS

The integration of the data transmission in the network of sensors that was developed in the framework of "SGL for USaR" EU project fully exploited capabilities of Zephyr. The integrated system was used during the field test of the network developed in the project.

Wireless technologies are quite important for vital signs transmission and for remotely acquiring this type of data from entrapped victims in collapsed buildings. However, the use of a belt-like probe around the victim's chest or arm for transmitting data, limits the use of the method in some instances of collapsed buildings. Acquiring data from victim's body guides research towards developing credible and practical interfaces of the body and acquisition device. Additionally, research is needed in order to cope with situations in which victims and posture in entrapment limits first responders from having full or partial access to the victim's body.

Another application of the examined solution is that of a reference method for evaluating the credibility of non-invasive diagnostic techniques such as breath and sweat analysis, especially when used in the field.

ACKNOWLEDGMENT

The authors would like to acknowledge the European Commission FP7 Security project "SGL for USaR" (217967), www.sgl-eu.org, for funding the present work.

REFERENCES

[1] Barbera (J.A.), Cadoux (C.G.). Search, rescue and evacuation. Critical Care Clinics 7(2), 1991, pag. 321–327.

[2] Macintyre (A.G.), Barbera (J.A.), Smith (E.R.). Surviving Collapsed Structure Entrapment after Earthquakes: A "Time to-Rescue" Analysis. Prehosp Disast Med 21(1), 2006, pag. 4–19.

[3] INSARAG Medical Working Group (MWG). The medical management of the entrapped patient with crush syndrome. Medical Guidance Note. INSARAG, UN, OCHA? Geneeva, February 2012, 12

[4] Noji (E.K.). Chapter 8. Earthquakes. In: Noji (E.K.) (Edit.). The Public Health Consequences of Disasters. New-York-Oxford, Oxford University-Press,1997, pag. 135-178.

[5] Seynaeve (G.J.R.). The pathogenesis of Earthquake Disasters. EUSDEM Guidelines Series 3. Brussel, European Society for Disaster and Emergency Management, EUSDEM, 2014, 83

[6] I. Maglogiannis, S. Hadjiefthymiades, EmerLoc: Location-based services for emergency medical incidents, in: International journal of medical informatics 76 (2007) 747–759.

[7] E. Magrabi, N.H. Lovell, B.G. Celler, Web based longitudinal ECG monitoring, in: Proc. 20th Annual Int. Conf. IEEE EMBS, vol. 20, 1998, pp. 1155–1158.

[8] S. Park, et al., Real-time monitoring of patient on remote sites, in: Proc. 20th Annual Int. Conf. IEEE EMBS, vol. 20, 1998, pp. 1321–1325.

[9] B. Yang, S. Rhee, H.H. Asada, A twenty-four hour tele-nursing system using a ring sensor, in: Proc. 1998 IEEE International Conference on Robotics Automation, 1998, pp. 387–392.

[10] Zephyr^{TM} technology, http://zephyranywhere.com/products/bioharness-3/

[11] L.G. Yamamoto, Instant pocket wireless telemedicine consultations, Pediatrics 104 (September (3)) (1999) 670.

[12] L.G. Yamamoto, L.K. Shirai, Instant telemedicine ECG consultation with cardiologists using pocket wireless computers, Am. J. Emerg. Med. 19 (May (3)) (2001) 248–249.

[13] P. Giovas, et al., Transmission of electrocardiograms from a moving ambulance, J. Telemed. Telecare 4 (1998) 5–7.

[14] S. Pavlopoulos, et al., A novel emergency telemedicine system based on wireless communication technology — AMBULANCE, IEEE Trans. Inform. Technol. Biomed. 2 (1998) 261–267.

[15] K. Shimizu, Telemedicine by mobile communication, IEEE Eng. Med. Biol. Mag. 18 (4) (1999) 32–44.

[16] R.H. Istepanian, et al., Design of mobile telemedicine systems using GSM and IS-54 cellular telephone standards, J. Telemed. Telecure 4 (1998) 80–82.

[17] J. Andreasson, et al., Remote system for patient monitoring using Bluetooth/spl trade Sensors, 2002, Proc. IEEE 1 (2002) 304–307.

[18] J. King, P. Mochalski, A. Kupferthaler, K. Unterkofler, H. Koc, W. Filipiak, S. Teschl, H. Hinterhuber and A. Amann. Dynamic profiles of volatile organic compounds in exhaled breath as determined by a coupled PTR-MS/GC-MS study. Physiol. Meas. 31 (2010) 1169–1184.

[19] J. King, A. Kupferthaler, B. Frauscher, H. Hackner, K. Unterkofler, G. Teschl, H. Hinterhuber, A. Amann and B. Högl. Measurement of endogenous acetone and isoprene in exhaled breath during sleep. Physiol. Meas. 33 (2012) 413.

[20] R Huo, A. Agapiou, V Bocos-Bintintan, L. Brown, C Burns, C S Creaser, N. Davenport, B Gao-Lau, C Guallar-Hoyas, L Hildebrand, A Malkar, H Martin, V H Moll, P Patel, A Ratiu, James C Reynolds, S Sielmann, R Slodzynski, M Statheropoulos, M Turner, W Vautz, V Wright, Paul Thomas, "The Trapped Human Experiment", Journal of Breath Research, 2011

[21] Statheropoulos M, Sianos E, Agapiou A, Georgiadou A, Pappa A, Tzamtzis N, et al. Preliminary investigation of using volatile organic compounds from human expired air, blood and urine for locating entrapped people in earthquakes Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences, 2005, 822, 112-117