Biomedical Wireless Radar Sensor Network for Indoor Emergency Situations Detection and Vital Signs Monitoring

Marco Mercuri[1], Peter Karsmakers[2], Bart Vanrumste[2], Paul Leroux[2] and Dominique Schreurs[2]

[1]Holst Centre / imec-NL, Biomedical Circuits & Sensors Department, Eindhoven, The Netherlands
[2]KU Leuven, ESAT, Leuven, Belgium
Email: Marco.Mercuri@imec-nl.nl

***Abstract*— In this work a biomedical wireless radar sensor network (BWRSN), enabling concurrent fall detection and vital signs monitoring, is presented and described. The proposed architecture is intended for indoor applications as a potential ambient assisted living (AAL) technology. Experimental results, conducted in a real room setting with human subjects, demonstrate the need for a wireless sensor network for the targeted application.**

***Index Terms*— Contactless, fall detection, radar remote sensing, vital signs monitoring, wireless radar sensor network.**

I. Introduction

The demographic change worldwide, mainly caused by a process of constant and increasing ageing, has resulted in a growing need for Ambient Assisted Living (AAL) technologies, aiming at enhancing the quality of life of older people [1]. In fact, ageing should be firstly seen as an opportunity to live longer. One of the AAL priorities is in-door long-term health monitoring. Within the latter field, the activities that can be characterized non-invasively using radar techniques are fall detection and vital signs monitoring [2], [3], [4], [5], [6], [7].

A single radar may be insufficient in real situations. In fact, in [8], the authors have demonstrated the need for a WRSN to overcome the single-radar's limitations (i.e., Doppler limitation, signal obstructed by presence of furniture). The WRSN was tested only for the operation of fall detection and tagless localization. In [8], nothing was reported on vital signs monitoring. Moreover, the human subject was holding a fixed position, avoiding also any random body movement.

In this work, the feasibility of using a biomedical WRSN (BWRSN) aiming, at the same time, at real-time fall detection and vital signs monitoring under real conditions is presented and discussed. Moreover, during the fall detection operation, the volunteer was invited to mimic daily activities, allowing therefore random body movements, in the area of the room where the antennas' beamwidths intersect.

In Section II, the system architecture is presented, while the experimental results are shown in Section III.

II. System Architecture

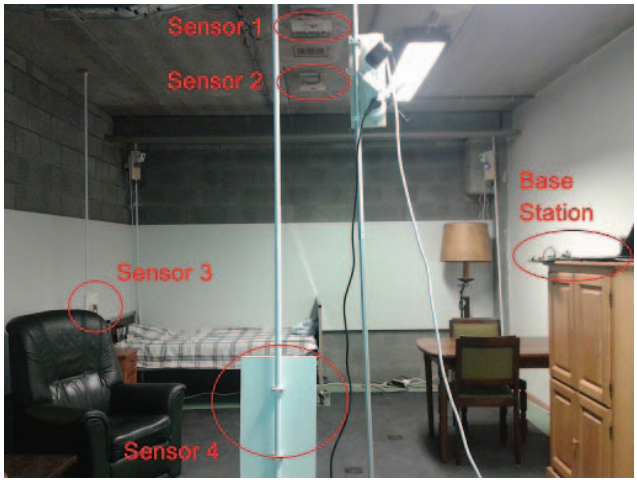
The BWRSN consists of four radar-based sensor nodes and a base station. Each node consists of a microwave radar, a Zigbee module, and a microcontroller, whose detailed description was reported by the authors in [7]. The radar block generates and sends a Continuous Wave (CW) waveform at 5.8 GHz to a subject, and receives its reflected echo, containing the Doppler shift caused by the subject's speed and by the mechanical movements of heart and lungs. The resulting digitized baseband signals are transmitted wirelessly to the base station for remote data processing to determine the vital signs rates and to detect fall incidents.

A movement classification technique based on the Least Squares Support Vector Machines with Global Alignment kernel (LS-SVM-GA) has been used to distinguish a fall event from normal movements, using the classifier reported in [9]. Moreover, in order to process in real-time a continuous stream of radar signals containing multiple activities (i.e., falls and random normal movements) invoked at unknown instants, the LS-SVM-GA has been extended by involving the sliding window principle [10]. In this work, the size of each window is set to 2 s while the overlap among windows is 95% (i.e., 1.9 sec). In fact, each node transmits data to the base station each 100 ms. The new information is concatenated with 1.9 s of previous signal to create a window that should be classified before new data is received. The detailed implementation of the BWRSN, together with its synchronization procedure and the techniques to avoid interferences among the sensors, are reported in [8]. It should be specified that in [8] a stepped-frequency waveform was also involved, whereas in this work only a single tone is used.

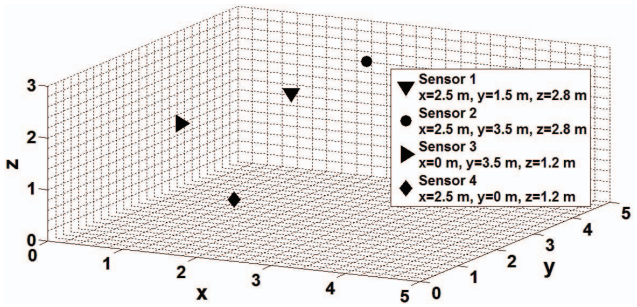
III. Experimental Results

The BWRSN has been tested in a lab of 5 x 5 m^2 which contains furniture, a bed, a sofa, tables, and chairs, in order to mimic a real room environment (Fig. 1). Two nodes have been fixed to the ceiling while the other two are on the wall, whose positions are reported in Fig. 1b.

Authorized licensed use limited to: KU Leuven Libraries. Downloaded on May 11,2020 at 13:59:25 UTC from IEEE Xplore. Restrictions apply.

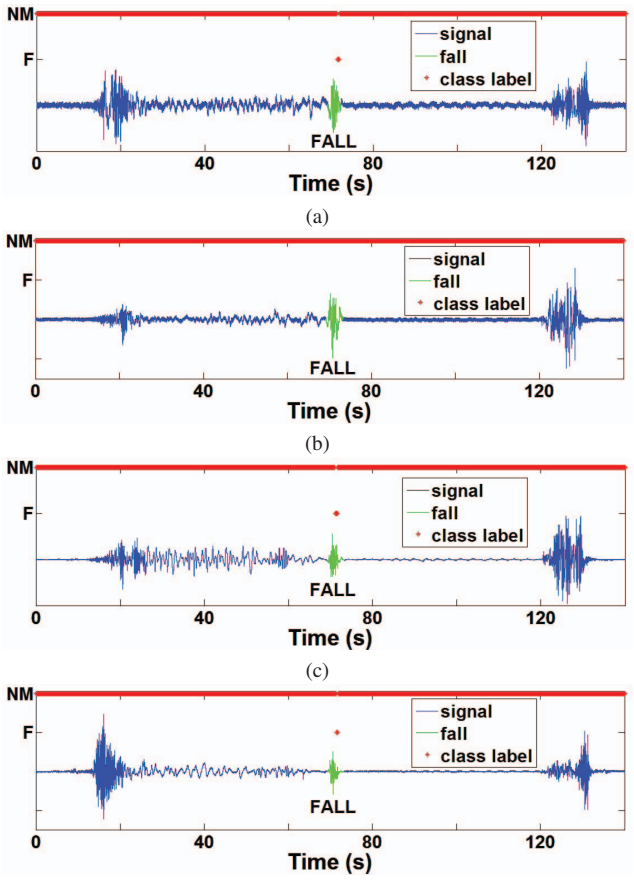


(a)



(b)

Fig. 1. Experimental set-up. (a) real room setting. (b) sensors physical positioning.



(a) (b) (c) (d)

Fig. 2. Real-time classification results of a signal measured, at the same time, with (a) Sensor 1, (b) Sensor 2, (c) Sensor 3, and (d) Sensor 4. Each dot represents the class where a window of 2 s of signal has been assigned. The fall is labeled as "F" while the normal movement as "NM".

Fig. 2 shows four signals, consisting of random normal movements and a fall event invoked at about 70 seconds, acquired at the same time by the four sensors. They are the results of monitoring a volunteer who was allowed to move without restrictions in the whole room. The signals have been processed in real-time by the base station. Since the frequency of the signal is proportional to the radial velocity of the person during the movement, each sensor node will experience a different signal. Fig. 2 shows that Sensors 1, 3, and 4 detect the fall incident, in contrast to Sensor 2. In fact, due to the Doppler limitation, it is not possible to detect falls perpendicular to the line of sight (LoS) of the antenna. In this situation, the related radial speed produces a lower Doppler frequency which was classified as normal movement. It should be specified that in this work, a fall alarm is triggered when at least a single node detects a fall event.

After the fall, the subject was lying on the ground in prone position for about 50 s (i.e., up to about 120 s in Fig. 2) until he stood up and left the room. In this example, the subject was lying below Sensor 1. After the detection of the fall, the biomedical WRSN monitored his breathing rate, as shown in Fig. 3. As it is possible to notice, all sensors detected the same respiration rate. However, depending on the position of the nodes and of the person, the resulting spectra present different magnitudes and harmonic contents. This is due to the different radar cross section (RCS) experienced by the nodes.

The experimental results clearly show the limitation of using one single sensor node in real situations and the importance of the BWRSN in detecting emergency situations while monitoring, at the same time, the respiration rate.

IV. Conclusion

In this work the feasibility of performing, at the same time, contactless fall detection and vital signs monitoring has been demonstrated. This represents an emerging asset in AAL applications, which strive to foster new technologies to enhance the quality of life of older people.

Future work will involve the investigation of a methodology to combine the data from multiple radar sensors such that a better estimate of the target's motion can be obtained. Moreover, the future goal is also to move from the lab environment to real residences, such that a more

Authorized licensed use limited to: KU Leuven Libraries. Downloaded on May 11,2020 at 13:59:25 UTC from IEEE Xplore. Restrictions apply.

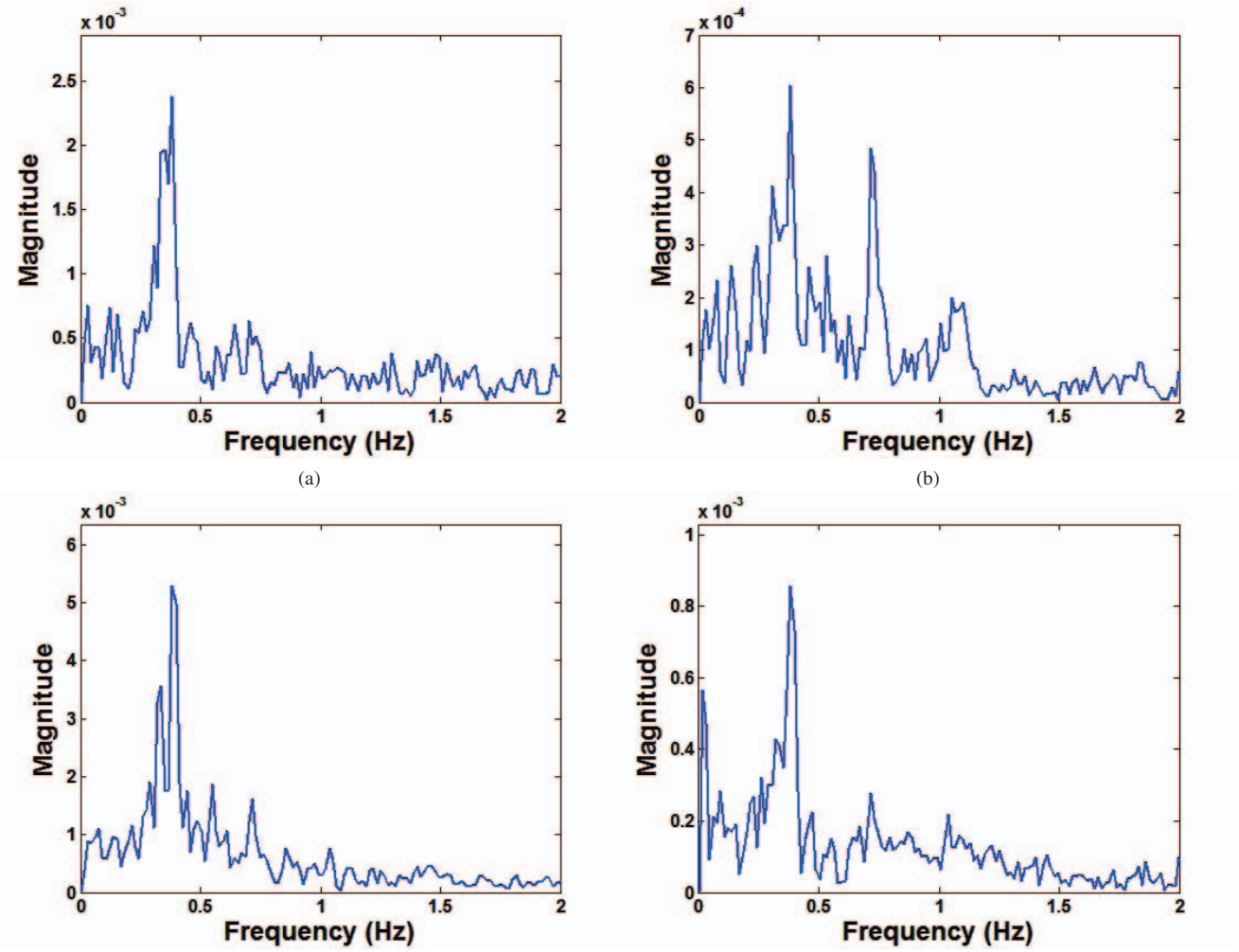


Fig. 3. Respiration rates of a subject in prone position after a fall event measured, at the same time, with (a) Sensor 1, (b) Sensor 2, (c) Sensor 3, and (d) Sensor 4. The spectra are calculated based on a 40 seconds interval.

realistic validation and an in-depth statistics study can be conducted, including also the development of a procedure to determine how many sensors, together with their proper physical positioning, are necessary to achieve the ultimate goal of reliable health monitoring.

ACKNOWLEDGMENT

This work was performed during the first author's PhD research at KU Leuven. The authors would like to thank FWO Flanders and the Hercules Foundation for supporting this work.

REFERENCES

[1] O. Boric-Lubecke and V. M. Lubecke, "Wireless house calls: using communications technology for health care and monitoring," *IEEE Microw. Mag.*, vol. 3, p. 4348, Sept. 2002.

[2] D. Schreurs, M. Mercuri, P. J. Soh, and G. Vandenbosch, "Radar-based health monitoring," in *Proc. IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-Bio 2013).* Singapore, China, Dec. 9-11, 2013, pp. 1–3.

[3] D. Schreurs and M. Mercuri, "Contactless medical sensing," in *IEEE MTT-S Int. Microw. Symp. Dig.,.* Phoenix, AZ, USA, May 17-22, 2015, pp. 1–4.

[4] C. Li, V. M. Lubecke, O. Boric-Lubecke, and J. Lin, "A review on recent advances in Doppler radar sensors for noncontact healthcare monitoring," *IEEE Trans. Microwave Theory Techn.*, vol. 61, no. 5, pp. 2046–2060, May 2013.

[5] A. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, L. Jenshan, and G. T. A. Kovacs, "Range correlation and I-Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring," *IEEE Trans. Microwave Theory Techn.*, vol. 52, no. 3, pp. 838–848, March 2004.

[6] M. Mercuri, D. Schreurs, and P. Leroux, "Optimised waveform design for radar sensor aimed at contactless healthmonitoring," *Electron. Lett.*, vol. 48, no. 20, pp. 1255–1257, Sep. 2013.

[7] M. Mercuri, P. Soh, G. Pandey, P. Karsmakers, G. Vandenbosch, P. Leroux, and D. Schreurs, "Analysis of an indoor biomedical radar-based system for health monitoring," *IEEE Trans. Microw.*

Authorized licensed use limited to: KU Leuven Libraries. Downloaded on May 11,2020 at 13:59:25 UTC from IEEE Xplore. Restrictions apply.

Theory Techn., vol. 61, no. 5, pp. 2061–2068, May 2013.

[8] M. Mercuri, M. Rajabi, P. Karsmakers, P. Soh, B. Vanrumste, P. Leroux, and D. Schreurs, "Dual-mode wireless sensor network for real-time contactless in-door health monitoring," in *IEEE MTT-S Int. Microw. Symp. Dig*. Phoenix, AZ, USA, May 17-22, 2015, pp. 1–4.

[9] C. Garripoli, M. Mercuri, P. Karsmakers, P. Soh, G. Crupi, G. Vandenbosch, C. Pace, P. Leroux, and D. Schreurs, "Embedded dsp-based telehealth radar system for remote in-door fall detection," *IEEE J. Biomed. Health Inform.*, vol. 19, no. 1, pp. 92–101, Jan. 2015.

[10] M. Mercuri, P. Karsmakers, A. Beyer, P. Leroux, and D. Schreurs, "Real-time fall detection and tagless localization using radar techniques," in *Proc. IEEE Wireless and Microw. Techn. Conf.* Cocoa Beach, FL, USA, Apr. 13-15, 2015, pp. 1–3.

Authorized licensed use limited to: KU Leuven Libraries. Downloaded on May 11,2020 at 13:59:25 UTC from IEEE Xplore. Restrictions apply.