Radar-based System for Non-Invasive Long-Term Home Monitoring

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***Abstract*—This report summarizes the outcomes of a PhD project conducted in the division ESAT-TELEMIC group of the KU Leuven Department of Electronic Engineering titled "Development of contactless health monitoring sensors and integration in wireless sensor networks". This research is situated in the field of health monitoring and aims at creating a smart sensing electromagnetic environment based on radar techniques enabling fall detection and tagless in-door localization under realistic conditions in order to alert caregivers when an emergency situation occurs. The target approach is contactless and no action by the monitored person is required. In order to improve the accuracy and to decrease the number of fall positives, multiple sensors will be integrated in a wireless sensor architecture.**

***Index Terms*—Contactless, fall detection, health monitoring, movement classification, radar remote sensing, real-time health monitoring, tagless localization, Zigbee communication.**

I. Introduction

FALL incidents and sustained injuries are the most dangerous causes of accidents for elderly people, and represent also the third cause of chronic disability [1]. The rapid detection of a fall event can reduce the mortality risk and increases the chance to survive the incident and to return to independent living. A variety of fall detection methods have been published in recent scientific literature. However, they suffer from critical limitations and the number of "false positives" is still unacceptably high.

This research is complementary and novel in the sense that it focuses on remote, contactless sensors integrated in wireless building networks. More precisely, the objectives are the design of a contactless sensing device enabling multi-parameter characterizations, namely fall detection and tagless localization, and to integrate such sensors in a wireless sensor network for room environment. In order to achieve this, speed and position of a person are to be detected remotely by adopting radar techniques. By combining the information coming from different radars, a better estimate of the person's motion is obtained opening a new possible scenario for home health monitoring.

This research is innovative and it allows to achieve the goals of monitoring the well-being of aged persons, allowing them to enlarge the period of living in their familiar home environment, and of long-term monitoring of patients whose medical condition is such that a contacting sensor is not favored.

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II. Current State of the Research

A full system for an indoor, non-invasive fall detection and tag-less localization has been designed and analyzed [2]. It consists currently of one sensor, combining radar, Zigbee, and microcontroller capabilities, and of a base station for data processing. A radar waveform is generated and sent to the target, while its reflected echo containing speed and absolute distance information, is collected by the receiver. These baseband signals are digitized and transmitted wirelessly to base station that consists of a Zigbee module, a laptop, and a microcontroller. The latter collects and transfers the data received of the Zigbee module to the laptop to determine remotely the target's absolute distances and to distinguish a fall event from normal movements (e.g., walking, sitting down). Another base station has been also developed consisting of a Zigbee module and a TMDSEVM6678 Multicore Digital Signal Processor (DSP) platform (Fig. 1). As demonstrated in [3], in order to satisfy the spectrum mask requirements and to have a practical commercial device, traditional radar architectures are not suitable solutions for this application. For that reason, an optimized waveform has been designed based on a hybrid approach by which a single tone at f_{ISM} = 5.8 GHz in the ISM band is alternated with a stepped frequency continuous wave waveform working in the 6-7 GHz UWB band. Moreover, this solution allows to avoid high-speed analog to digital converters and high level processors, rendering the sensor cost-effective, and at the same time it satisfies the European and Federal Communications Commission (FCC) UWB mask requirements.

An integrated two-element dual-band antenna has been also designed to operate at both the radar (5.8 – 7 GHz) and Zigbee 2.45 GHz ISM frequency bands [2]. The main challenge was to reduce the backscattering and crosstalk effects. In fact, the backscattering within the frequency band where the sensor is used to locate the target and determine its speed must be strongly reduced to enable maximum forward power towards the target. A failure in doing so will obviously limit the forward transmit power, resulting in a weak reflection from the target, and in a waste of energy. Moreover, since the sensor is intended to be mounted either to the wall or to the ceiling, the relative reflection will bury the much weaker target's reflection. Another challenge that arises when attempting to arrive at a compact system size is the problem of the inter-element antenna cross-coupling. Such large cross-

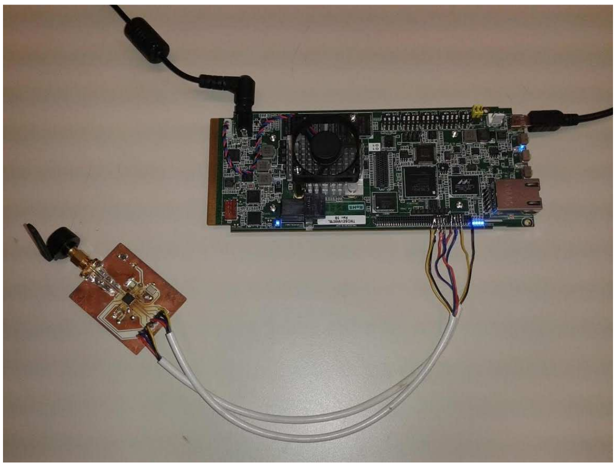

Fig. 1. DSP-based base station.

coupling enables the power "overflow" from the transmitting antenna to the adjacent receiving element involving a strong reflection. These two undesired effects therefore involve the decrease of the total receiver's gain to avoid the saturation both of the amplifiers and of the ADC. Thus, the longer the distance is, the weaker is the reflection such that it is no longer perceptible by the ADC's resolution, and then buried in the noise. Another challenge was to have a semispherical radiation pattern to cover a whole room setting. No off-the-shelf antennas are available for this application dealing those challenges.

A data processing algorithm in Matlab have been developed and tested [2], [4]. A movement classification based on the machine-learning technique is applied to analyze the speed signals distinguishing falls from normal movements. On the other hand, an algorithm based of Inverse Fast Fourier Transformer (IFFT) is used to extract the target's reflection dealing also the effects of backscattering, cross-coupling, and clutter present in environment [5].

The system is proven to be accurate in real-time [6]. Experimental tests, conducted under real human volunteers in a real room setting, have shown an adequate detection of the person's absolute distance and a success rate to detect fall events of 100% with a maximum delay of about 350 ms, without reporting false positives. The subjects were free to move in the whole room with no constrains in their movements. The sensor was fixed to the wall at 1.25 m of height.

III. Budget

The award has had a fundamental impact in supporting this research. Part of the budget has been used to fabricate six copies of the sensor. This included 920 EUR to fabricate the sensor boards, 600 EUR to fabricate the two-element dual-band antennas, and the cost to buy the COTS devices to be integrated in the sensors. These include PLLs, wideband VCOs, LNAs, gain blocks, I/Q Mixers, RF switches, baseband circuitry, microcontrollers, Zigbee modules, and linear voltage regulators. Passive components were also required. The cost of the off-the-shelf devices for each sensor is about 400 EUR.

The TMDSEVM6678 Lite Evaluation Module has been also bought to implement the base station (Fig. 3). The cost of this kit was about 330 EUR.

IV. Personal Statement

The MTT-S Fellowship 2013 Award played an important role in this research. As described in Section III, it helped me to support part of this research. This allowed me also to participate and to win the 2nd place award of the 2013 IEEE MTT-S YouTube/YouKu Video Competition [6]. Moreover, the travel supplement gave me the chance to attend IMS 2013. This gave me the big opportunity to discuss and to take contacts with experts from all over the world working in my fields and, especially, to live and to understand deeply the role of the Microwave Theory and Techniques Society (MTT-S), increasing further my love for research.

Being a member of MTT-S, I also expect to improve my knowledge on RF and Microwave Design obtaining an excellent and solid background that I can always exploit in research beyond the end of the PhD. In fact, my main goal is to continue working in the research world at the end of the PhD.

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