Development of radar-based system for monitoring of frail home-dwelling persons: A healthcare perspective

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Abstract. This interdisciplinary project aims to develop and assess the functional potential of radar technology in the care services. The project mainly has an exploratory character where the technological and functional potential of impulse-radar sensor are tested out in monitoring of elderly and disabled people living in their own home. Designing a non-invasive system for monitoring of movements of frail persons living at home is the main goal, with the intent of assessing health and functional status through monitoring of activities of daily life (ADL) and detecting potentially dangerous situations, not the least related to a long lie following falls.

1. Introduction: Development of novel radar technology in home care services

The task of this Polish-Norwegian project is the development of novel technology for care services; specifically – designing a non-invasive and non-intrusive radar-based system for monitoring of movements of frail persons living at home is the main goal. Monitoring of activities of daily life (ADL) and gait characteristics provides vital information regarding health and functional status; such information may provide early warning signs with regard to potential dangerous falls.

We are presently viewing an increased need for complex care services due to the longevity of people, and a rising number of elderly who will suffer from several chronic conditions, disability or frailty. Today we observe a marked tendency towards compression of morbidity, *i.e.* more people live longer and an increasing number of them are disabled or frail only a short time at the end of their lives (from a few weeks to a few years) [1]. Falls among elderly people are one of the main causes of their hospitalization [2-10]. The number of deaths globally caused by fall events was around 391,000 in 2003, where approximately 40% of the falls were from people over 70 years of age [11,12]. A recent WHO publication [13] suggests that future health and care needs should be met by strengthening health promotion and community-based services, and by acknowledging family and informal home-based care. These ends can be reached by, *e.g.*, facilitating innovation, including employment of ambient technology. The present project deals with development of the telecare part of ambient technology. We aim at developing a system, which is less intrusive than existing vision-based or body-worn devices. Our paper will convey some preliminary experiences regarding opportunities and challenges in this interdisciplinary project.

This paper reports on experiences, with regard to designing a non-intrusive and non-invasive system for fall detection, and preliminary findings in the project. The lessons learned from the interdisciplinary teamwork are likely to be applicable to several technology development projects.

2. Methods

The design of radar modules employed is based on impulse-radar sensors NVA series 6000 (manufactured by Novelda AS, https://www.novelda.no/content/radar-ics) being fully integrated nanoscale radar transceivers, designed for low-power applications. In order to obtain the desired parameters of the developed radar modules, two separate antennas have been designed taking into account the limitation concerning the radiation power in the target frequency band (6.5–8GHz) and characteristics of the receiver and of the transmitter. The radar sensors are connected with an amplifier board and the antennas by means of low-loss semi-rigid coaxial cables and high-grade SMA connectors. The single-board computer is connected to a compact PCB that interconnects its USB ports and routes them to the sensor's USB-to-SPI converter. All the electronic elements of the Radar Module are contained within an aluminum box whose dimensions are 120 mm × 120 mm × 57 mm [14]. The observational angle of each radar is 90 degrees. The radars are capable of measuring the distance in the range from 0.1 to 6 meters up to 15 times per second. One of the radar modules is shown in figure 1.

Figure 1. An exemplary RADCARE radar module.

In the first phase of experiments, a set of fall scenarios was designed in collaboration with two physiotherapists and one occupational therapist in Bergen, Norway. Because the RADCARE radar sensors were not yet available, the falls were performed and recorded using APDM Opal sensors [15], synchronized and controlled using a wireless communication system. These sensors provided us with three-dimensional accelerometric data, as well as additional data from gyroscopes, magnetometers and temperature sensors. The sensors were attached to the body at different levels: hip, shoulders and head. Fall experiments were performed in cooperation with Warsaw University of Technology (WUT) which provided technical requirements. The data acquired in this set of experiments were sent from Bergen University College (BUC) to WUT and used for testing signal processing algorithms before first data from RADCARE radar sensors would be available.

The second phase of fall-related experiments was also set up in collaboration with the above mentioned two physiotherapists and one occupational therapist, this time in the movement laboratory at BUC, using Qualisys movement capture system [16] based on a set of very sensitive infrared cameras which can observe markers reflecting the infrared radiation. The test person was marked with 20 markers in frontal, sagittal and transversal planes (bilateral on ankles, knees, hips, shoulders, elbows, wrists, forehead, ears, back head, and the back). We had 7 motion capture cameras, and an area of ca. 3 m × 3 m covered with multiple layers of thick Airex mats. We explored falls based on typical ADL (Activities of Daily Life) situations and known fall risk situations, like stumbling (*e.g.* related to doorsills and carpets) and sitting to standing movements (*e.g.* from bed or toilet). This broad focus covers falls due to intrinsic (*e.g.* low blood pressure), extrinsic (*e.g.* walking sticks) and environmental causes (*e.g.* insufficient light).

We also assessed the possibility of using the RADCARE technology for the indication of the physical activity of the monitored person. The third phase of experiments involved the use of a system for estimating the two-dimensional position of monitored persons, based on two RADCARE radar modules developed at WUT. Some experiments were performed in laboratory conditions in order to estimate the achievable measurement uncertainty. In these experiments, marks – distant from each other by 1 m – have been placed on the floor at 21 points in the observed area, which enabled us to walk along predefined trajectories. Walking with known speed has been assured by making half-meter steps (according to the marks on the floor) in equal time intervals, signalled by a metronome. The measurement setup used in these experiments is presented in figure 2.

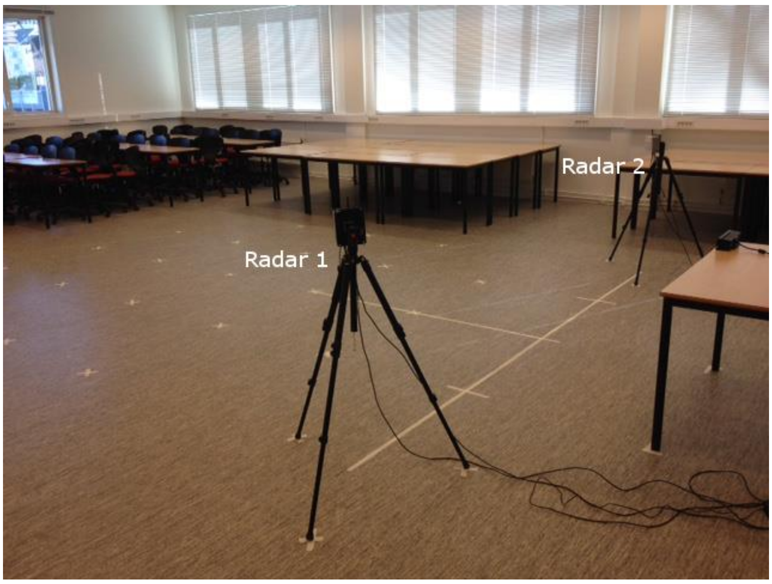

Figure 2. The measurement setup in the laboratory experiments involving a radar-based system for measuring the two-dimensional position of monitored person.

In other experiments, data representative of 10 different movement scenarios were acquired by means of the radar-based system, *viz.* sit to stand, stand to sit, walking, turning, lying down, rising from floor, as well as sitting activities as drinking from a cup, doing ones hair and tying/untying shoe laces.

There are also ongoing experiments which involve the monitoring of an elderly person in her household.

3. Results and discussion

Since the character of the project was mainly exploratory, the capabilities of radar technology, regarding the monitoring of elderly and disabled persons, were tested out, taking into account the present and future needs related to assistive care. It turned out that such objective requires an interdisciplinary approach in various aspects. The relevance and reliability of the developed system depends as much on health sciences insight and healthcare personnel experiences as on technology knowledge and experience. The input from the health sciences proved to be important for identification of significant movements and vital signs in daily life activities, and for developing promising areas for observation and measurements. The most promising results have derived from mapping the capability and feasibility of the RADCARE technology to infer information that acts as indicators of general health status and wellbeing. Measurements of daily life movements in the test home have proven to have clinical relevance, and to provide telecare support and assistance for living well and longer at home.

More specifically, it was possible to detect presence and length of stay at selected places at specific points of time (also behind non-metal walls), and distance covered in monitored space. It was also possible to measure the amount of time spent by a person without any motion, which could indicate the occurrence of a dangerous incidence, such as a fall. Such data can be used for activating alarms if motion is not detected in a selected interval of time, *e.g.* one hour during daytime.

It was also proved that the monitoring system based on two radar sensors can provide estimates of several quantities useful for the healthcare staff, such as:

- average gait speed,
- movement direction,
- the travelled distance,
- acceleration and de-acceleration of the monitored person’s center of mass.

Although the movement direction is not an informative quantity in itself, it provides data that can be used to infer vital information about the patient’s ability to plan, to remember, to find and replace utensils, clothes or props, or indicate a tendency to deliria at specific times. Information on meals and medication and sleeping habits can be used as a backdrop when interpreting movement data.

The estimates of the travelled distance can be summarised for a selected period, such as the last eight hours or the last week. The visualisation of the distance travelled each day during a longer period may help the medical or healthcare staff to detect a long-term trend indicating an improvement or deterioration of health.

Acceleration and de-acceleration related to activities like starting to walk, stopping, and changing the direction, provide valuable information about the monitored person’s balance, postural and motor control.

It proved possible to map movement in different positions (lying, sitting, upright position) and quality of gait (rhythm, sway), all of which are vital information for healthcare personnel. We were, however, not able to identify position and movements of arms and legs.

With regard to falls, the project revealed that the most important issue does not appear to be the trajectory of a fall and hence fall detection, but to differentiate between injurious and non-injurious factual falls. We are presently exploring to which extent the RADCARE technology can contribute to making this most important distinction.

The experiments challenged the key question of what is a fall, how do people fall, what happens during fall, and what precedes a fall. The technology also posed some challenges when it came to production of artefacts and markers falling off the test person. Our focus in the project has hence increasingly been directed towards identification of important components of a fall:

1. speed of movement in a horizontal and vertical planes,
2. positive and negative acceleration,
3. the long lie, *i.e.* the time spent motionless from the moment of impact until the time the person is helped out; the long lie dramatically increases morbidity and mortality.

RADCARE technology has not so far been capable of delivering data that can be used in fine-tuned movement analysis, or data that are refined enough to calculate the relationship between base of support and center of mass, or detecting the amount for compensating movements during everyday living – those data could enable the healthcare personnel to recognize person's reduced balance and increased risk of falling. Nevertheless, the information on gait, provided by the developed system, *e.g.* its speed, cadence, acceleration, and variability, provides the healthcare researchers with valuable information for predicting the functional state and health of the person and hence – the risk of falling [17-20].

4. Conclusions

Interdisciplinary collaboration, where insight from health and social scientists and practitioners is as important as technical knowledge, was proved to be crucial in the RADCARE project – aimed at the development of novel technology for the healthcare sector. Based on the experience we gained when designing a system for detecting and indentifying body movements and ADL of a home-dwelling elderly who may suffer from several chronic conditions, disability or frailty, we were able to define challenges, opportunities and important topics. The wider context of falls in homes needs to be taken into account, with regard to intrinsic, extrinsic and environmental factors.

Our experiments provided valuable data related to human movements, vital for assessing the general health and functional status of a person and, therefore, the risk of falling. The RADCARE technology also seems promising for detecting the most dangerous types of situations, *i.e.* falls followed by a long lie. More effort will be put into this work, and further experiments will be carried out to enable the detection of the potentially very harmful long lie. From our point of view, it is feasible to use a radar-based monitoring system – alone or in combination with other non-invasive monitoring techniques – for preventing falls.

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