Development of software application dedicated to impulse-radar-based system for monitoring of human movements

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Abstract. The importance of research on new technologies that could be employed in care services for elderly and disabled persons is highlighted. Advantages of radar sensors, when applied for non-invasive monitoring of such persons in their home environment, are indicated. A need for comprehensible visualisation of the intermediate results of measurement data processing is justified. Capability of an impulse-radar-based system to provide information, being of crucial importance for medical or healthcare personnel, are investigated. An exemplary software interface, tailored for non-technical users, is proposed, and preliminary results of impulse-radar-based monitoring of human movements are demonstrated.

1. Introduction

The life expectancy has been growing in Europe for many years, while the healthy life expectancy has been slightly diminishing since the last decade of the XXth century (*cf. http://www.healthy-life-years.eu/*). The problem of organised care for elderly people is, therefore, of growing importance. Hence the demand for research on new technologies that could be employed in monitoring systems supporting care services for such persons. The capability of those systems to detect dangerous events, such as person's fall, is of key importance [1, 2].

The systems for monitoring of elderly and disabled persons are, of course, expected not only to detect dangerous events, but also to predict those events on the basis of acquired measurement data, and therefore contribute to the prevention of such events. The analysis of gait, as well as of the itinerary and timing of activities of monitored persons, may thus contribute to prevention [2–5].

Recently, numerous attempts have been made to apply radar technology for monitoring of elderly and disabled persons (*cf.*, for example, the documents [6–9]). They are mainly motivated by the conviction that this technology may be less intrusive, less cumbersome, and less invasive with respect to the home environment than existing solutions. Another attractive feature of the radar-based systems is the possibility of the through-the-wall monitoring of human activity [10–12].

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2. Visualisation of intermediate results of measurement data processing

It should be taken into account that the end-users of the fall detection and prevention systems, the medical and healthcare personnel, are interested only in a limited number of vital parameters, and are rather ignorant about technical details of such systems. Therefore, comprehensible visualisation of measurement data, acquired by means of various sensors, has recently attracted the attention of the research community [4, 13–17], though only with respect to well-established monitoring techniques. Depending on the applied technique, different types of information can be acquired, *e.g.*:

- if the monitoring is based on motion and pressure sensors [16, 17], then the data representative of the patient's location (*i.e.* in the occupied room) are gathered, and some inferences concerning the patient's health condition are made on the basis of the changes in his/her daily routines; *e.g.* early symptoms of depression can manifest as an increase or decrease in sleep activity, while early onset of dementia can cause the increase in wandering out of the apartment [18];
- if the monitoring is based on accelerometers and gyroscopes [19], the stress is put on the qualitative and quantitative characteristics of the patient's movements (*e.g.* number of walks per day, length of walks, and movement velocity) which can be used for identification of the changes in his/her health condition; *e.g.* as suggested in [20], walking velocity is a vital sign – it is very complicated and involves all bodily functions; to be able to walk at a normal velocity ($\geq$ 1 m/s), the overall health status must be good which means that if it deteriorates, it will be possible to observe this by a quick assessment of the person's walking manner.

Apparently, the majority of specified data can be successfully acquired in impulse-radar-based systems for monitoring of human movements. The next sections of this paper are focused on the capability of such systems to provide data being of crucial importance for medical or healthcare personnel, and on the comprehensible visualisation of those data.

3. Monitoring potential behind impulse-radar sensors

Since electromagnetic waves propagate through non-metal walls, a pair of impulse-radar sensors can localise a moving person in a monitored multi-room apartment. Therefore, a system based on such sensors can incorporate features of systems based on motion and pressure sensors; it becomes possible, *e.g.*, to create (on the daily basis) the so-called *heat maps* [4], *i.e.* diagrams depicting time spent by a monitored person in selected flat areas during a day.

An impulse-radar-based system can also incorporate some features of systems based on accelerometers and gyroscopes. Acquisition of sequences of measurement data, representative of the patient's position, followed by their numerical differentiation, enables one to quite accurately track the patient's movement, and to characterise it in terms of its direction and velocity. Moreover, it is possible to statistically summarise the movement parameters over some periods of time, *i.e.* to compute the average velocity, total distance travelled, time spent in motion, time spent motionless, *etc*. Those statistical parameters are believed to be sufficient for making useful inference on patient's health condition, and – consequently – preventing dangerous events (such as falls) based on timely identification of the health deterioration [19, 21, 22].

4. Proposed software application

Within a project aimed at the development of an impulse-radar-based system for monitoring of elderly and disabled persons, a simple software application has been designed – a kind of interface adapted to the expectations of its non-technical users.

In figure 1, the application panel designed for constant monitoring of human movements is shown. It enables one to check on-line the patient's location, his/her current movement direction and velocity, or the time spent motionless. Moreover, its user can generate a movement summary by clicking the appropriate button. An example of a movement summary is shown in figure 2; it contains the information enabling a medical caretaker to check the latest physical activities of the monitored person.

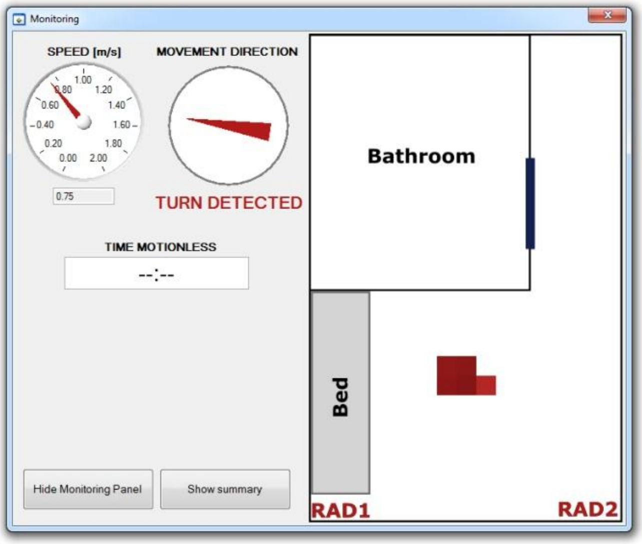

Figure 1. Monitoring panel of the application.

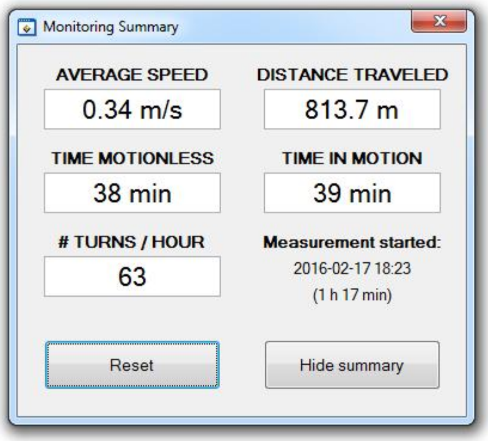

Figure 2. Example of movement summary.

The visualisation of the estimates of the patient's position and derived quantities in real time is a useful method for communication of the results of monitoring to the healthcare personnel. First, displaying the current position, together with the time passed since the last movement, enables the staff to identify a dangerous incident such as long time spent motionless after a fall. Moreover, motion detection during the night can be used to assess the quality of sleep – *e.g.* many motion events, detected during the night, may indicate sleeping problems. Next, a summary containing information on the estimates of the average movement velocity, total travelled distance, total time spent in motion and motionless, as well as the number of turns per hour may serve for inference on the patient's current health status, and on the need for its further investigation. Frequent turns, for example, may result from the patient's confusion – when he/she reminds himself/herself about something, or forgets where he/she was heading, and goes back – therefore the number of turns counted during a selected period may be an indicator of his/her mental health.

A system for monitoring of human movements, developed by the authors, may detect people behind a non-metal wall, although the accuracy of the location estimate is lower behind the wall than it is inside the room in which the radar modules are placed; however, it is sufficient for rough identification of the area. Therefore, the use of such modules allows for detecting the presence of monitored person at selected places in a household without the need to install them in each room.

After the preliminary tests in the laboratory environment, in order to acquire the real-world data, the system has been installed in the flat of one of the project participants. The radar sensors have been placed in a hallway located among other rooms – living room, kitchen, and bathroom – allowing for the acquisition of big and easily interpretable data sets. The scheme of the hallway is presented in figure 3; the symbols RAD1 and RAD2 indicate the positions of the radar modules.

In figure 3, an exemplary movement trajectory (marked with red crosses) is shown; it presents a movement from the kitchen to the living room and then to the bathroom. It can be seen that the system makes possible quite accurate tracking of the monitored person, though some small errors can also be observed. Such errors – like passing through the solid door – occur during the measurement data processing, but are mainly caused by the complexity of the measured radar signal (caused in turn by the complex structure of the human body being the subject of the monitoring).

In figure 4, an example of the movement histogram, created on the basis of the measurement data acquired during a few hours of continuous monitoring, is shown; in this figure – the warmer and more intense the colour, the more frequently the path is attended. It can be observed, that the histogram clearly indicates the paths between the rooms, with the most frequent one – between the living room and the kitchen. Moreover, as it can be seen, the monitored person quite frequently sits on the couch.

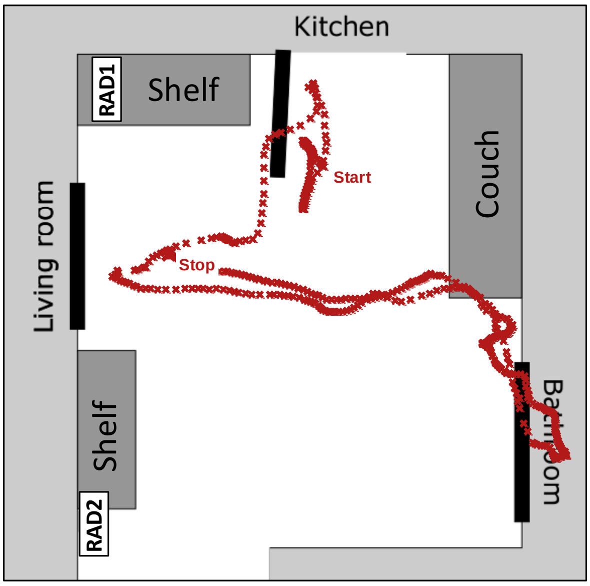

Figure 3. Example of movement trajectory.

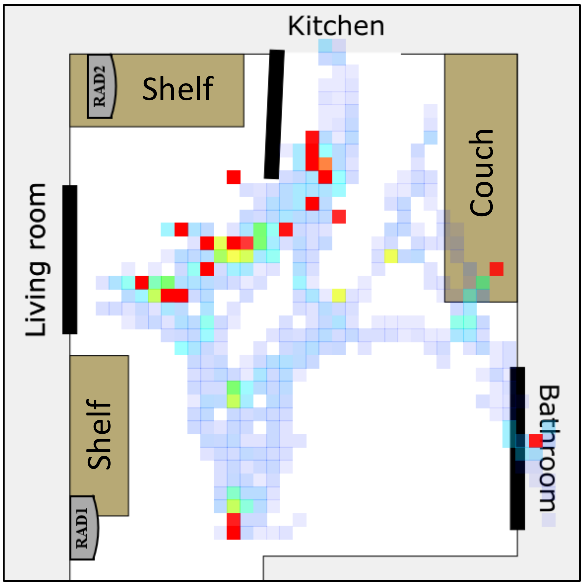

Figure 4. Example of movement histogram.

The two-dimensional location of the monitored person can be used for observing his/her presence at selected places in the household, such as the bedroom or the bathroom, at different times of day. It is then possible to determine a sequence of places visited in some equal time intervals during a number of hours or days. This type of monitoring – through the movement histograms and heat maps – facilitates *e.g.* the pre-fall, post-fall, and fall injury prevention [1]. It enables one to evaluate the variability of the walking patterns of the monitored person; moreover, those data – along with the knowledge about the patient's history and habits – can be used for designing a personalised prevention and warning system which can be tuned according to individual needs.

5. Discussion

It may be argued whether presented impulse-radar-based system is truly non-invasive, if it enables the healthcare personnel to acquire such diverse and detailed data on the monitored person. It has to be noted, though, that in order to provide a reliable monitoring of an elderly person, who is prone to fall, some compromise has to be made. From all the monitoring techniques applied today, radar sensors appear to be the least invasive with respect to monitored person's life (since they only acquire data representative of the person's location) while maximising the healthcare-related possibilities. On the contrary, there are video cameras, which obviously leave no place left for person's privacy and whose field of view is restricted only to the room they are installed in, and body-worn sensors which have to be constantly attached to the person's body and – more importantly – have to be remembered to be worn.

Another thing worth commenting on is that elderly persons aware of being monitored are easily motivated by this fact, what increases their velocity and vigour. On the one hand, more vigorous lifestyle might increase the risk for falls, but it is a mean for fall prevention, health promotion, and a facilitator for healthy behaviour on the other. Moreover, a vigorous life style increases the possibility for quick recovery after a fall, and reduces the risk of injurious falls and long lies after the impact. Therefore, another trade-off is being faced, but – ultimately – healthy ageing at home justifies a possible increase of the risk of falling.

Last but not least, some concerns, regarding the exposition of the elderly persons to the electromagnetic radiation, may be raised. In [23] it is shown that the Effective Isotropic Radiation Power (EIRP) of a single impulse-radar module nearly complies to the requirements of the ultra-wideband standards obligatory in the Europe [24]; this is sufficient for the research purposes, but must be improved in case of practical application. Nevertheless, it has to be remembered that different regulations exist, *e.g.* in the United States, causing potential limitations to the proposed system.

6. Conclusions and prospects for further work

The fall detection and prevention systems are meant to be used by the medical and healthcare personnel interested only in a limited number of vital parameters and being rather ignorant about technical details of such systems; therefore, the development of the human-system interface is not trivial and needs a multidisciplinary approach.

In this paper, the applicability of impulse-radar sensors for monitoring of human movements has been analysed and demonstrated using a prototype software application. In particular: the capability of the impulse-radar-based system to provide data needed by the medical and healthcare personnel has been investigated and preliminary results of the monitoring of human movements, visualised by means of the software interface designed for non-technical users, have been demonstrated.

Starting with information about the person's location, it is possible to derive many healthcare-related quantities being of crucial importance for medical or healthcare personnel, *viz.* the patient's current movement direction and velocity, the average movement velocity, the total travelled distance, the total time spent in motion and motionless, as well as the number of turns per hour.

There are still several issues that should be addressed in the future:

- the set of healthcare-related quantities can still be extended *e.g.* with the estimates of the person's acceleration obtained in three types of situations, *viz.* starting to walk, stopping, and changing the direction; those data can provide valuable information about the monitored person's movement dynamics, which is related to his/her health and fitness;
- the impulse-radar sensors can also be utilised to detect the breathing rhythm and heart beating of the monitored person [25]; incorporation of those functionalities would considerably enhance the quality and reliability of the monitoring;
- integration of the impulse-radar-based monitoring technique with other non-invasive techniques, *e.g.* depth sensors, can also be considered to increase the system's reliability.

Taking into account the non-intrusiveness and unobtrusiveness of impulse-radar systems, one may indicate them as promising means of reliable personalised monitoring of elderly and disabled persons in their home environment.

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