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HealthGate: Unobtrusive Home Monitoring of Vital Signs, Weight, and Mobility of the Elderly

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ABSTRACT

This paper presents the HealthGate (HG) setup for totally unobtrusive monitoring of the vital signs and functional ability of the elderly in their home. It is based on three different sensor types: an imaging mm-range radar, seat and bed foil force detectors and an array of weight sensors installed under a chair. The HG measurement of biosignals (heart and breathing rate while seated or in bed), functional parameters (dynamics of movement and standing up), and sleep will enable comprehensive monitoring of the status of the resident and sudden changes in it. In this paper, the first real life pilot setup and experiences are presented, along with preliminary data from controlled test sessions using the HG setup and reference sensors.

Keywords: Smart home, Elderly, Functional ability, Heart rate, Millimetre wave radar, Seat foil

INTRODUCTION

The population is aging and the pressure to enable the elderly to continue living in their own homes, despite their age-related problems, increases constantly. One enabler is technology: various assistive solutions, automated adjustments and anomalies of the ambience, and monitoring of the status quo and events in health and behaviour. A recent systematic literature review (Maswadi 2020) provides a comprehensive list of review articles analysing different aspects of the technologies used to assist and protect the elderly. In Lunardini et al (2019), the concept of continuous monitoring in a smart home was proposed in practical terms: sensors, data flow and actions.

For care givers and relatives, continuous information of health and mobility of a person reduces the need for check-up appointments and allows fast intervention in case of problems. There are a lot of consumer products that can be used to monitor physiology and physical activity: rings, wristbands and watches, chest bands (e.g., Jalal 2019, Al-khafajiy 2019). However, the elderly tend to regard wearable sensors invasive and unpleasant, suggesting that remote or embedded monitoring devices would be more acceptable in this focus group (Grossi 2020).

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A comprehensive model for unobtrusive home monitoring was presented in a review by Wang et al. (2021). The target of monitoring of a person and the ambience can be classified into physiological (vital signs, weight…), movement and functional ability (activity, gait, food intake, daily activities), emergency detection (falls, severe acute health problems), security (fire, water or gas leak, intruders) and social behaviour (phone calls and messaging, visitors).

In this paper, we introduce the HealthGate (HG) setup designed to unobtrusively monitor physiology and function of an elderly person living independently. The setup is described and the first results of implementation in private apartments, guided test sessions and end-user appraisals are presented.

HEALTHGATE IMPLEMENTATION

The two main principles in HG design are unobtrusiveness and protection of privacy. Contact sensors are not used, and the system does not record voice or video data. HG uses three sensor types: a 2D imaging *radar*, a four-sensor *weight* array at seat and piezoelectric *force* sensor arrays both at seat (Sefo) and at bed mattress. The sensors are monitoring the favourite chair in living room and the bed (Figures 1 and 2).

The house-made radar (VTT, Finland; Forstén 2020) operates at mm-range (60 GHz) with Frequency Modulated Continuous Wave sweep mode (FMCW). The radar has eight transmit (TX) and eight receive (RX) antennas resulting in 64 virtual channels. Frequency-division multiplexing generates

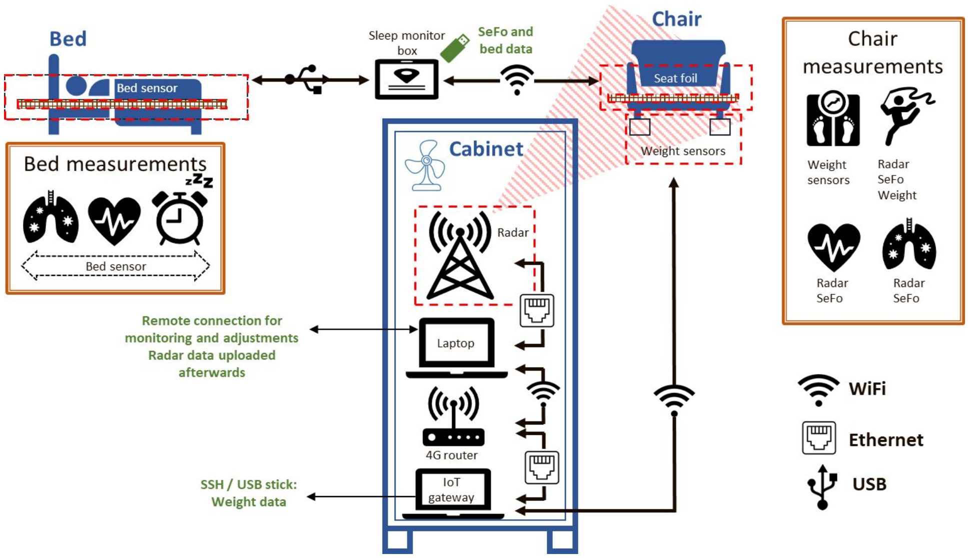

Figure 1: The setup used in the apartments. The measurements take place when the person is sitting in the chair (weight, mobility, heart rate and breathing) and in bed (heart rate, breathing, movements and sleep time). The remote control and data export is shown in green.

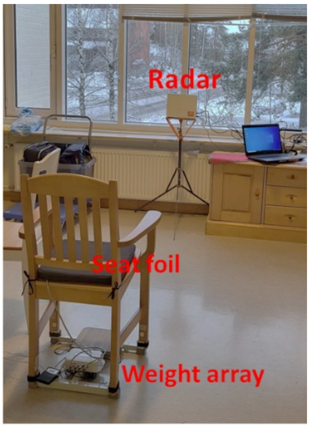

Figure 2: Implementation in an apartment (left) and for the controlled tests (right).

nonoverlapping frequency sweeps for each TX antenna so that each transmit signal can be separated from the received signals. This provides simultaneous sampling of the 2D image frames and enables monitoring of moving targets. The spatial mapping by range-FFT operations results in a 2D image of 160° by 20 m (horizontal x distance) with angular resolution of 3.5° and distance resolution of 30 mm. The radar signal was analysed in detail over a region around the chair and the seated person (ca. 20° by 1.0 m). The heart rate and breathing rate for a seated person were derived as in Turppa 2020.

Prototype of the weight array system (Benete Ltd, Turku; Sensoan Ltd, Finland; VTT, Finland) has four weight sensors attached into the corners of an adjustable H-frame onto which a 4-legged chair can be positioned. Individual sensor acts like a strain gauge which can translate up to 500 N into an electrical signal. All four sensors are attached to a sensor box (IoT node) where pre-processed sensor signals are transmitted wirelessly to a gateway box (IoT gateway). Communication protocol is based on Wirepas Massive IoT architecture developed by Wirepas Ltd.

The bed and seat sensors (eLive Ecosystem Inc., Finland) detect ballistocardiographic signals. A patented multi-channel method is applied for the on-line processing of the vital signs (Kortelainen, 2007). The seat foil sensor has four sensor elements (area 35×30 cm^2) and the bed sensor has eight (35×60 cm^2). The seat sensor is mounted in the seat cushion, placed on top of the seat. Both seat and bed sensor provide motion activity, heart rate and respiration analysis, added with the overnight sleep analysis from the bed sensor.

The apartments were monitored for a 2-week period. A controlled test was arranged close to the monitoring period in order to collect uniform data. The baseline physical condition was measured using standard functional, balance and strength tasks. To compare radar, weight array and seat foil data with each other and to inertia sensors, placed on chest and around both ankles (Movesense HR+, Suunto Ltd, Vantaa, Finland), a fixed movement protocol was used. It consisted of periods of sitting still in the chair, walking ca. 5 meters away and back, and a sequence of three stand up - sit down sequences with 10 s delays in both ends. The physical condition test results are not discussed in this paper.

The participants were interviewed at the end of the monitoring period for their health and sleep as well as for their opinions about the setup and its future use possibilities.

THE PRELIMINARY RESULTS AND DISCUSSION

The experiments started in December 2022 and at the moment, eleven subjects of the target N of 25 have completed the monitoring period and six of them have participated the controlled tests. Data acquisition will go on until spring 2023.

In the next chapters, the first data from controlled tests are presented and some practical aspects and participant viewpoints are discussed. More detailed analysis and inter-sensor validation will be done as the data accumulates. The analysis of home monitoring data is in process.

Controlled Tests

The multisensory data recorded during sit-stand-sit sequence from two participants is shown on the top row in Figure 3. For the agile participant (left), the transitions between seated and standing are sharp and there is little swaying back and forth. For the participant suffering from poor mobility (right), the

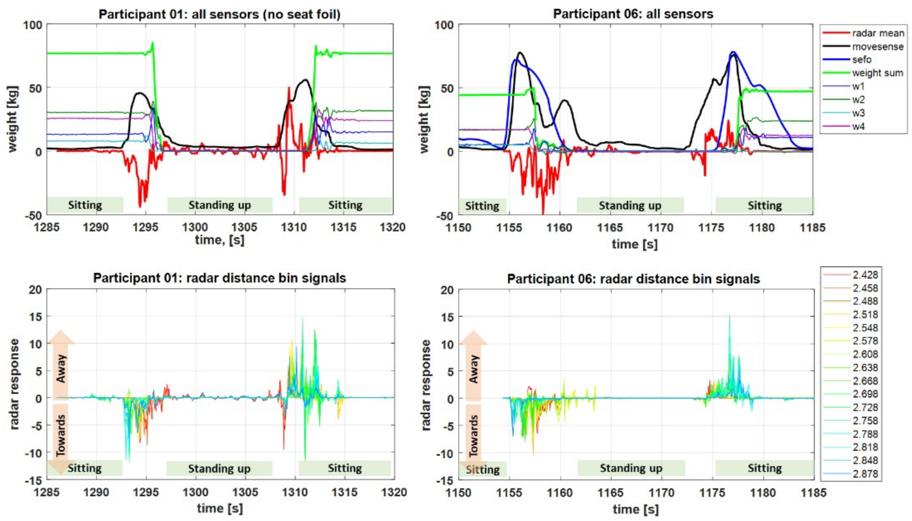

Figure 3: Integrated sensor data (top row) and movement direction from radar at different distances between the radar and reflection site (bottom row) during stand up – sit down sequence. Data for two participants is shown: an agile person (01; left) and a person with challenges in getting in and out of the chair (06; right). The y-axis scale is for weight only. The sitting/standing labels in the graphs are indicative only, based on the accelometer reference data (movesense). In the bottom row graphs, the sign of the values indicates the movement direction, and the values of radar distance (in meters) are shown in the corresponding legend.

movement is slower and less smooth. The different sensors reflect different aspects or the movement. The weight sum provides the weight of the person and reports the moment the weight leaves/enters the chair. Single weight sensors can detect the shifts between the end and front of the chair, or in the lateral direction, monitoring any swaying. The responses in radar, seat foil and accelometer are broader, reflecting the movement before the weight is lifted off or placed back on the chair.

Analysis of the distance bins of the radar signal for the direction of the movement (Figure 3, bottom row) provides more details of the movement. During standing up, the location of the movement shifts gradually towards the radar. In a smooth transition, the distance between the person and the radar decreases monotonously. Any swaying or pumping motion is visible as well.

The extraction of biosignals from the radar and seat foil data is shown in Figure 4. In this case, HR in well in line with reference HR, yet noisier. This is typically the case when the participants are immobile (our data and Turppa 2020). For BR, the agreement between the radar and seat foil particularly after the walk sequence is poor, possibly due to talking.

The standard deviation on the radar signal, indicating movement, was used to compute the stand-up and sit-down times (beginning and end of the movement gradient) and maximum speeds (maximum of the derivative of the movement gradient). The values in Table 1 are mean ± std of the three trials. As the data in Figure 3 suggests, the onset and end of movement is often ambiguous and uncertain. For the two participants (01 and 06) shown in Figure 3, the stand-up times are similar but the maximum speed for the less agile person (06) is much slower than for the agile person (06). In sitting down, the speeds do not differ.

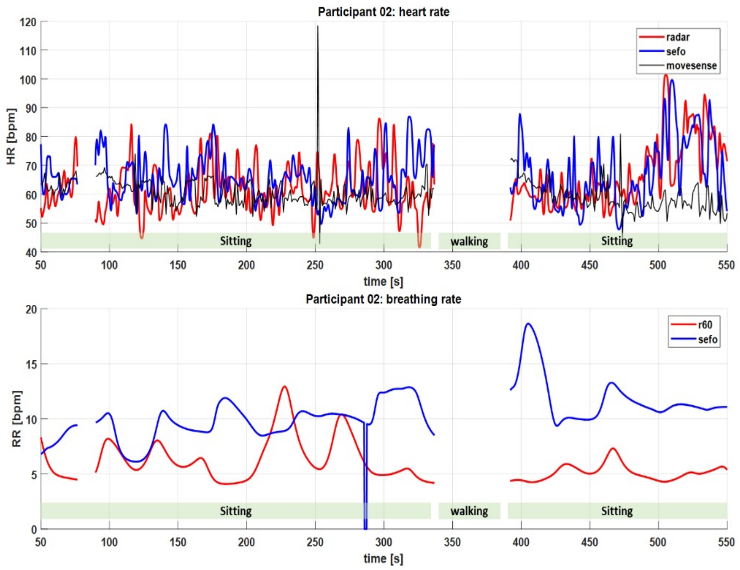

Figure 4: Heart rate (top) and respiration rate (bottom) data computed from data acquired during sitting still.

Table 1. Duration and maximum speed of the standing up and sitting down, as estimated from radar signal. The values presented are mean ± std of the three trials for each direction.

Participant	time up, s	time down, s	speed up, m/s	speed down, m/s
01	3.0 ± 0.4	3.0 ± 0.3	0.12 ± 0.02	0.11 ± 0.03
02	3.3 ± 0.8	3.1 ± 0.4	0.19 ± 0.04	0.21 ± 0.02
03	2.7 ± 0.8	2.6 ± 1.2	0.13 ± 0.07	0.22 ± 0.09
04	2.7 ± 0.5	3.0 ± 0.1	0.24 ± 0.05	0.20 ± 0.02
05	3.1 ± 0.1	2.8 ± 0.1	0.13 ± 0.04	0.19 ± 0.01
06	2.6 ± 0.4	2.7 ± 0.6	0.26 ± 0.05	0.25 ± 0.08

User Viewpoints

In interviews, the setup was considered interesting and, once in full use, the data it collects was considered important for feeling safe. The lack of video and audio recording was considered a benefit, reducing the feeling of intrusiveness. However, a few participants said they would not like to use it themselves, unless they had a severe health problem requiring monitoring, such as cardiac problems.

The access to the data should be given to the person herself and, with consent, to her healthcare professionals and to chosen relatives. The direct involvement of companies was considered somewhat suspicious; the service was considered more trustworthy if it comes through the public or private healthcare provider.

The participants live independently but some of them suffer from moderate dementia. Among them, the cabinet sometimes caused confusion as they didn't quite remember what it was and if they should somehow change their routines because of it. It is important to provide contact information, preferably written on the device itself, so that the resident, visiting family members or caregivers can reach the researchers.

Practical Observations and Future Direction

Typical to a pilot study in real life setting, the data loss has been quite high, due to both technical and practical reasons. There have been issues with running stability of the radar acquisition PC over the two weeks monitoring period. Some participants unplugged power cords. In some setups, the weight sensors could not be installed: the person only had a sofa or the non-sliding, heavy weight sensor frame was impractical for the dining chair the person preferred. With some, the computer and cabinet fan noise disturbed sleep and the radar acquisition had to be stopped.

For easier setup and more reliable measurements, both in monitoring and in test sessions, the devices should be integrated, and a convenient way to see if all devices are alive and acquiring should be arranged. Also, the system should be easier to control and reboot remotely. This is one of the next steps in device development. There are some technical improvements needed, too, particularly in the weight array that was considered bulky, difficult to fix securely and too high.

The data analysis presented in this paper is preliminary and mostly qualitative. The development will now focus on extracting parameters that are relevant for assessing the functional status: characteristics of the dynamics of the weight and seat foil data during standing up, distance information from the radar near the chair and while walking. Besides conventional data analysis for each sensor, we will investigate whether AI methods could be used to model the integrated sensor data, using accelometer data and test results as target of classification. The parameters and models created for test session data could then be used to understand and analyse the data recorded in the apartments.

CONCLUSION

The real-life implementation of the health gate setup was successful, even if several practical development needs were discovered and the data loss in the first monitoring periods was reasonably high. The sensors used in HG provide complementary information of the biosignals and mobility of a person. The results from controlled sessions will provide basis for analysing the monitoring data.

Developing the HG towards a tool to monitor an elderly person will require deeper collaboration with caregivers and medical professionals. The relevant parameters and events need to be identified and thresholds for alerts need to be defined. The experiments presented here provide a good starting point for the work.

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