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Unobtrusive Vital Sign Acquisition in the Domain of AAL

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Abstract

Addressing applications in the area of Ambient Assisted Living, this contribution presents a new kind of unobtrusive, and non-stigmatizing, continuous measurement of vital signs as respiratory rate by the observation and analysis of surrogating signals caused by interdependencies between ultra-wideband radar signals and altering target locations and coherent shapes e.g. the upheaval of the breast or contraction of a muscle. The key part of the approach is based on a mixture of techniques of pre-processing, feature extraction and information fusion including the context aware interpretation for the treatment of multidimensional reflection data sets from the UWB-sensor node. After a brief introduction to the application context including an explanation of specific user demands, physical fundamentals of measurement and utilized electronics, the applied principles of spatial and temporal data mining are described including meaningful experiments.

1 Introduction

The scientific area of Ambient Assisted Living, abbreviated by the acronym AAL, gained much more importance in recent years and was expedited by a couple of research projects funded by the BMBF. Considering the typical target group of AAL-systems, the development of technical solutions such as human centred assistance systems should be accomplished in accordance to usual user demands and restrictions. Therefore, the implementation of medical applications like cooperative compliance control mechanisms, medicine management systems, emergency detection agents, preventive diagnosis systems or in general, health monitoring appertains to the mandatory tasks to scientist and engineers. Health monitoring needs a reliable and robust acquisition of vital signs for evaluation, analysis and diagnosis purpose. And, in addition, requires gapless and equi spaced time series without artefacts when a high rate of recognition is pursued an objective. Established solutions of the telemedicine reveal a lot of specific restriction when applied in the context of technical assistance systems as explained below.

1.1 Current issues in the telemedicine

Common telemedical devices have numerous deficits considering usability, significance and validity of gathered raw data and raise questions of ethics when utilized in AAL-domains. Unfortunately, patients have to handle telemedical devices autonomously by themselves so far. In accordance to their current medical condition and latest therapy recommendations, this has to be done at exactly determined instants of time. Otherwise, the raw data may be not trustworthy or out of sync – extracted information may be diagnostically less conclusive. But besides that, the handling of the equipment is also uncomfortable and inconvenient. Thus, the applied BSN (Body Sensor Network) restricts the user in their autonomy, agility and mobility. This is aggravated by the fact that these BSNs stigmatize the user. Therefore, in the context of AAL, visible measurement of health parameters must be avoided in home care scenarios. The usage of one possible suggestion, imaging techniques based on the evaluation of surveillance camera systems for the identification of position, posture, activity, agility and emotional condition is in this case inappropriate. Generally, the user rejects, or often accepts them only with reservations because this approach procures an impression of observation. In respect to these adducted disadvantages, it is necessary to substitute camera-based systems or BSNs by contactless measurement devices which are integrated as a standalone component or a data point within a multi-sensor network resp. a complete data acquisition infrastructure. To improve our multi-level approach for a human-centered assistance system [1], we prefer the utilization of ultra-wideband radar to achieve long-term vital sign measurement campaigns without any notification by the user. The hardware is either embedded within furniture for resting such as armchairs or mounted on walls as single sensor nodes for position tracking or posture recognition. This publication is constrained to the detection of breathing and related properties.

2 Methodology

At the first glance, contactless measurement of vital signs implies the non-consideration of typical features which are addressed by the established telemedicine such as bioelectric signals (ECG) and others. At this point, the basic idea of the non-invasive measurement deals with the detection of surrogating signals which are directly evocated by the sought source. This source can be the expanding lung or the contracting heart muscle. Thinking about changes in appearance e.g. breast upheaval, the analysis of changes in signal runtime offers a chance to reach the aim of contactless measurement. Thus, UWB-radar systems seem to be a promising technical initial point for further considerations.

2.1 Infrastructure and procedures

Currently we are using an ultra-wideband radar device developed and manufactured by our project partner from the Technical University of Ilmenau and add specific algorithms for signal processing and feature extraction.

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2.1.1 Related Work

UWB-systems with various types of signal modulation are propagated and tested for a widespread area of applications. For example, in order to discover hidden objects or in particular, humans through massive walls, an m-sequence UWB-radar was used by [2]. An alternative approach for through-wall radar imaging was introduced by [3]. The assignment of localization tasks in the context of an automobile parking system to UWB-solutions was proposed by [4]. Recapitulatory, one elaborate survey about current through-wall imaging technologies and coherent applications comes from [5]. An investigation about the benefit of UWB-components for BAN-communication in the domain of telemedicine was published by [6].

Remembering the main topic of this contribution, the detection of vital parameters or distinct features/properties of the human body, UWB-sensor nodes were used by [7] for the examination of different organic tissue including impedance analysis to detect changes in fluid content – emerging edema. The usage of UWB-sensors in order to correct and calibrate MRT-systems was part of the work of [8]. He pursued the goal to find the patient's exact position regarding to the body tissue, in particular of the chest.

2.1.2 Measurement approach

The hardware platform which is currently still in use, is an m-sequence UWB-sensor mainly consisting of a FPGA and a DSP. The basic idea behind the distinctive feature of the m-sequence is the generation of a multiple binary sequence by e.g. a fast shift register. This sequence has the shortest auto-correlation function and additionally, the energy of the emitted signal can steadily be distributed over a large bandwidth. For more details refer to [9].

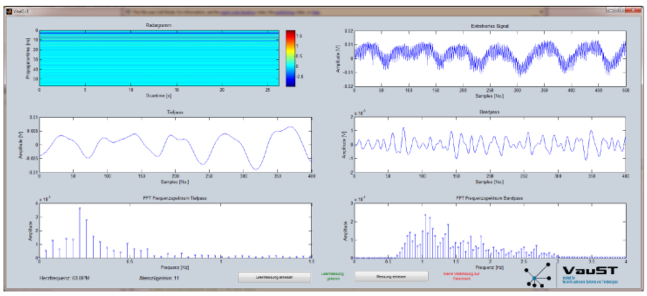

Figure 1: Control GUI including gathered vital signs

The acquisition of dynamic, organic processes as respiratory belongs to the detection of the mechanical signal caused by the organic process itself. Obviously, breathing modifies the appearance and position relative to the sensor node. This assumption leads directly to the conclusion that the analysis of the runtime and their variance allows an inference to the characteristic of the signal. Therefore, reflections caused by the thorax must be isolated and examined in the frequency domain in respect to the number of samples. To achieve unobtrusive measurement, we decided to embed the sensor node within resting furniture – an armchair. One advantage of this setup is the fact that the person is locked into a stable position when sitting in the armchair. The ability to move the body during active measurement is reduced to a minimum; a very important aspect because the dynamic of body movement belongs to the same range as the respiratory does. In order to reduce disturbing influences from moving objects in front of the measurement system, we preferred the installation of the emitting and receiving aerials (type: ordinary Vivaldi-antenna) within the furniture's backside. The sensor system covers a bandwidth of 3.9 GHz from DC with a transmission power of 1mW; a negligible quantity of radiation. Actually, the evaluation software for the treatment of the multidimensional reflection data is implemented in Matlab running on a desktop PC (refer to fig. 1). The sequence of executed steps for the feature extraction and context aware assessment is depicted in fig. 2.

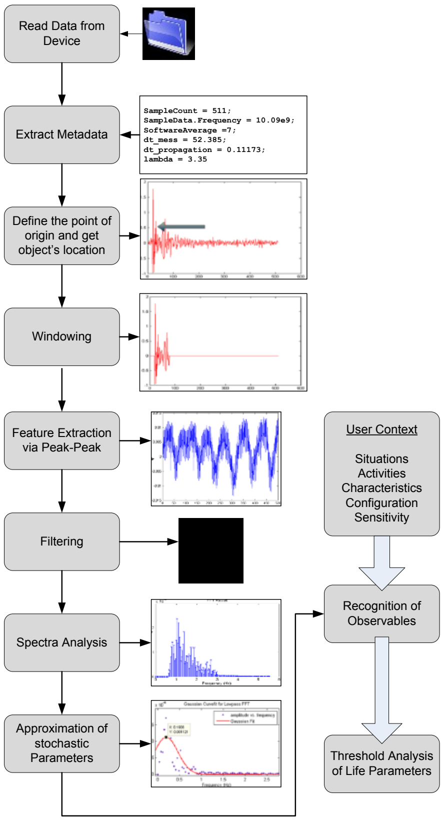

Figure 2: Signal feature analysis process

Device control and data access: For testing purpose, the device is triggered via an UI using USB 2.0 or Ethernet; this includes control access and parameterization (frame length, decimation factor, etc.). Received raw data packages are parsed and arranged in accordance to coherent meta-information.

Determination of the origin: The first step in data analysis deals with the finding of the zero point resp. the origin of the spanned coordinate system. Due to sensor characteristics, this significant point is shifting within the raw data, but fortunately it can be associated with the characteristic cross-talk of the antennas which remain in a constant position. Knowing the distance between the antennas, the zero point can easily be determined by the evaluation of the signal propagation time.

Elimination of static content: Knowing the zero point in every sample, static signal content induced by objects in

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the domain as such as furnishings, the walls or doors, can easily be eliminated by simple subtraction of images. Obviously, there is one "master image"' containing the reflection data caused by the environment. Thus, the deviation between this image and consecutive samples regards dynamic processes in the domain – background removal.

Identification of characteristic signs: The identification of inconstant periodic signals within the reflection depends on a reliable peak-to-peak detection.

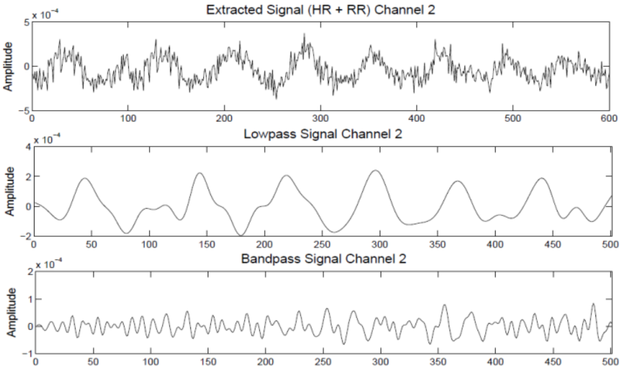

Figure 3: Extracted dynamic content in a TS-representation

Parsing the data, we use identified amplitudes or other significance to determine vertical boundaries for the final windowing procedure. After this preprocessing, only periodic signals including noise remain located within a specific runtime interval. This interval corresponds directly with a distance or in particular, a spatial extent where the movement occurs. Additionally, to scale the data correctly, it is important to consider some physical properties of the measurement system. These properties are the range resolution $\Delta r = c/2B$ and the distance resolution $\Delta d \approx 0{:}35 c \cdot n / B \cdot V0$ with c = velocity of light in vacuum 299.792.458m/s, bandwidth B = 3.9 GHz, $n = RMS_{Noise}$ and default signal amplitude of the sender V_0. Range resolution describes the lowest distance between objects which can be distinguished by the evaluation of reflection data. The distance resolution regards the smallest motion recognizable by reflection data analysis. The result of this process is a time series (refer to fig 3) also fitting following specification: $Y_{nTs} = T_{nTs} + Z_{nTs} + S_{nTs} + R_{nTs}$, $T_s \in R^+$, $n \in N$. This additive model consists of the random noise R_{nTs}, the short-term non-random influence S_{nTs} and the long term behavior $G_{nTs} = T_{nTs} + Z_{nTs}$. Hereby, T_{nTs} describes the trend of a parameter and Z_{nTs} expresses seasonal influence for large intervals. This representation is important for our long-term monitoring approach and not only restricted to UWB-contained information.

Spectra Analysis: Now considering the line-by-line scanning process, limited by previously identified boundaries, we use different filter types with different coefficients in accordance to the addressed feature. Thus, for example for the detection of the respiratory rate, we utilize a low-pass filter with a cutoff-frequency corresponding with 2 Hz at maximum ↔ 120 breaths per minute. For the moment, we are using two types of filters for the flattening noise content in our signal. To preserve significant content such as extrema, the implementation of a polynomial based filter such as Savitzky-Golay is very useful. Particularly, for signals with a characteristic curve progression such as motion patterns of the abdomen, we prefer this type of filtering. In order to create filters with a high attenuation, IIR-filter based on Chebyshev-Polynomials are recommended. In order to approximate the most likely frequency of breathing, the time series is decomposed into its spectral components. Therefore, we are using a Fast Fourier Transform-FFT with different types of windowing methods (Hamming, Hanning, Bartlet etc.) to reduce the leakage effect's influence.

Feature Extraction: The last step in analysis of the raw data is the identification of any trend development. In addition, all features are evaluated due to their stochastic characteristics. This includes the identification of distribution parameters also as the approximation of the best fitting distribution function itself. Each identified parameter is treated in the context of the current estimated user situation [1]. Therefore, every situation is related to a specific set of parameters and vital sign boundaries. The activity "sleeping" is associated with a lower average heart rate than the activity "watching TV". These subsets of vital sign thresholds are a result from an anthropometric survey with test persons. Obviously, in a real world scenario our system behaves like a "prolonged transient response" during the calibration process.

3 Results

3.1 Preliminary experiments

Beginning with test measurement campaigns to check the meaningfulness of our concepts, we focused on experiments to identify the real physical behavior of our setup. Done by causing a "short circuit", we got a device dependent individual spectrum from DC-3.9 GHz as illustrated in fig. 2.

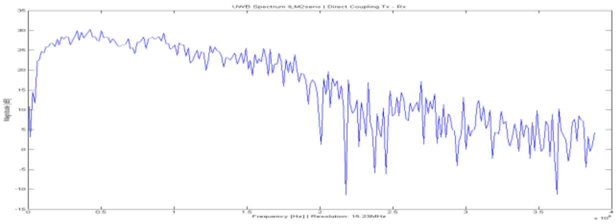

Figure 4: Output spectrum test device

To test the accuracy of the sensor device and the implemented algorithms to detect movement and motion, we utilized a linear-drive in order to generate a deterministic mechanical signal. This linear-drive is configured via a CNC-script with exact values for acceleration ramps, end velocities and motion distances. Analyzing the gathered reflection data, we extracted the motion signal as depicted in fig. 5. The color indicates the value of the amplitude (bipolar). In the radar-gram, the reflection caused by the linear-drive's continuous motion (forwards and backwards) complies with a sinusoid with a period of 2.73 s. It is a very significant and characteristic signal covering an oscillatory motion over a distance of 47 cm. In order to find the lower sensitivity limit, we configured the linear-drive for smallest executable motion. Consecutive measurements have shown a reachable accuracy of 99.8% in

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comparison to adjusted motion characteristics for large distances. In this case, the identifiable accuracy of the measurement device was limited by the signal generator itself. Small signals with a low movement range of 1mm are detected in a significant and reliable manner by the sensor node with an accuracy of 97.6 %. This fact proves robustness and fitness for our desired vital sign acquisition functionality.

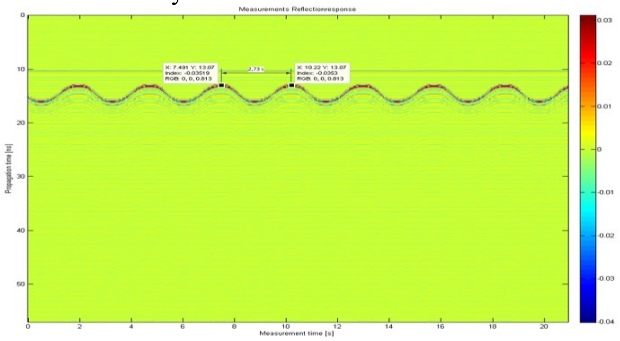

Figure 5: Radargram covering a generated motion

The aim of unobtrusive vital sign acquisition via UWB is accomplished and will soon be tested in a clinical trial. Concerning the detection of respiratory rate and the implemented improvement of the hardware setup (shielding and antenna), our approach proves reliability and worth for telemedical implementations (refer to the result from test campaigns in our laboratory documented in table 1).

Test Person	RR Detection Rate 1(before shielding and antenna adjustment)	RR Detection Rate 2 (after shielding and antenna adjustment)
A (m), 1: 84 m,74 kg	86 %	99.5%
B (m), 1: 72 m,82 kg	73%	98.8%
C (m), 1: 92 m,86 kg	84%	99.4%
D (m), 1: 81 m,78 kg	87%	98.6%
E (f), 1: 67 m,59 kg	71%	98.7%

Table 1: First results of measurement

The shielding has a positive influence for respiratory rate recognition. In addition, the accuracy increased after recalibrating the position of the aerials. Thinking about heart rate detection, which is also part of our work, there are still open issues. In addition, the accuracy depends on the constitution of the person and the position of the antenna. Obviously, the coverage of the interesting body region by the sensor resp. antenna causes this abnormality in accuracy.

Conclusion and outlook

The first experiments with the sensor device and the implemented techniques for feature extraction reveal a great potential for unobtrusive vital sign acquisition in the context of geriatric care. In addition, collaborating with intelligent and predictive situation recognition processes, the single sensor node offers the opportunity to realize a complete solution for an early emergency detection mechanism embedded within furniture. But however, due to the fact that measurement accuracy depends on the patient's shape and stature, it is important to revisit the number of receiving aerials embedded within the armchair for a robust detection of signal with a small amplitude (heart rate – results are not documented here). Therefore, the evaluation of an array of four receiving antennas offers the opportunity to select the best fitting one; the one with the highest significance will be chosen for further data analysis. The next steps will be to investigate the best positions of our transmitter and receiver antennas such as the trans-receiver antenna could point the dorsal or ventral para-axial. The use of multiple channels and coupling Patch antenna or m-array antennas for better data collection is another vision. Concerning the problem of varying frequencies and signal modulation types, the identification of specific signal content as heart rate variances, signal rise times or the isolation of characteristic waveform contents like QT-time considering ECG-recordings, a switch from periodic signals (sinusoids) to wavelets for reconstruction is unavoidable and part of the upcoming working package in research. And finally, thinking about real world scenarios, there is still another open issue; the compensation of overlapping signals as such as WLAN.

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