ULTRA-WIDEBAND SIGNALS FOR THE DETECTION OF WATER ACCUMULATIONS IN THE HUMAN BODY

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Abstract: In this paper, the concept for an Ultra-wideband (UWB) radar system for the detection and quantification of water accumulations in the human body is presented. With this system, the amount of water in human organs (e.g. the bladder or the lung) can be estimated by processing reflected UWB signals. A simulation-based prove of concept of this approach is presented and it is shown that the system promises a feasible way to implement a mobile on-body water detection system for medical applications. Based on the simulation results, it can be concluded that UWB technology is a very promising opportunity for the realization of a mobile and continuous on-body water detection system that can drastically reduce the costs in different areas in the fields of urology and cardiology.

1 INTRODUCTION AND MOTIVATION

The continuous detection and quantification of water accumulations in the human body is an important topic in various medical fields. In urology, neurological diseases can cause a loss of the ability to detect the fluid level in the bladder (eg. paraplegic patients) which makes an external determination of the urination intervals necessary and often causes a permanent catheterization. Also, these therapies often cause complications due to infections and lead to immense follow-up costs for the health care system (Hohenfellner, 2009), (GBE, 2009). Another use is the monitoring of the fluid level in the bladder of senior persons that suffer from dehydration because they regularly don't drink enough (DGE, 2007).

In cardiology, heart failure (HF) is one of the top three most common causes of death (Destatis, 2009), (GBE, 2009) and a pulmonary edema is an indication of an insufficient heart functionality (GBE, 2009), (Fromm et al., 1995). Being able to continuously monitor the patients lungs could help to instantly notice decompensation and react with an adapted treatment.

In both fields, a mobile detection and monitoring of the amount of water in human tissue or organs could prevent patients from being hospitalized and save resources. In this paper, a new approach to measuring the amount of water inside the human body based on Ultra-wideband technology is presented.

The reflections of UWB pulses impinging on the human body are used to deduce the fluid concentration in the reflecting organ or tissue. In Fig. 1 the concept scheme of the proposed method is shown.

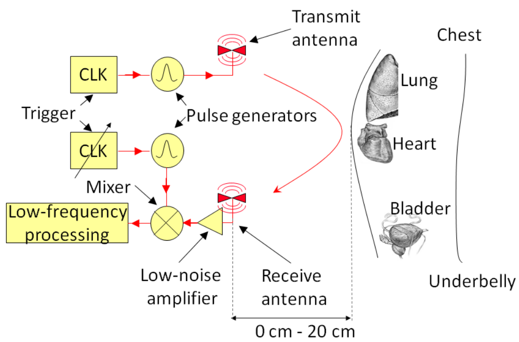

Figure 1: Concept of the on-body water detection system.

In section 2, an analysis of the state of the art in the fields of UWB radar systems and medical applications

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of UWB technology is presented. In section 3, results of a simulated setup are shown to prove the feasibility of this approach. In the last sections conclusions and an outline of planned future research on this topic is presented.

2 STATE OF THE ART

2.1 Definitions and Terminology

Ultra-wideband describes a radio pulse technology with a signal bandwidth greater than 500 MHz or the fractional bandwidth of 20 %. In Germany, the Federal Network Agency ("Bundesnetzagentur") has adopted the regulations of the European Conference of Postal and Telecommunications Administrations (CEPT) for UWB signals (Bundesnetzagentur, 2008). It is important to be noticed that a maximum spectral density of -41.3 dBm/MHz is allowed for all UWB applications.

The main application areas for the technology include imaging, radar and communication systems and the field is currently under very intensive research. For low power communication, first commercial chips will be available in the near future (Decawave, 2008).

2.2 Ultra-wideband Radar

One of the most interesting research areas is the usage of UWB pulses for radar applications. Different objects and their positions can be detected by interpreting reflected UWB signals. The short pulses (typical time domain duration of Full Width at Half Maximum of 100 ps) provide a very high range resolution and the large bandwidth (more than 500 MHz) allows a fine radar resolution of closely spaced objects (Rahayu et al., 2008). So far, the main applications are in the fields of automotive (e.g. parking assistance, pre-crash sensing, blind spot detection, stop&go (Dominik, 2007)) and of through-wall detection (Chamma, 2007), (Lubecke et al., 2007).

2.3 Medical Applications

Also in medical imaging, UWB signals can be used as radar. A scan of the part of the body under examination results in an image of the underlying structure. A precise analysis of the reflected signal can deliver information about the substances in the body and their amounts (Tan and Chia, 2004). Depending on the frequency range used, further possible applications include cardiac biomechanics and chest movements assessments, obstructive sleep apnoea monitoring, soft-tissue biomechanics research, heart and chest imaging, and also cardiac and respiratory monitoring, sudden infant death syndrome monitor and vocal tract studying (Staderini, 2002). A feasibility study on using one UWB device for communication and radar is presented in (Bilich, 2006). In (Gupta et al., 2008) a FM-UWB system for sensing purposes in biomedical applications is proposed and implemented in a Heart Rate Monitoring application.

So far, not much work has been done concerning measurements of water accumulations in the body. To our knowledge only one other group did also identify water blobs in the human body in the course of work on an imaging systems for breast cancer detection (Khor and Bialkowski, 2007).

3 SIMULATION

Goal of the simulation is to show the feasibility of the system concept. The reflections of UWB pulses impinging on a realistic model of a section of the human body are recorded. All parameters are adjusted and tuned to obtain a realistic simulation of the bladder in the human body.

3.1 Setup

The developed model of the human bladder is based on the anatomical drawings from (R.Pabst, 2009), Fig. 2.

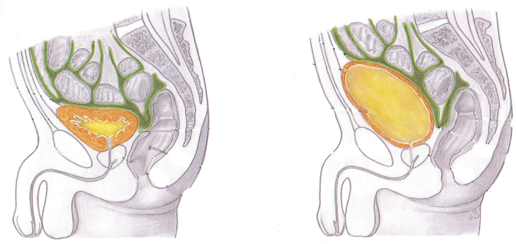

Figure 2: Anatomical drawings of the human bladder, empty and full.

For the simulation, multiple dielectric layers (skin, fat, muscle, bladder and bone) are used as a representation of the bladder (Fig. 3). The thicknesses of the different layers were chosen in accordance to the anatomical model from (R.Pabst, 2009) for an exemplary human body, the thickness of the layer that represents the bladder is changed in accordance to the state (empty or full).

According to (C. Gabriel and Corthout, 1996), (S. Gabriel and Gabriel, 1996), the frequency dependency of the dielectric properties of the biological tis-

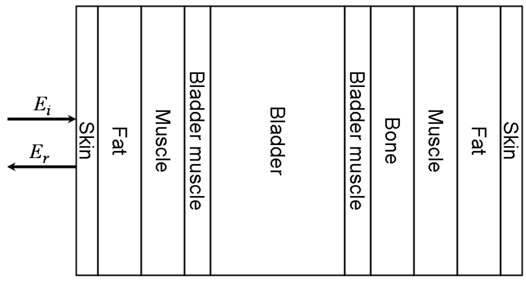

Figure 3: Model of the bladder with multiple dielectric layers for simulation (E_i: incident electric field, E_r: reflected electric field).

sues are considered. An approximation of the frequency dependency of the dielectrics is applied. The direction of an incident wave (E_i) is orientated perpendicularly to the left surface skin (Fig. 3). A plane wave is applied at a distance shortly before the layer of skin to generate the UWB pulse. Due to this impinging wave penetrations and reflections of UWB pulses in the multiple dielectric layers are performed. The reflected signal (E_r) is received by a probe at a distance of 0.5 m.

3.2 Results

Two simulations of the proposed model are taken. A full bladder with urine and an empty bladder are modeled. The differences between these two cases are the thickness of the bladder muscle (thinner for the "full" case) and the amount of urine (larger amount for the "full" case i.e. thicker bladder). The reflected UWB pulses are recorded, the results are shown in Fig. 4 with a solid line for the full bladder and dotted line for the empty bladder.

Three strong reflections marked with numbers are identified from the received electric field E_r in both cases (the peak of the transmitted pulse is 1 V/m). The skin and urine in the bladder have an increased permittivity in comparison to the fat, muscle and bone. The strong reflections r_1 and r'_1 occur on the boundary between air and skin. r_2 and r'_2 are the reflections from the boundary between bladder muscle and urine, while r_3 and r'_3 are caused by the boundary between urine and right bladder muscle. A time difference between r_3 and r'_3 in the two simulation results (full case, empty case) is noticed. This is due to the expansion of the bladder and the displacement of the reflection point which results in a different propagation time of the electromagnetic waves through the bladder in the two cases. Thus, the reflection properties can be utilized for the recognition of water in the body and its amount in the bladder can be estimated.

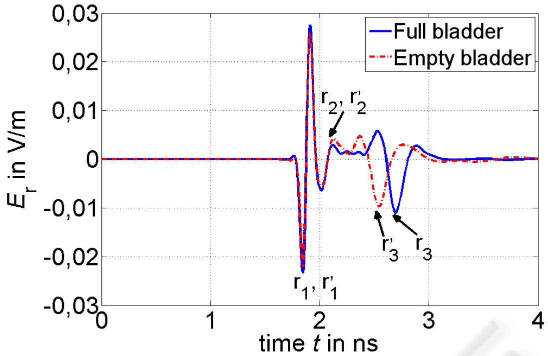

Figure 4: Received electric field E_r of the UWB pulses by the probe: full (solid) vs. empty (dotted) bladder. (full case: r_1, r_2 and r_3; empty case: r'_1, r'_2 and r'_3).

For the detection and the measurement of water accumulations in other human organs like the lung, an evaluation of the amplitudes has to be added to the signal processing in addition to the propagation time analysis. The measuring principle remains the same.

4 CONCLUSIONS

The results of the simulations show that the proposed concept is a feasible way to detect water accumulations in human organs. In the presented example the detection of water in the bladder is simulated. To apply the concept to the lung or other organs, the signal processing has to be adapted and the different attenuation properties and the velocity of propagation have to be evaluated. This approach allows to develop a mobile on-body prevention system for various medical problems that require a continuous monitoring of the fluid level in a human organ.

5 FUTURE WORK

The next steps include the continuation of the simulations by verifying, crosschecking and refining the introduced model of the human bladder to obtain results as realistic as possible. It is then planned to also model the human lung and to develop signal processing algorithms to evaluate not only the signal offset but also the amplitude changes of a reflected signal in dependency of the water amount or concentration in the measured organ. After that, a prototype will be developed for experimental testing and evaluation of the signal processing algorithms.

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