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Progress in Clinical Diagnostics and Treatment with Electromagnetic Fields

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***Abstract*—There is a need for novel diagnostic and treatment systems to overcome the limitations with todays modalities. Microwave and THz based system has the potential to become both sensitive and specific in several applications. In this paper we discuss several applications that are currently being developed at the Chalmers University of Technology.**

I. Introduction

There is presently great and increasing strain on the world wide health care system. Reasons are, at least, twofold. Demographic changes result in an increasing number of elderly people. In addition medical instruments are becoming increasingly complex and thus more expensive. This drives the quest for new cost efficient technologies in medical diagnostics and treatment. One such technology is based on electromagnetic waves in the microwave and THz region. These techniques have the potential to solve some of the outstanding problems in treatment and diagnostics. In the design and construction of the hardware instrumentation one can largely benefit from the development of components that are driven by the considerably larger telecommunication market. The direction of development is here toward smaller, cheaper and more accurate components. In this paper we present our applied research and development for medical diagnostics and treatment based on this technology. The research is interdisciplinary and ground breaking as preliminary results suggests that a common technology platform can be used for a broad set of medical applications. The projects we are currently working on are listed below:

- Microwave tomography for breast cancer diagnostics
- Microwave helmet for stroke detection
- Near field beam forming for microwave hyperthermia treatment of cancer
- THz imaging for biomedical diagnostics

A large part of the instrumentation and the algorithms in the microwave applications are common. On the other hand, the THz technology requires an entirely different instrumentation but many of the strategies and algorithms used for imaging in the microwave region can be applied also in the THz applications. Short descriptions of each project are given under separate sections below.

II. Microwave tomography

The main task in this application is to diagnose breast cancer tumors. For the examination the object under investigation is surrounded by a number of transmitting and receiving antennas. In the measurements each antenna is operated as a transmitter as well as a receiver for every possible combination of antennas. We use ultra wide band (UWB) frequency data to synthesize time domain signals that are used in a FDTD based algorithm to perform reconstruction of the dielectric parameters. Currently we are developing a clinical prototype.

The UWB measurements are performed in the frequency domain with a network analyzer, [1]. However, this measurement strategy is relatively slow due to the switching required between different antennas pairs of an antenna array. In addition, the size and high cost of network analyzer are also limiting factors for many commercial applications. We therefore develop a dedicated time domain system for microwave tomography, [2].

III. Microwave helmet

In this application we aim at developing the microwave technique for diagnosing stroke patients. Approximately 85% of all strokes are blood clot induced and 15% are caused by a bleeding. Early thrombolysis has proved very successful for blood clot induced stroke patients. If given to bleeding stroke patients the treatment in itself could instead be lethal. The treatment has to be given within three hours to be effective. Due to the time consuming chain of care, including MRI or CT for the diagnosis, at the hospitals today only a tiny fraction of the patients with a blood clot induced stroke are given the treatment in time. Microwave diagnostic equiplment can be miniaturized and fit into ambulances. Potentially the diagnosis could then be made already in the ambulance and the trombolytic treatment could given at an earlier stage than today.

The measurement strategy in this application is similar to what is traditionally used in microwave tomography applications. A number of transmitting and receiving antennas are mounted inside a helmet that are worn during the examination of the skull, [3]. UWB data is measured and analyzed. One possibility for the data analysis we are investigating is to use a microwave tomographic imaging algorithms. The other strategy we investigate is a statistical classifier algorithm, [4]. We have performing a clinical study on 20 stroke patients of which 10 have a bleeding stroke and 10 a blood clot. For comparison we also make measurements on healthy volunteers. The preliminary results look promising and further studies are planned.

IV. Microwave hyperthermia

During the last decade clinical studies have demonstrated the ability of microwave hyperthermia to dramatically enhance the response to radiation therapy and chemotherapy leading to increased cancer patient survival. One of the challenges of hyperthermia is to adequately heat deep-seated tumors while preventing surrounding healthy tissue from undesired heating and damage. We here present our system that attempts to resolve this challenge. The system is based on a new focusing technique based on the time-reversal characteristics of electromagnetic waves. In this method the wave front of the source is propagated through the model of the patient from a virtual antenna placed in the tumor. The simulated radiated field is registered in the surrounding antenna system in the computer model. The real antenna system is then transmitting the field in a time-reversed order. We have performed experiments confirming the promising results from our earlier full scale simulations of the system, using both breast and neck tumor models. We have developed an experimental system for initial studies on phantoms and volunteers, [5].

V. THz imaging

While it is early days for this technology as a medical imaging modality, it does have the potential to have a wide range of clinical applications where it can improve and aid the detection and diagnosis of disease, [6]. Due to the high electromagnetic losses at these frequencies the potential applications are however restricted to surfaces, thin substrates or material with low losses, i.e. low water content. In this project we investigate two different potential diagnostic applications.

The simplest method for creating THz images is a single transmitter and detector configuration, i.e. line-of-sight detection. In a practical system operating at 1 THz the spatial resolution could approach about 0.5 mm and is limited by the diffraction of the THz radiation. To overcome the diffraction limit we face an image reconstruction problem that has many similarities with the microwave image reconstruction problem. The THz instrumentation we use, [7], is a set-up for CW transmission characterization at 108GHz. In this case, the source consists of an Agilent E8257D PSG signal generator, a Spacek high power amplifier and a Heterostructure Barrier Varactor (HBV) tripler. The source, set to 10 mW output power, was used to feed the lens, coupled via a conical standard gain horn (W-band). An open-ended waveguide probe, connected to an Erickson Power Meter (PM2), was used as the RF-detector. We have the possibility to perform imaging and characterization up to few THz with in-house sources and detectors.

We are currently building a system and developing imaging algorithms for initial studies of a number of potential clinical applications.

VI. Conclusions

There is a need for novel diagnostic and treatment systems to overcome the limitations with todays modalities. Microwave based system has the potential to become both sensitive and specific in diagnostic applications to a fraction of the cost of conventional technology. We are currently investigating several different applications. A significant overlap between the different applications for example in instrumentation, measurement techniques, signal processing and imaging algorithms adds favorable synergy and increases the potential for success in each part.

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