ERCIM "ALAIN BENSOUSSAN"
FELLOWSHIP PROGRAMME

Scientific Report

First name / Family name	ROHIT CHANDRA
Nationality	INDIAN
Name of the *Host Organisation*	NTNU
First Name / family name of the *Scientific Coordinator*	ILANGKO BALASINGHAM
Period of the fellowship	01/07/2014 to 30/04/2015

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

The period during fellowship was mostly dedicated to research for development of a localization technique based on microwave imaging for an in-body radio frequency source as in wireless capsule endoscope. For this, computer simulations using an electromagnetic simulator were done on a numerical phantom. MATLAB™ code was written for processing the data obtained through the computer simulations. The obtained localization results using the developed technique were promising as an accuracy of about 1.6 cm was obtained in a three-dimensional case for a simple phantom. A conference paper was written based on the results for three-dimensional localization. Moreover, investigations were done on the effect of frequency and noise on such a localization technique. This also resulted in a conference paper.
Feasibility study for the use of microwave imaging for the detection of brain tumour was also done. This study showed that a small size of tumour can be detected through differential microwave imaging. The results of this study would be presented in EUCAP 2015 in Lisbon.
Furthermore, in depth study of various medical applications of microwave imaging was also done. A review journal article was written based on the study that is currently under review.

Apart from research activities, I also acted as a reviewer for various reputed journals (IEEE Transactions on Antennas and Propagation, IEEE Antennas and Wireless Propagation Letter, IEEE Transactions on Biomedical Engineering, Scientific Reports, IEEE Vehicular Technology Magazine) and various other conferences.

I also acted as a committee member (MC) from Norway for the COST Action TD 1301 that is involved in the development of a European-based collaborative network to accelerate technological, clinical and commercialization progress in the area of medical microwave imaging (MiMed).

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

1. R. Chandra, H. Zhou, I. Balasingham, and R. M. Narayanan, "On the Opportunities and Challenges in Microwave Medical Sensing and Imaging," IEEE Transactions on Biomedical Engineering (Submitted for publication)

   Abstract: Widely used medical imaging systems in clinics currently rely on x-rays, magnetic resonance imaging, ultrasound, computed tomography, and positron emission tomography. The aforementioned technologies provide clinical data with a variety of resolution, implementation cost, and use complexity, where some of them rely on ionizing radiation. Microwave sensing and imaging (MSI) is an alternative method based on non-ionizing electromagnetic (EM) signals operating over the frequency range covering hundreds of MHz to tens of GHz. The advantages of using EM signals are low health risk, low cost implementation, low operational cost, ease of use, and user friendliness. Advancements made in microelectronics, material science, and embedded systems make it possible for miniaturization and integration into portable, handheld, mobile devices with networking capability. MSI has been used for tumour detection, blood clot/stroke detection, heart imaging, bone imaging, cancer detection, and localization of in-body RF sources. The fundamental notion of MSI is that it exploits the tissue dependent dielectric contrast to reconstruct signals and images using radar-based or tomographic imaging techniques. This paper presents a comprehensive overview of the active MSI for various medical applications, for which the motivation, challenges, possible solutions, and future directions are discussed.

2. R. Chandra, and Ilangko Balasingham, "Investigations on the Effect of Frequency and Noise in a Localization Technique Based on Microwave Imaging for an In-body RF source," in *Proceeding of SPIE Defence, Security and Sensing*, Baltimore, April 2015 [Accepted]

   Abstract*:* Localization of a wireless capsule endoscope finds many clinical applications from diagnostics to therapy. There are potentially two approaches of the electromagnetic waves based localization: a) signal propagation model based localization using *a priori* information about the person's dielectric channels, and b) recently developed microwave imaging based localization without using any *a priori* information about the person's dielectric channels. In this paper, we study the second approach in terms of a variety of frequencies and signal-to-noise ratios for localization accuracy. To this end, we select a 2-D anatomically realistic numerical phantom for microwave imaging at different frequencies. The selected frequencies are 13.56 MHz, 431.5 MHz, 920 MHz, and 2380 MHz that are typically considered for medical applications. Microwave imaging of a phantom will provide us with an electromagnetic model with electrical properties (relative permittivity and conductivity) of the internal parts of the body and can be useful as a foundation for localization of an in-body RF source. Low frequency imaging at 13.56 MHz provides a low resolution image with high contrast in the dielectric properties. However, at high frequencies, the imaging algorithm is able to image only the outer boundaries of the tissues due to low penetration depth as higher frequency means higher attenuation. Furthermore, recently developed localization method based on microwave imaging is used for estimating the localization accuracy at different frequencies and signal-to-noise ratios. Statistical evaluation of the localization error is performed using the cumulative distribution function (CDF). Based on our results, we conclude that the localization accuracy is minimally affected by the frequency or the noise. However, the choice of the frequency will become critical if the purpose of the method is to image the internal parts of the body for tumour and/or cancer detection.

3. R. Chandra, and Ilangko Balasingham, "Detection of Brain Tumour and Localization of a Deep Brain RF-source Using Microwave Imaging," in *Proceeding of the 9th European Conference on Antennas and Propagation, EUCAP*, Lisbon, April 2015 [Accepted]

   Abstract: This paper presents a feasibility study using numerical simulations for microwave imaging based brain tumour detection. An anatomically realistic numerical phantom with a model of brain tumour is used, where scattered electromagnetic signals are generated using the phantom by finite-difference-time-domain (FDTD) simulations. The microwave imaging technique based on Levernberg-Marquadt iterative scheme is used to solve the inverse scattering problem for the head of the phantom in the 403.5 MHz medical radio (MedRadio) band. Two-dimensional quantitative images having the electrical properties of the brain are reconstructed. Differential images are obtained by taking the difference between the reconstructed images with and without the tumour model, and with and without the expected effect of the contrast agents. Although it is difficult to detect a small tumour in the reconstructed image, a tumour of diameter 5 mm can be detected in the differential image in high signal-to-noise ratio (SNR) cases. The simulation results show that at least 45 dB SNR is required for small size tumour detection.
   Moreover, the paper presents a study of a localization method based on microwave imaging for deep- brain RF-source. The method can be useful for precise positioning of a neuro-endoscope. The simulation results show that it is possible to localize a deep-brain RF-source in two dimensions with a localization accuracy of 5 mm at an SNR of 30 dB.

4. R. Chandra, and Anders J Johansson, "Analytical Model, Measurements, and Effect of Outer Lossless Shell of Phantoms for On-body Propagation Channel Around the Body for Body Area Networks," in *Proceeding of the 9th European Conference on Antennas and Propagation, EUCAP*, Lisbon, April 2015 [Accepted]
   Abstract: This paper presents the experimental verification of an analytical model for the propagation channel for the devices placed around body in body area networks. Measurements are done over a semi-solid physical phantom using on-body antennas. A good agreement between the analytical model and the measurements is obtained at 2.4 GHz. Further, the effect of the outer lossless shell, usually present in the phantoms, is discussed. Through simulations, it is shown that the outer lossless shell results in decreasing the link loss for around the body propagation whereas the effect of the shell for along the body propagation is minimal.

5. R. Chandra, Ilangko Balasingham, et al. "A Microwave Imaging-based 3D Localization Algorithm for an In-body RF source as in Wireless Capsule Endoscopes," in *Proceeding of 37th Annual International Conference of the IEEE*

Engineering in Medicine and Biology Society, Milano, Aug. 2015 [Submission Pending]

Abstract: A microwave imaging-based technique for 3D localization of an in-body RF source is presented. Such a technique can be useful for localization of an RF source as in wireless capsule endoscopes for positioning of any abnormality in the gastrointestinal tract. Microwave imaging is used to determine the dielectric properties (relative permittivity and conductivity) of the tissues that are required for a precise localization. A 2D microwave imaging algorithm is used for determination of the dielectric properties. Calibration method is developed for removing any error due to the used 2D imaging algorithm on the imaging data of a 3D body. The developed method is tested on a simple 3D heterogeneous phantom through finite-difference-time-domain simulations. Additive white Gaussian noise at the signal-to-noise ratio of 30 dB is added to the simulated data to make them more realistic. The developed calibration method improves the imaging and the localization accuracy. Statistics on the localization accuracy are developed by randomly placing the RF source at various positions inside the small intestine. The cumulative distribution function of the localization error is plotted. In 90% of the cases, the localization accuracy was found within 1.67 cm, showing the capability of the developed method for 3D localization.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1. To attend 9th European Conference on Antennas and Propagation, EUCAP, Lisbon, 11-17 April 2015
2. To attend SPIE Defence, Security and Sensing, Baltimore, 20-25 April 2015

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Local Scientifc Coordinator: Dr. Marco A. Antoniades
Name of REP Organization: University of Cyprus, Nicosia
Country: Cyprus
Department: Department of Electrical and Computer Engineering
Dates: 12th February to 23rd February, 2015.

I discussed my research interests with the local scientific coordinator (Dr. Antoniades). He told me about various research work in which he is involved, such as metamaterial antennas. We also discussed for a possible future collaboration as he has a research interest in using metamaterial antennas for biomedical applications. Overall, it was a fruitful discussion. I gave a seminar attended by students, researchers, and professors from the University of Cyprus and the Fredrick University, Nicosia, on the topic “Microwave Imaging-based localization of wireless capsule endoscopes, and antennas and propagation for wireless body area networks.”