# Exploitation of Electromagnetic Radiation Properties for Medical Diagnostic

Gaddi Blumrosen[1], Dana Porrat[1], Boris Rubinsky[1,2], and Danny Dolev[1]

[1]School of Computer Science and Engineering, Hebrew University, Givat Ram Campus, Jerusalem, Israel

[2]Department of Biomedical Engineering, University of California at Berkeley, Berkeley, CA, USA

**Abstract — A modern health system increasingly relies on modern sensing tools to aid in patient care. This paper suggests exploiting accessible electromagnetic radiation properties of propagation delay, attenuation and dispersion to extract biomedical parameters and to assess medical conditions continuously, in a non-invasive way, and with a minimal cost. It is performed by employing a set of sensors equipped with wireless capabilities that transmit to the medium of interest a known pattern of electromagnetic radiation. From the partial reception of the signal at the sensors, parameters like tremor characteristics, distance between body parts, and tissue bleeding indicator, can be derived and then used for medical diagnosis.**

***Index Terms*** **— Biomedical telemetry, Microwave measurements, Parameter extraction, and Motion analysis.**

## I. Introduction

An Electro-Magnetic (EM) radiation is a form of energy propagated through free space or through a material medium in the form of electromagnetic waves. An EM wave has magnetic and electrical fields which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. An EM wave can be characterized by the wave frequency which is inverse proportional to the EM wavelength.

A common way to produce EMR is by oscillating current in a radio antenna. The antenna of a radio transmitter is part of an electric resonance circuit in which the charge is made to oscillate at a desired frequency. The EM wave can be received by a similar antenna connected to an oscillating electric circuit in the tuner that is tuned to that same frequency. The electromagnetic wave in turn produces an oscillating motion of charge in the receiving antenna.

EMR is not affected by travelling through static electric or magnetic fields in a linear medium such as a vacuum. When electromagnetic radiation is incident on matter, it causes the charged particles to oscillate and gain energy. Interactions between EM and nonlinear media can cause the EM wave to alter its speed and polarization. Dispersion is a frequency-dependent response of a medium for EM wave propagation. The EMR can be re-radiated and appear as scattered, reflected, or transmitted radiation [1]. It may also get dissipated into other microscopic motions within the matter, manifesting itself as thermal energy in the material. The EMR in space decreases according to the inverse-square law in a quantity which is inversely proportional to the square of the distance from the source of the radiation. The EMR is further attenuated due to absorption or scattering. As a result, an EM wave radiated from a radio antenna propagates in a dispersive medium and scattered to different multi-paths with different attenuations and propagation delays.

Electromagnetic (EM) radiation is widely used in medicine [2]. A main application of the EMR is in medical imaging, e.g. X-ray computed tomography (CT) [3] or Magnetic resonance imaging (MRI) [4]. Another main use of EMR is for medical treatment. In [5], for example, short duration electrical fields are used to permanently permebilize the cell membrane, and is used as a treatment of a tumor. Most of the systems that exploit EMR needs expensive infrastructure that can reach to millions of dollars, requires heavy computation sources [6] and is mostly not portable. As a result it cannot be accessible to the majority of world population.

The main goal of this paper is to show different way to exploit fundamental EMR properties to extract biomedical parameters that can be used for medical assessment. A major effort was given that the proposed medical technologies will be accessible to the majority of the world, not expensive, portable and can be used almost anywhere. This research focus mainly on three basic properties of the EMR: 1) EM wave propagation delay; 2) signal attenuation in space and 3) signal dispersion in medium. These properties can be measured by three parameters that can be obtained by existing and future commercial systems.

For each of the three EMR properties we present in this research a sensing system and a criterion to derive out of the raw data the medical parameters needed for medical assessment and treatment. We demonstrate the exploitation of the three EMR properties for medical diagnosis by three medical applications: 1)Exploitation of EM wave propagation delay to quantify neurological tremor; 2) Exploitation of EM wave attenuation to obtain human motion kinematics; 3) Exploitation of dispersion of EMR in a tissue to monitor an internal bleeding. We suggest implementation schemes, perform a experiments for feasibility tests for each of the system and suggest direction for future research.

The paper is organized as follows. The second paragraph describes the system modeling for the three technologies to obtain the parameters needed for medical diagnosis and treatment. For each technology we describe the system, and give a criterion to derive the parameters data which are used for the medical diagnosis. In the paragraph section we describe the experimental set up used for feasibility tests and to evaluate the technology performance similar to the one used in [7],[8] and in [9]. The fourth paragraph gives preliminary performance results. In the fifth section we conclude the research and suggest directions for future research for each technology.

## II. System Modeling

An EM can be radiated to a medium from a radio transmitter which is equipped with an RF circuit. The transmitter itself generates in its RF circuit a radio frequency alternating current, which is applied to the antenna. When excited by this alternating current, the antenna radiates the EM wave. The EMR can carry a baseband signal which can be modulated to carry a data [10]. The transmitted signal can be represented by its complex envelope [11] which is defined as:

$$x(t) = \mathrm{real}\{p(t)e^{-(2\pi f_c t+\emptyset)}\}, \qquad (1)$$

where $\mathrm{p(t)}$ is baseband signal, with amplitude A, and duration $\mathrm{T_p}$, $\mathrm{f_c}$ is the RF frequency and $\emptyset$ is an arbitrary phase of the electromagnetic wave.

The transmitted signal is diffracted and reflected from and dispersed through objects and scattereres in the medium [11], and is received by a radio receiver. The receiver is an electronic device equipped with an RF circuit that receives its input from an antenna, uses electronic filters to separate the radio signal from all other signals picked up by this antenna, amplifies it to a level suitable for further processing, and by digital processing can detect the data which was carried by the EM wave.

The complex impedance Z includes is a measure of electrical characteristics of a medium. It is defined as the ratio of electrical potential difference (voltage) and electrical current and is given by:

$$Z(f) = 1\backslash\left(\sigma(f) + i\omega\epsilon(f)\right), \qquad (2)$$

where f is the EM wave frequency, σ is the conductivity of the medium which is related to resistance to the EM electrical field and ε is the permittivity of the medium which is related to resistance to EMR energy storage. Studies have shown that different tissues have different electrical properties [12-14]. From analyzing the changes in complex impedance we can determine tissue properties which can be used for medical diagnosis.

The commonly electromagnetic propagation model between the transmitter and the receiver can be characterized by a complex channel model composed of sum of different multi-paths [11]. The transfer function that represents the channel model is:

$$h(t) = \textstyle\sum_k b_k(t)\delta(t-\tau_k), \qquad (3)$$

where $k$ is the path index, $\delta$ is Dirac delta function, $\tau_k$ is the k'th propagation delay and $b_k(t)$ is complex reflection term which is composed of phase shift $\theta_k$ and amplitude attenuation $\beta_k$, $b_k(t) = \beta_k(t)e^{-\theta_k(t)}$ . The number of Multi-Path Component (MPCs) in the medium is infinite. Still in practical models it is used to relate to discrete number of dominant MPCs which are combination of many paths and thus contain most of signal energy. The parameter $b_k(t)$ is related the complex impedance $Z$ of the k'th object in the medium. In dispersive materials, like biological tissues, the complex impedance is frequency dependent.

The received signal at instant time t, can be obtained by the real part of time convolution of $x(t)$ and $h(t)$:

$$r(t) = real\{\textstyle\sum_k \beta_k(t)p(t-\tau_k)e^{-(2\pi f_c(t-\tau_k)+\emptyset+\theta_k(t))}\} + n(t), \qquad (4)$$

Where $n(t)$ is an additive noise component. The noise includes thermal and amplifier noise which can be modelled by white Gaussian processes, distortion from non linearity of amplifiers and interference from other radio signals from narrow band systems. In many wideband systems, the transmitted pulse $p(t)$ suffers from distortion which affects the performance.

Time of Arrival (ToA) is defined as the time the transmitted signal propagated in space till the reception in the receiver. Each MPC has a different ToA which is determined by the propagation delay $\tau_k$:

$$ToA_k = \left(t_{R,k} - t_T\right) = \tau_k, \qquad (5)$$

where $t_T$ is the transmission time and $t_{R,k}$ is the reception time for the $k$'th MPC. Higher ToA of MPCs related to the same transmission, indicates that the signal has propagated a longer way in the medium till it has been received.

The power profile of the received signal is important feature of the signal and is commonly used for analysis. The power profile at instant time t is defined as the received signal power:

$$P_r(t) = r^2(t). \qquad (6)$$

For phase shifts $\theta_k$ statistically independent and uniformly distributed over [0,2π) the power profile of the received signal is:

$$P_r(t) = \textstyle\sum_k \beta_k^2(t)p^2(t-\tau_k) + n'(t), \qquad (7)$$

where $P_r(t)$ is the power profile spectrum (as displayed on the oscilloscope) and $n'(t)$ is the additive noise which is related to the noise term in (4).

The power spectrum, as measured by RSSI measurements, changes in time as scatterers and sometimes the transmitter are dynamically moving [15]. It is usually obtained by averaging the instantaneous received power in (7):

$$RSSI = \textstyle\int_T P_r(t), \qquad (8)$$

where $T$ is a period determined by the communication standard and moves between milliseconds to seconds. The ratio between the RSSI and the known transmitted power is an indicator to the absolute value of total signal attenuation.

The main goal of this paper is to exploit these parameters for medical diagnosis. The ToA and RSSI are widely used in communication and are periodically computed in many communication standards. The complex impedance can be measured either by a set of radio transmitters and receivers or by electrodes. We suggest using continuous measurements of ToA to quantify neurological tremor, of RSSI to obtain human motion kinematics and of complex impedance of a tissue to monitor an internal bleeding.

## III. Deriving Medical Parameters From Electromagnetic Properties

Further details are provided in the remainder of this paper for specific situations.

### *A. Tremor assessment based on electromagnetic wave propagation delay*

Tremor characteristics can be obtained from the displacements in 3-D of the TBP over time. For 1-D (one sensor node), the Minimum Mean Square Error (MMSE) criterion for a transformation that extracts the l'th TBP's displacement from the received signal in (3) is:

$$\hat{f} = \mathrm{argmin}_f \mathrm{E}\left\{\left(f(\mathbf{r_m}) - \mathbf{b_{l,t}}(m)\right)^2\right\}, \qquad (9)$$

where $\mathbf{b_{l,t}}(m)$ is the displacement at time index m of the l'th TBP in the x direction, $f(\cdot)$ is a transformation of the sampled received signal to displacement, $\mathbf{r_m}$ is an $N_h$ length vector of received signal as defined in (3) and $E[\cdot]$ denotes expectation over all stochastic noise sources in the observation period.

We choose an observation period small enough so that the patient can be considered as stationary and the TBP's displacements are around a center location. As a result, the MPCs related to the TBP are relatively constant during the observation period and differ in time mainly by a delay shift. This delay shift is in a range that is determined by the tremor amplitude and the frequency of the change of the time shifts in the observation period is determined by the tremor frequency. To simplify the criterion in (9) we replace $f(\cdot)$ by a linear transformation on the sampled received signal. A Linear MMSE criterion that utilizes the statistical information from all pulse repetitions in the observation period and the known clinical tremor amplitudes and frequencies range is:

$$\{\widehat{w}, \hat{\tau}\} = \mathrm{argmin}_{w,\tau} \mathrm{E}\left\{\sum_{m=1}^{m=M}\left(w_{\tau_m}^T r_m - s_{l,m}\right)^2\right\}$$
$$\text{s.t. } w_{\tau_m}^T w_{\tau_m} = 1, -\frac{A_t}{2c} < \tau_m < \frac{A_t}{2c}, f_{t_L} < \mathrm{argmax}_f|\mathrm{FFT}(\tau)| < f_{t_H}, \qquad (10)$$

where $r_m$ is an $N_h$ length vector of the sampled received signal for pulse index m, 1≤m≤M, $s_l$ is a scalar representing the signal energy reflected from the l'th TBP surface for pulse index m, $\tau_m$ is the m'th time shift, $w_{\tau_m}$ is an $N_h$ length weight vector w shifted by $\tau_m$, $w_{\tau_m}(n) = w(n - \tau_m)$, $\tau$ is an M long vector that includes the time shifts, $\tau = \{\tau_1, \tau_2 .. \tau_M\}$, $f_{t_L}$ and $f_{t_H}$ are the lower and upper clinical tremor boundaries (usually 2-12 Hz), $A_t$ is the maximal clinical tremor displacement (in the range 1-4 cm) and $E[\cdot]$ is the expectation operator in the observation period $w_{\tau_m}(n) = w(n - \tau_m)$.

A feasible solution to the criterion is presented in the work of [7]. A set of tremor frequencies and amplitudes can be obtained by a Fourier transform of the sensor nodes displacements $\hat{\tau}$. For a single dominant tremor frequency the estimated tremor frequency and amplitude are:

$$\hat{A}_{t,i} = max|FFT(c\hat{\tau}_i)|, \hat{f}_{t,i} = argmax_f|FFT(\hat{\tau}_i)|, \qquad (11)$$

where i is the sensor node index, i=1...Q and $\hat{\tau}_i$ is the time shift vector as estimated by the i'th sensor node.

### *B. Tracking Motion Based on Electromagnetic Wave Attenuation*

To track the mobile node, we need to continuously estimate using the set of N power measurements, the location of the mobile node. The MMSE optimal transformation of the measurement matrix Pr can be obtained by solving: the following criterion:

$$\hat{f} = argmin_f E(L - f(P_r))^2 \qquad \text{s.t. } \left|L^{t+1} - L^t\right| < \delta, \qquad (12)$$

where $L$ consists of $M$ consecutive coordinates of the mobile node; $M$ refers to the size of a frame; $P_r$ is the $N \times M$ power measurement matrix that contains the N anchor nodes power measurements over $M$ measurements; $f$ is a transformation of the power measurements to location; $E[\cdot]$ is the expected value over all stochastic sources; and $\delta$ is a bound on the difference between consecutive location estimations which are a function of transmission rate and mobile node velocity. With high RSSI transmission rate consecutive RSSI measurements imply proximate locations.

A feasible solution to the criterion is presented in [8]. For medical applications, multiple sensor nodes need to be attached to the patient's body. The sensor nodes can include additional sensors like inertial sensor nodes. For optimal communication between the nodes, there is needed to be LOS conditions. Still, with proper calibration performed on the patient body, a communication between the sensor nodes can be obtained using the creeping EM wave energy. The nodes that are relatively static, like the one attached to the torso, can be referred to as anchor nodes. The RSSI based tracking algorithm can give information about the relative displacement of the body parts. Imprecise calibration can affect the distance approximation accuracy. Still, the pattern of change of the relative displacement of the different body parts can be used for medical diagnostics. For advanced medical analysis these sensor nodes information can be used to additional integration with other sensor nodes.

### *C. Extracting Tissue Blood Concentration Based on Electromagnetic Wave Dispersion Measurement*

The bulk changes in the composition of the tissue (e.g. hypoperfusion or hyperperfusion of blood) relative to a baseline composition reference (usually taken at the start time of measurements) produce changes in the transfer function H. It was found in [16] that the phase shift is more sensitive over most of the frequencies to composition changes in the brain and consequently statistically more informative than the gain shift. This phase shift represents the difference in the Time of Arrival (ToA) of the electromagnetic wave induced by the inductive coil due to changes in the composition of the tissue due to dispersion. Therefore, in this study we will use, instead of the complex transfer function, only the phase shifts.

The phase shift difference $P_I(t; f_i)$ is sampled at sampling frequency $T_s$ for a set of $N_F$ inductive frequencies and stored in descending order in a $N_F$ length vector $P_t$. The sampling frequency must be fast enough to capture inductive phase shift changes caused by internal injuries.

A Minimum Mean Square Error (MMSE) criterion to find changes in fluid composition can be reduced to finding a function of the phase shift difference that minimize the prediction square root error over a set of different induction frequencies:

$$\hat{f} = argmin_f E(f(\Delta\boldsymbol{P}) - \Delta C)^2, \tag{13}$$

where $\Delta C$ is a scalar, representing the bulk change in the tissue composition from a baseline reference value $C_0$. In clinical situation like hyperperfusion or ischemia, $\Delta C$ is related mainly to change in tissue internal blood concentration, $\Delta\boldsymbol{P}$ is an $N_F$ length vector of normalized phase shifts which is the vector of phase shift $P_t$ subtracted by a basal phase reference $P_0, \Delta\boldsymbol{P} = P_t - P_0$. The basal phase reference $P_0$ is the phase measurement which is related to baseline reference value $C_0$ at start of measurements. $f(\cdot)$ is transformation of the sampled received signal to displacement, and $E[\cdot]$ denotes expectation over all stochastic noise sources in the observation period.

The phase shift change compared to basal reference at a certain induced frequency is equivalent to the average propagation delay caused by the change in the tissue composition due to dispersion. This change tends to be continuous and happen to be higher in certain frequencies according to the tissue composition. A feasible solution to the criterion was obtained in [9]. A medical diagnosis algorithm can be obtained by pattern matching of the bulk concentration changes $\Delta\hat{C}$ over time with known pathological conditions that can be stored in data base at the DPM. It is anticipated that this will be a continuously growing data base which will store information on a growing population of patients with various pathological conditions, e.g. stroke, bleeding, edema, hypoperfusion, hyperperfusion.

## VI. Experimental Setup

Experiments were performed mainly to show feasibility of the system and to give preliminary performance evaluation for each technology. The experimental setup for the tremor assessment based on ToA measurements is shown in Fig. 1. The experimental setup consisted of an UWB 1-D tremor acquisition system composed of one sensor node prototype, a reference video recording system and a tremulous arm model that mimics tremor. The experimental setup for tracking motion based on RSSI measurements is shown in Fig. 2. It includes two sensor nodes were used as anchor nodes and a third one that was used as a mobile node. The mobile node was attached to a toy car which modeled patient hand movement on 2-D, and transmitted data packets. The anchor nodes received the packets, calculated the RSSI measurements and sent them through the base station to the notebook for further processing. The experimental setup for bleeding assessment based on inductive measurements is shown in Fig. 3. It was used to simulate brain hypoperfusion (ischemia) or bleeding (hematoma) by changing ethanol concentration inside hand model.

## VI. Results and Discussion

### *A. Tremor assessment based on electromagnetic wave propagation delay*

Utilizing the data analysis methods in [7], the frequency estimation was shown to be excellent with mean error of less than 0.1 Hz. The UWB system provides a set of tremor amplitudes along the TBP, while the video system includes only single tremor amplitude related to the marker location on the TBP. The approximation of the tremor amplitude differed on average from the video amplitude approximation by less than 0.2 mm. A marker with a smaller reflecting surface is expected to improve the UWB amplitude estimation quality. Still, as the current diagnosis of clinical neurological diseases is based more on tremor frequency than on tremor amplitude [17], an UWB based system with its accurate tremor frequency estimation can be used for clinical diagnosis. An advantage of the UWB acquisition system over the optical based system and over inertial sensors is that it includes information of all tremulous body parts and gives additional information on patient kinematics, which in the future can be aggregated in the analysis to improve the quality of the medical diagnosis.


(a) (b) (c)

Fig. 1. The tremulous arm model and UWB and reference video systems. The UWB tremor acquisition system is shown in Figure **Error! Reference source not found.**.a. It was implemented by a UWB sensor node prototype that consists of a transmitter (pulse generator and Tx antenna), a receiver (Oscilloscope and Rx antenna) and a processing unit and storage units (notebook computer). The reference video recording system is shown in Figure 2.b and described in Appendix A. The tremulous arm on Figure 3.c was based on an electrical current which induced electromagnetic field and created force which moved the arm in a cycle with the frequency of the AC current frequency. The arm surface was moving back and forth from and to the UWB acquisition system in a way that the reflection surface is maximized and horizontal to the video camera to capture full tremor amplitude.

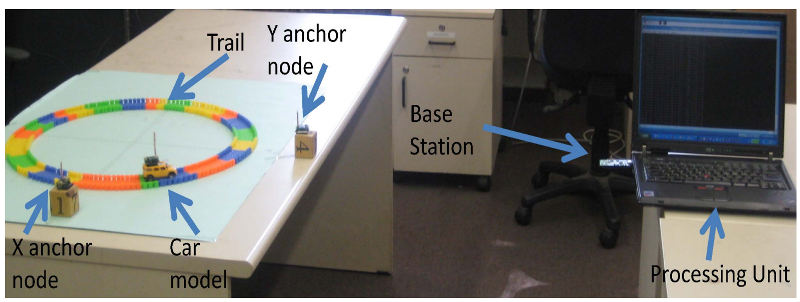


Fig. 2. RSSI tracking system model consists of a plastic trail, 2 anchor nodes, located in x and y axes, a car model that functions as a mobile node, a base station, and a notebook that functions as a processing unit

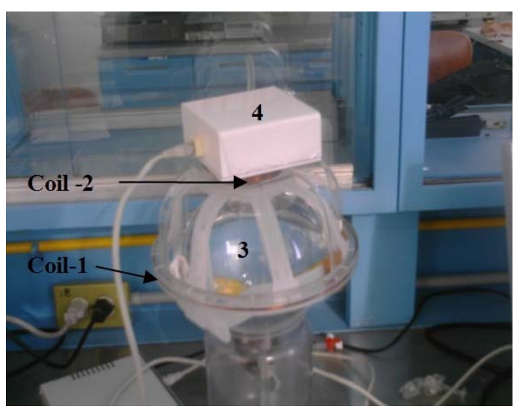


Fig. 3. Experimental setup for brain hypoperfusion vs bleeding detection: 1) Sensor coil radius 15cm. 2) Inductor coil radius 3cm. Both coils were made by ten turns of magnet wire AWG22. 3) Spherical human head model composite made of two glasses sphere; a 7.4 cm radius centered inside of a second 8.4 cm radius. Central sphere was filled with 1000 ml of ethanol and the remnant volume of the external sphere was partially filled with physiological saline NaCl 0.9%. 4) Inductive spectrometer prototype. A 60ml-syringe was used to modify the relative volume of saline respect to ethanol.

### *B. Tracking Motion Kinematics Based on Electromagnetic Wave Attenuation*

The developed tracking system provides instantaneous location estimates for any path. With the processing techniques presented in [8], it can achieve a high accuracy in a scale of around 5 cm with standard deviation of around 2 cm which is better than other existing RSSI-based tracking techniques and the static location theoretical bound.

The system was designed for 2-D, and the tracking accuracy will be affected by changes in sensor node instantaneous orientation changes in 3-D. This work should be adopted in the future to fit these changes and to the one in non-omnidirectional antennas. The RSSI-based tracking we proposed can further be improved by accumulating other sensor information, e.g. an auto-calibration method that provides online information from inertial sensors that can be used as a feedback to improve the offline calibration method we developed.

### *C. Extracting Tissue Blood Concentration Based on Electromagnetic Wave Dispersion Measurement*

Utilizing the data analysis presented in [9], the sensor had an average estimation error of only 4.8 ml and standard deviation of around 1 ml which was sufficient to obtain, according to nearest neighborhood classification of bleeding or hypoperfusion conditions. There is a tradeoff between the size of data base and the accuracy as the solution. Classification methods that match the phase shift directly to pathological conditions (bleeding or hypoperfusion in the brain) can be derived in future, e.g. intensity of the blood fluctuation can be indicator to a certain physical condition. Establishing a reliable data base will require substantial future clinical research.

## VII. Conclusion

A modern health system increasingly relies on modern sensor tools to aid in patient care. Technologies that allow for non-invasive physiological monitoring need to incorporate novel sensors that will meet a range of engineering design challenges.

The suggested UWB technology promises to have many advantages over the common video recording system based on optical technology. Clinical research with real patients with multiple TBPs, and with and without a metal marker should be conducted in the future. Tremor assessment with small UWB active wireless tags attached to the patient TBP of interest and similar to the active markers used in the video should be investigated. An automatic mechanism to find optimum ratios of UWB pulse repetitions and efficient UWB radiation power should be developed in the future. In the future, multiple UWB sensor nodes, well synchronized (e.g. by 802.15.4a standard) and placed in different locations in an indoor environment can offer continuous non contact 3-D tremor assessment from all body parts. Unlike the video, the UWB technology can work in any light conditions, penetrate through walls, and obtain tremor amplitude values of different body parts. UWB data transmission capabilities can be further used to transfer the raw data from the sensor node to an UWB hub with internet access to enable long-term tremor monitoring acquisition.

Tracking motion by sensing channel attenuation can be used in future for assessment of gait parameters like stride length. Spatial calibration which includes the antenna pattern can improve the performance. Auto-calibration during activation can exclude the need for calibration in advance and mitigate channel distortion. Aggregation of gyroscope and accelerometer measurements to the RSSI measurements is planned to be investigated in future.

Sensing tissue characteristics, in particular assessment of changes in blood content in a tissue after and during injury, is a promising technology. Conventional technologies that monitor changes in the brain such as MRI and CT are expensive and not portable and thus cannot be used for great majority of the world population and in emergency medicine. Utilizing dispersive measurements, can be used in future for pervasive monitoring and diagnosis of internal head injury condition, in particular changes in blood content in the brain, after and during head injury, tumors in the brain, and stroke. One application is in emergency medicine network where fast monitoring of the condition of the disease is crucial and in some cases a matter of life and death Another application is continuous stroke monitoring of patient in risk of having stroke in particular, patients who had first stroke and in risk of having second one.

Exploitation of electromagnetic radiation properties in medical diagnostic is a field that can improve diagnostic in more locations at lower price. Still lots of research efforts should be dedicated in order to reach this potential. We hope that in the future, new medical technologies will be based on this work and will exploit the commonly available electromagnetic radiation properties to help the world having better medical diagnosis and treatment.

## Acknowledgement

The authors wish to acknowledge the assistance and support of the COMCAS Steering Committee, to Mr. Moshe Uziel for building the UWB radar and in help in the experiments, to Dr. Cesar Gonzales for constructing the bleeding sensor hardware and helping in the bleeding detection experiments, and to Mrs. Bracha Hod for the help in all what was regarded to wireless sensor technology, in particular to the excellent course she has taught in Hebrew University in 2009.

## REFERENCES


[1] M. Kerker, "The scattering of light and other electromagnetic radiation," *Academic Press,* 1969.

[2] A. B. Reed, "The history of radiation use in medicine," *Journal of Vascular Surgery,* vol. 53, pp. 3S-5S.

[3] J. Ravenel, "The Essential Physics of Medical Imaging, 2nd ed," *Am. J. Roentgenol.,* vol. 180, pp. 596-, March 1, 2003 2003.

[4] M. Egred, G. D. Waiter, A. Al-Mohammad, S. I. Semple, T. W. Redpath, and S. Walton, "Blood oxygen level dependent (BOLD) MRI: A novel technique for the detection of myocardial ischemia," *Eur J Intern Med,* vol. 17, pp. 551-5, Dec 2006.

[5] B. Rubinsky and G. Onik, "Irreversible Electroporation: First Patient Experience Focal Therapy of Prostate Cancer," in *Irreversible Electroporation*, J. H. Nagel, Ed.: Springer Berlin Heidelberg, pp. 235-247.

[6] K. Lorincz, D. J. Malan, T. R. F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, M. Welsh, and S. Moulton, "Sensor networks for emergency response: challenges and opportunities," *Pervasive Computing, IEEE,* vol. 3, pp. 16-23, 2004.

[7] G. Blumrosen, M. Uziel, B. Rubinsky, and D. Porrat, "Tremor acquisition system based on UWB Wireless Sensor Network," in *Proceedings of the 2010 International Conference on Body Sensor Networks*, 2010, pp. 187-193.

[8] G. Blumrosen, B. Hod, T. Anker, D. Dolev, and B. Rubinsky, "Continuous Close-Proximity RSSI-Based Tracking in Wireless Sensor Networks," in *2010 International Conference on Body Sensor Networks*, 2010, pp. 234-239.

[9] G. Blumrosen, B. Rubinsky, and C. A. Gonzalez, "New Wearable Body Sensor for Continuous Diagnosis of Internal Tissue Bleeding," in *Wearable and Implantable Body Sensor Networks, 2009. BSN 2009. Sixth International Workshop on*, 2009, pp. 120-124.

[10] J. G. Proakis, "Digital communications," *McGRAW-HILL INTERNATIONAL EDITIONS, New York. 3rd ed,* pp. 780-782, 1995.

[11] A. Saleh and R. Valenzuela, "A Statistical Model for Indoor Multipath Propagation," *Selected Areas in Communications, IEEE Journal on,* vol. 5, pp. 128-137, 1987.

[12] C. Gabriel, S. Gabriel, and E. Corthout, "The dielectric properties of biological tissues: I. Literature survey," *Phys Med Biol,* vol. 41, pp. 2231-49, Nov 1996.

[13] S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Phys Med Biol,* vol. 41, pp. 2251-69, Nov 1996.

[14] S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues," *Phys Med Biol,* vol. 41, pp. 2271-93, Nov 1996.

[15] S. S. Ram, Y. Li, A. Lin, and H. Ling, "Doppler-based detection and tracking of humans in indoor environments," *Journal of the Franklin Institute,* vol. 345, pp. 679-699, 2008.

[16] O. Flores, B. Rubinsky, and C. A. Gonzalez, "Experimental sensitivity study of inductive phase shift spectroscopy as non-invasive method for hypoperfusion vs bleeding volumetric detection in brain," in *30th Annual International Conference of the IEEE,EMBS 2008.* , 2008, pp. 678-681.

[17] H. Ben-Pazi, H. Bergman, J. A. Goldberg, N. Giladi, D. Hansel, A. Reches, and E. S. Simon, *Synchrony of rest tremor in multiple limbs in parkinson's disease: evidence for multiple oscillators* vol. 108, 2001.