ERCIM "Alain Bensoussan" Fellowship Scientific Report

Fellow: Fabio MESITI

Visited Location : NTNU, Norwegian University of Science and Technology
Trondheim (Norway)

Duration of Visit: 9/3/2011 – 8/3/2012 (12 months)

Scientific coordinator: prof. Ilangko BALASINGHAM

I - Scientific activity

My research activities carried out during the ERCIM period spent in NTNU focused on the impact of electromagnetic (EM) waves on the neuronal system. A particular interest has been devoted to the analysis of possible regression of neurodegenerative diseases as Alzheimer. Recent studies published in 2010 by the Alzheimer's Research Center in Florida (USA), have tested the possibility of using EM radiations generated by mobile devices to induce a regression of Alzheimer's disease, observing improvements in cognitive ability and memory of mice. From this motivation, our research in this multi-disciplinary area was conducted at different levels.

After an overview of the literature in related fields, we identified and defined the main ideas and the fundamental steps for a possible contribution. In the first part, we analysed the propagation of EM waves through the human body, particularly through the skull, to determine the residual field inside it and, consequently, the induced current on the cerebral tissue. Indeed, there are evidences that a possible induced current at neuronal level can trigger, in turn, some hidden mechanisms or change some properties. To this end, we investigated the dielectric properties of living tissues (bone, gray matter, white matter) and their dependence on the frequency of the EM wave (complex conductivity). As second step, we reviewed some neuronal models in the literature, among others the Integrate-and Fire and the Hodgkin-Huxley, along with the propagation of signals through the structure of neurons (soma, axons and dendrites) under EM exposure, resorting to the Cable Equation. Afterwards, we supported theoretical investigations with computer simulations, carried out with dedicated software. On one hand, *CST Microwave* to simulate the impact of microwave EM fields on the human body (by means of a Human Body model). On the other hand, *NEURON-Yale* and *NeuroConstruct* to design and evaluate accurately neuronal systems, from single neuron up to complex networks. Combining these available tools, we investigated the behavior of individual neurons and small networks of neurons under several field and impulsive stimulation signals, to evaluate the response of neuronal system in relation to characteristics of the field and the current induced on the cellular membrane. Interesting effects have been observed in both amplitude and frequency of Action Potential firing of single neurons. However, unclear mechanisms at the membrane level have to be unveiled. Among others, the possible biological demodulation of modulated signals inside the brain can explain part of the effects observed in exposed neuronal membranes.

The final part of the period focused on the definition of a communication paradigm suitable for the analysis of neuronal systems from the classical communication perspective. Single neuron and populations of neurons behave similarly to communication devices, where the information is *encoded* and transmitted between nodes located in different areas of the brain. In this respect, a possible application in networks of nano-machines is envisioned, where artificial and biological neurons are interfaced one another. To this end, mathematical tools to analyse the statistical meaning of the neuronal response have been considered. Understanding the amount of information circulating in a population of neurons and its stochastic behaviour can provide interesting hints to quantify any possible deviation of the neuronal system from the natural response, when an external input, i.e., EM field and induced/injected currents, is applied to the system. Small-World networks are a possible candidate to fit the actual neuronal structure of the brain. Such networks are able to exploit the ability of neurons to group into functional clusters (where neurons represent the same biological function) connected by a large amount of communication channels (axons). A fundamental issue resides in finding a relation between the characteristics of such networks (clustering, path-length), the stimulation and the amount of information. Research in this fertile area is still ongoing and under development. Possible applications are the design of novel strategies for non-invasive treatment of neurodegenerative diseases and future generation nano-devices for machine-brain interfaces.

II- Publication(s) during your fellowship

II.a) Published papers

Journals

Fabio Mesiti, Pål Anders Floor, Anna Na Kim, Ilangko Balasingham
"On the modeling and analysis of the RF exposure on biological systems: A potential treatment strategy for neurodegenerative diseases"
Nano Communication Networks, Vol. 3, No. 2, June 2012, Pages 103–115

Abstract:
Mobile communication devices, body area networks, monitoring systems, and diagnostic and therapeutic tools are based on radio frequency emissions, raising the public concern on the possible negative effects on the human health. The future is also oriented towards the use of in-body (nano) sensors for medical applications. Biological alterations caused by non-thermal induced effects have currently been under investigation and experimental results on long-term effects are often discordant. To this end, recent experiments on transgenic Alzheimer mice revealed a progressive regression of the neurodegenerative disease after controlled exposure to mobile phone radiations. Therefore, the importance of understanding the RF-induced effects on the neuronal activity is twofold. Future wireless devices can be designed minimizing unhealthy effects whereas novel RF-based diagnostic and treatment devices for neurodegenerative diseases can be envisaged (in-body micro and nano-sensors and non-invasive techniques). In this paper, we propose an alternative approach in the investigation of such hidden biological mechanisms, where traditional concepts from radio communications are applied to neuroscience. The interaction of RF sources with the neuronal activity is the key point as well as the information exchanged in neuronal networks and the small-world topology of such network, heavily altered in Alzheimer patients.

Conference proceedings

Fabio. Mesiti, Ilangko Balasingham
"Novel treatment strategies for neurodegenerative diseases based on RF exposure"
ISABEL '11 International Symposium on Applied Sciences in Biomedical and Communication Technologies, Barcelona, Spain - October 26 - 29, 2011

Abstract:
In this paper we propose a novel engineering approach in the treatment of neurodegenerative diseases, based on controlled radio frequency (RF) exposure. In recent experiments on mobile phone exposure of transgenic Alzheimer's disease (AD) mice, improved cognitive functions were observed, inspiring a possible regression of the disease after RF treatment. To this end, we define a parallelism between neuronal and communication systems, defining a conceptual RF-neuronal interface to exploit the impact of the electromagnetic (EM) induced currents on the cellular membrane, where the biological messages are generated. Preliminary simulation results confirmed this hypothesis. In a therapeutical perspective, controlled RF exposure is expected to affect the brain activity at networking level where, in AD patients, broken links between functional areas of the brain give rise to cognitive and behavioural dysfunctions. A possible solution is to restore the missing paths enhancing the neuronal activity by means of controlled RF exposure.

II.b) Submitted manuscripts:

Fabio Mesiti, Ilangko Balasingham
"An overview on the impact of electromagnetic induced currents on the neuronal activity"
submitted to IEEE Wireless Communication Magazine, special issue on
"Wireless Communications at the Nanoscale"

Abstract:
The cerebral cortex consists of a huge amount of neuronal cells interconnected each other in synapses. During normal biological conditions, the neuronal information regulating fundamental living functions, is transmitted between neurons along myelinated axons, playing the role of communication channels. On the other hand, there is a vivid interest in the investigation of the neuronal activity when the cerebral cortex is exposed to electromagnetic fields (EM), due to the ubiquitous presence of wireless communication devices in the environment. Since the cerebral cortex can be considered a special type of dielectric material, an EM field propagates along the tissue, inducing local currents which can excite or inhibit the neuron in the generation of Action Potentials (AP), which encode the neuronal information. In this article, the response of essential parts of the cortex to the field is investigated in two different levels. As first step, the intensity of the field and the current induced in the cerebral tissue is evaluated. Then, the current is integrated in a mathematical model of the neuron to quantify the possible impact of the field in the generation of the AP. The proposed overview will provide the reader with the essential knowledge to understand the communication between neurons and its dependence on external electromagnetic stimulation. This can be of great importance in future scenarios, where artificial neurons or nano-machines can be potentially interfaced with biological neurons, e.g., for medical treatment.

III -Attended Seminars, Workshops, and Conferences

Name: ***N3CAT-2011 - 3rd NaNo Networking Summit, Catalunya***
Date: June, 22-23, 2011
Place: Barcelona (Spain)

Name: ***The Second International MELODY Project Workshop***
Date: October 17-18, 2011
Place: Oslo University Hospital, Rikshospitalet - Oslo (Norway)

Name: ***ISABEL 2011 - 4rd International Symposium on Applied Sciences in Biomedical and Communication Technologies***
Date: October 26-29, 2011
Place: Barcelona (Spain)

IV – Research Exchange Programme (12 month scheme)

1st visit:
ERCIM Institute: ***INRIA Nancy-Grand Est, Loria***
Research Team: *CORTEX, Computational Neuroscience* (Head: prof. Frédéric Alexandre)
Date: June 23-29, 2011
Place: Nancy (France)