PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Giovanni Cavallo

XXX Cycle

Training and Research Activities Report – Second Year

Tutor: Prof. Annalisa Liccardo

1. Information

PhD Candidate: Giovanni Cavallo

MSc title: Master's degree in Electronic Engineering (cum laude), University of Naples Federico II

Doctoral Cycle: XXX - ITEE – University of Naples Federico II

Fellowship type: European Social Fund (ESF)

Tutor: Prof. Annalisa Liccardo

Year: Second

I graduated, cum laude, in Electronic Engineering at University of Naples "Federico II". I am a PhD Student of the XXX cycle of ITEE.
My fellowship is financed by European Social Fund (ESF). My tutor is Prof. Annalisa Liccardo.

2. Study and Training activities

a. Courses

- Occasionally course, *"Field Computation and Magnetic Measurements for Accelerator Magnets",* Prof. Stephan Russenschuck and Prof. Pasquale Arpaia, November 23rd – 27th 2015, ***4 CFU****;*
- Ah hoc module, *"Sensori e Trasduttori di Misura"*, Prof. Aldo Baccigalupi, July 2016, ***9 CFU***.

b. Seminars

- *"Perception-based surround sound recording and reproduction"* organized by Prof. Giovanni Poggi, University of Naples Federico II, February 22nd 2016, ***0.3 CFU****;*
- *"Programmable network conjugations"* organized by Prof. Roberto Canonico, University of Naples Federico II, February 26th 2016, ***0.4 CFU****;*
- *"Microcontrollori di misura: La piattaforma ST Microelectronics Nucleo™"* organized by Prof. Pasquale Arpaia, University of Naples Federico II, March 21st 2016, ***0.4 CFU****;*
- *"ST Microelectronics Wireless applications of Soft Measurement Transducers for IoT"* organized by Prof. Pasquale Arpaia, University of Naples Federico II, April 14th 2016, ***0.4 CFU****;*
- *"Challenging real-time measurement systems for immersive life-size augmented environment"* organized by Prof. Pasquale Arpaia, University of Naples Federico II, April 29th 2016, ***0.4 CFU****;*
- *"Medical Robots Research at IPR – KIT Karlsruhe"* organized by Prof. Bruno Siciliano, University of Naples Federico II, May 9th 2016, ***0.4 CFU****;*
- *"The development of a Fast Pick-and-Place robot with an Innovative Cylindrical Drive"* organized by Prof. Bruno Siciliano, University of Naples Federico II, May 16th 2016, ***0.3 CFU****;*

- *"ItaloGorini 2016"*, Doctoral Summer School promoted by the Italian "Electrical and Electronic Measurement" (GMEE) and "Mechanical and Thermal Measurement" (MMT) associations, Cagliari, September 5th -9th 2016, ***3 CFU***.
- *"Half day EMC Design and troubleshooting Course"* organized by Prof. Nicola Pasquino, University of Naples Federico II, September 29th 2016, ***0.8 CFU***

3. Research activity

My second year has been based on a continuation of the two important topics presented in my first year of doctorate, so Compressive Sampling and Terahertz Technology.

Compressive Sampling (CS) is an exciting, rapidly growing field that has attracted considerable attention and has already become a key concept in various areas of applied mathematics and computer science. This methodology is used by engineers for a variety of applications in astronomy, biology, medicine, radar and spectroscopy, etc. CS is a sensing/sampling paradigm that goes against the common knowledge in data acquisition. In fact, the conventional approaches to sampling signals or images follow Shannon's theorem: the sampling rate must be at least twice the maximum frequency present in the signal (so-called Nyquist rate). This principle underlies nearly all signal acquisition protocols used in consumer audio and visual electronics, medical imaging devices, radio receivers and so on. The key idea of CS is to recover certain signal and images from far fewer samples or measurements than traditional methods use, using convex optimization algorithms.

Terahertz (THz) frequency region is often defined as the last unexplored area of the electromagnetic spectrum. THz spectrum refers to the frequency domain ranging approximately from 100GHz to 10THz (corresponding to wavelengths from 3mm to 30μm) and having as lower limit the microwaves, widely used in mobile and satellite communications, and as upper limit the far-infrared, where remote control devices and optical communication systems usually operate. Over the past few years, the full access and exploitation of this frequency window in order to close the so-called "THz gap" have been the objective of intense research efforts both in academia and industry. Progress in this area has played an important role in opening up the possibility of using THz electromagnetic radiation (T-waves) in science and in many real-world applications. T-waves are not perceptible by the human eye, are not ionizing and have the ability to cross many non conducting materials like paper, fabrics, wood, plastic and organic tissues.
Such technology can be applied in different areas, spanning from biology to chemical, pharmaceutical, and environmental sciences, and everyday applications within a broad range of industries including the medical, security, cultural heritage, manufacturing and aerospace sectors. The use of THz radiation allows contactless and non-destructive analysis of the materials under investigation both by study of their "fingerprint" via spectroscopic measurements and by high-resolution spatial imaging operations, exploiting the see-through capability of T-waves.

My research activity has, in part, focused on the use of Terahertz Technology to realise THz spectroscopic measurements and so fingerprinting operations on samples as nanotubes of carbon (NTC) realized by Department of Chemical, Materials Engineering and Industrial Production. Each sample was characterized by defining its electro-dynamic properties, such as refractive index, absorption coefficient and conductivity, and observing what succeed varying the concentration of nanotubes present in the base polymer matrix. Each nanotube is characterized by two essential parameters, diameter and length; this has allowed to realize the measures and therefore characterizations of different sets of samples, in which the distinctive element is a merit factor equal to the ratio between the two parameters. This study it was possible thanks to the Department of Physics of Federico II and in particular with Prof. Antonello Andreone, who has given me the possibility to use a THz system, working in the time domain (THz-TDS system).

At the same time, it was carried on the discussion to combine the two main research themes. In this case, the study involved the analysis of images acquired by THz radiation and reconstructed through CS-solver. On these images, that are sub-millimetric defects, it was realized a study of the reconstruction quality using the quality metric indexes, (i) The Mean Square Error (MSE) as Pixel Difference Measurement and (ii) the Structural SIMilarity index (SSIM) as Human Visual Based Measurement. These are the most employed parameters in Full Reference (FR) image metrics, i.e. metrics of quality in which the reference image is fully available and, therefore, a comprehensive comparison between the reconstructed image and the reference image can be performed. The MSE is evaluated by means of the formula:

$$MSE=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j)-Y(i,j)]^2$$

where M and N are the sizes of the image; $X(i,j)$ is the pixel at the $i-th$ row and $j-th$ column of the reconstructed image; $Y(i,j)$ is the pixel at the $i-th$ row and $j-th$ column of the reference image.
The advantage characterizing the use of MSE are: (i) it is computationally inexpensive; (ii) it is similar to other figure of merit adopted in signal theory and, therefore, it has a clear meaning; and (iii) satisfies properties of convexity, and differentiability, so it can be used in optimization applications. The main drawback is the independence on the image structure; as an example, two distorted images can have very different types of errors while having the same MSE.

The SSIM is based on the hypothesis that the human eye perceives structural information of an image. This index, thus, measures the degradation of structural information, rather than the degradation of the quality of each pixel. It is defined as:

$$SSIM(X,Y)=\frac{(2\mu_X\mu_Y+C_1)(2\sigma_{XY}+C_2)}{(\mu^2{}_X+\mu^2{}_Y+C_1)(\sigma^2{}_X+\sigma^2{}_Y+C_2)}$$

where X and Y are respectively the reconstructed and reference images; μ_X is the pixels average of the image X; μ_Y is the pixels average of the image Y; $\sigma^2{}_X$ is the pixels variance of the image X; $\sigma^2{}_Y$ is the pixels variance of the image Y; σ_{XY} is the covariance of pixels of X and Y. The two constants C_1 and C_2 are two very small constants, that limit the SSIM when the denominator is near to zero and are defined as $C_1=(K_1L)^2$ and $C_2=(K_2L)^2$, where L = 255 for 8-bit images, and $K_1K_2\ll 1$

The advantage related to the use of SSIM is the capability of estimating the degradation of the image structure as perceived by the human observer. The main drawback relies on the computational costs, which make the SSIM not suitable for real time application.
Even in this case, the research objective was not only to study the quality of the reconstruction, but rather also reduce the reconstruction time of an image when compared with those of the common technique of raster scan.

Finally, the research activity for the third year is projected to use Compressive Sampling in eddy current testing techniques. In fact, in the last years, the effort of the research is been focused on the development of eddy current measurement procedures capable of providing as much information as possible about the presence, the location and the geometrical characteristics of defects. To this aim, newer signals characterized by a wide spectral content able to penetrate in the different layers of the material under test are substituting the older sinusoidal excitation. In particular, there the most important objective is the manipulation of the data acquired, in fact for each acquisition there are 100000 data, so to reduce these numbers the idea is to apply CS, so that the subsequent operations are realized with a smaller number of data. It is also clean that it will be try to reduce acquisition times applying CS not only in the transfer data process but also in acquisition process.

4. Products

a. Publications

- "*Performance and metrological characteristics of THz systems for dual use applications*"
  Antonello Andreone, Leopoldo Angrisani, Francesco Bonavolontà, Giovanni Cavallo, Annalisa Liccardo, Gianpaolo Papari, Rosario Schiano Lo Moriello; 2nd International Forum on Research and Technologies for Society and Industry (RTSI 2016), Bologna 7-9 September;

- "*THz Measurement Systems*"
  Antonello Andreone, Leopoldo Angrisani, Giovanni Cavallo, Annalisa Liccardo, Gianpaolo Papari. Chapter of the book "New trends and developments in metrology" edited by Luigi Cocco, InTech. http://dx.doi.org/10.5772/59388

- "*Quality Analysis of reconstructed images with CS-THz process*"
  Leopoldo Angrisani, Antonello Andreone, Francesco Bonavolontà, Giovanni Cavallo, Annalisa Liccardo, Gianpaolo Papari, Rosario Schiano Lo Moriello

5. Conferences and Seminars

- "*Performance and metrological characteristics of THz systems for dual use applications*"
  Antonello Andreone, Leopoldo Angrisani, Francesco Bonavolontà, Giovanni Cavallo, Annalisa Liccardo, Gianpaolo Papari, Rosario Schiano Lo Moriello; 2nd International Forum on Research and Technologies for Society and Industry (RTSI 2016), Bologna 7-9 September;

6. Activity abroad

I have spent no time abroad during the first year PhD course.

7. Tutorship

Exams Assistant for the B. S. course "Fondamenti di Misure (FM)", taught by Prof. Mauro D'Arco,18 hours.

Exams Assistant for B. S course "Misure per l'automazione e la produzioneindustriale (MAPI)", taught by Prof. Annalisa Liccardo and Prof. Rosario Schiano Lo Moriello, 23 hours.

CS Summary

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Cycle XXX

	Credits year 1								Credits year 2								Credits year 3									
		1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Total	Check
Modules	20	0	3	7	0	9	0	19	15	4	0	0	0	9	0	13	0							0	32	30-70
Seminars	7	0	3,6	2,1	2,2	0	3	10,9	5	0	0,7	1,2	0,7	0	3,8	6,4	0							0	17	10-30
Research	33	10	3,4	0,9	7,8	1	7	30,1	40	6	9,3	8,8	9,3	4	6,2	44	60							0	74	80-140
	60	10	10	10	10	10	10	60	60	10	10	10	10	13	10	63	60	0	0	0	0	0	0	0	123	180