ALMA MATER STUDIORUM
UNIVERSITÀ DEGLI STUDI DI BOLOGNA

# Relazione scientifica sul soggiorno di Studi all'Estero grazie all'incentivo Marco Polo

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During my training period (from 15/01/2012 until 30/04/2012) I was a guest as Visiting PhD student at the School of Electrical and Computer Engineering of Georgia University of Technology (USA).

As a visiting PhD student I worked under the supervision of PI Yezzi, an expert in geometrical partial differential equations for image processing and computer vision, and PI Fedele, an expert in non linear wave mechanics, fluid dynamics, computational methods and inverse problems.
Dr. Yezzi and Dr. Fedele coordinate the research project "BEM - Fluorescence Optical Tomography via Active Surfaces for Breast Cancer Diagnostic Imaging" along my researched advisor Prof. Fiorella Sgallari.

The primary objective of this proposed research is to develop,validate and optimize an innovative class of shape-based computational algorithms for optical fluorescence tomography (with a focus on mammography applications).

The standard procedure in tomographic imaging is to generate an image of the volume by applying various transforms to the raw tomographic measurements and then analyzed it in an independent process for features (e.g. edges, textures, patterns, templates) that are then used to build geometric information about the objects within the reconstructed image.
The goal of my research is the direct reconstruction of 3D geometric shapes (tumors) within the interior of the volume (breast) being measured. The importance of this idea is that we will not be attempting to create a highly detailed image reconstruction of the intervening tissues from the raw optical measurements on the skin surface, but rather a precise reconstruction of the geometric surfaces(tumor boundaries) within the volume of interest.

The primary motivation for the proposed approch is that light signals emitted into the breast at the tissue surface are so highly attenuated when they enter the tissue, excite the fluorescence dye, and then travel back to the detectors on the skin surface, that a full volumetric reconstruction using the current state of the art in optical tomographic sensing is overly regularized and therefore not well suited for the follow-up volumetric processing of detecting small tumors.

I will combine mathematical and computational methodologies that have matured largely in isolation from each other within differing engineering disciplines.

Direct shape reconstruction allows us to concentrate all of our computational resources on modeling the shape surface itself (Active Surface methods and Parametric Level Set methods) and on modeling the physical equations related to the tomographic imaging method (Helmholtz equations in the case of fluorescence tomography) along the shape surface (Boundary Element Methods). Particular emphasis will be placed on the use of Boundary Element Method (BEM) and Geometric Active Surfaces.

In typical image processing applications the Active Contour are 2D geometric entities that evolves in response to image pixel intensity. Active contours ( or Active Surfaces in 3D) are means of model-driven segmentation. Their use enforces closed and smooth boundaries for each segmentation irrespective of the image content.

BEM is a numerical technique for the solutions of PDE's. Using BEM we can obtain the solution of PDE's along the boundary of volumetric regions without the need for computational nodes within the volume.

Combining BEM techniques and Active Surfaces is conceptually straight forward. The Active Surface plays the role of the unknown tumor boundary, and the BEM technique is used to discretize this boundary (along with the breast surface) to solve the forward problem (Helmholtz equations) based on the instantaneous location and shape of the Active Surface.

We will refer to the proposed system of evolving BEM equations along an evolving surface as a BEM Active Surface.

I point out that the hypothesis of the proposed research is that BEM-based fluorescence tomography exploited in the framework of geometric Active Surfaces will yield robust and computationally efficient reconstructions of arbitrarily complicated multiple inclusions and their associated optical properties with no a-priori information on the number of tumor targets (as Active Surfaces implemented using level set techniques may be allowed to change topology as they evolve).

BEM-based fluorescence optical tomography via Active Surfaces is a new concept still untested applications. It is of significant relevance for breast cancer research because it will yield new algorithmic paradigms for potential future clinical applications that use molecularly targeted fluorescent dyes for the diagnosis of tumors at their early onset, eventually affecting mortality.

The objectives of my research are the following:

1. Learn the theory behind the Boundary Elements Methods and their numerical implementation.

2. Learn of the theory of Active Surfaces, with particular focus on two-dimensional (2-D) contours

3. Formulate of the first BEM-based active surface numerical algorithm that is able to reconstruct 2-D tumoral lumps from synthetic data.

To obtain the above mentioned aspectives the following research task were complied out while at Georgia Tech.

**Task 1:** I attended the course taught by PI Yezzi, "Partial Differential Equations for Image Processing", where I learned the foundamental aspects of active surfaces and active contours theory.

**Task 2:** I worked on developing numerical algorithms for Boundary Elements Methods for 2D contours.

**Task 3:** I conducted late survey affining to fill on Inverse Problems and Treffold Method

My principal goal in my PhD thesis is to combine the BEM algorithm (that I developed in Task 2) with the active surfaces (that I learned in Task 1) in order to formulate a new algorithm that is able to reconstruct a 2D tumoral lumps from syntetic data.

During my period at ECE I also studied the problem of using Active Contours to detect the geometry of a shape of interest embedded within a contrasting medium lay by directly caracterizing its boundary. I applied the proposed technique to determine the size and the location of a circular object embedded in a homogeneous medium(the material properties of the medium and the inclusion are known).

During the spring Semester at GaTech I also attended the graduate course "Advanced Numerical Methods for PDE's" by Prof. Lee at the Department of Math. This class first reviews finite difference methods for parabolic and hyperbolic equations, analysis, finite volume (Godunov, MUSCL, ENO etc) for conservation laws, and finite elemet methods for elliptic problems. Then it covers FEM for parabolic problems and NAVIER Stokes equation, DG methods, MAC and Projection methods for Navier-Stokes, interface methods including front tracking, VOF and level set methods, and more advanced methods for conservation laws and Hamilton-Jacobi equations. The course consolidated my knowledge in the numerical analisys field.

In addition the graduate course of "Medical Image Processing" teached by PI Wang help me learn concepts, methods and issues in biomedical image processing. This class covered the Organ-level and Microscopic-level imaging modality and the fundamentals topics of digital image processing:

**1** Intensity Transformations and Spatial Filtering.

**2** Image enhancement and filtering in frequency domain ,image restoration.

**3** Color image processing.

**4** Image segmentation.

**5** Image representation and description.

**6** Morphological image processing.

**7** Image pattern recognition.

**8** Image Registration.