NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Autonomous systems for guided endoscopic navigation and theranostics

Ph.D. candidate

Claudia DELPRETE

Cycle

XXXIX

Tutor

Prof. Engr. Vitoantonio Bevilacqua, PhD

1. Description of the research program

The aim of the research project is to study, design, develop and validate innovative Autonomous Systems for guided endoscopic navigation and theranostics to improve the accuracy, safety, and efficacy of such procedures in clinical practice.

Endoscopic procedures have emerged as critical tools in diagnosing and treating various diseases, especially those related to the gastrointestinal tract, respiratory system, and urology. It involves inserting a flexible or rigid tube with a camera and other instruments into the body to visualize and manipulate internal organs or tissues. While these minimally invasive techniques offer numerous advantages, such as reduced recovery time and minimized surgical trauma, they still pose challenges in terms of navigation accuracy and the delivery of targeted therapeutics.

Thanks to the development of the theranostics field, fusion between therapy and medical imaging is possible, solving the problem of undesired variations in biodistribution and therapeutic efficacy of drugs. However, endoscopic procedures can be challenging, especially in complex anatomical locations, requiring high levels of expertise and experience. Furthermore, endoscopic procedures have limitations in terms of the ability to access certain areas of the body and to perform therapeutic interventions.

In light of these challenges, the project aims to develop an advanced navigation system that can autonomously guide the endoscope through intricate anatomical pathways, reducing the risk of injury and enhancing the precision of target localization. The navigation system will use advanced imaging and sensing technologies, such as magnetic resonance imaging, computed tomography, and ultrasound, to create 3D reconstructions of the internal anatomy of the patient, so that the endoscope can be guided to the target location.

Simultaneously, the goal is to design and develop an autonomous intelligent system for diagnosis and therapy delivering during endoscopic procedures. The proposed system will integrate data acquired from real-time imaging systems and sensors to enable accurate and efficient diagnosis and treatment. It will also incorporate robotic and miniaturized instruments to perform therapeutic interventions, such as tissue biopsy, ablation, and drug delivery.

This autonomous intelligent system has the potential to find applications in the field of Interventional Radiology (IR). IR is recognized for its minimally invasive approach, utilizing X-rays and various imaging techniques to navigate catheters and instruments to the precise location of medical issues, offering both diagnosis and treatment without the necessity of surgical procedures. This approach has experienced substantial growth, especially within the realm of oncology, owing to its advantages, which include shorter recovery times, enhanced patient comfort, and reduced risks of complications.

In the context of modern patient management, particularly in cases involving cancer patients, there is a call for a personalized approach that factors in the molecular and histogenetic attributes of tumors. Nevertheless, this tailored approach presents challenges for IR. For instance, when conducting liver biopsies on small tumors that are easily identifiable through MRI but challenging to locate using ultrasound or CT, typically employed for procedural guidance. Consequently, there is an increasing demand for methods capable of validating the precise placement of needles during procedures like biopsies or percutaneous interventions, such as thermal ablations. This necessity to access intricate lesions for diagnostic and therapeutic purposes has led to the development of navigation systems and multimodality imaging techniques, which enable the precise targeting of specific tissues of interest.

Lastly, the ultimate objective is the validation of the realized autonomous systems in preclinical and clinical studies, demonstrating their potential to improve endoscopic procedures and quality of care for patient.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Study of Autonomous Systems for Endoscopic Navigation	Exploration of intelligent frameworks suitable for real-time endoscopic navigation. Analysis and review of Machine Learning (ML) and Deep Learning (DL) algorithms tailored for navigation through body structures.	6 months	NO
Exploration of Instruments for 3D Anatomical Rendering	Investigation of tools and methodologies for 3D representation of internal body structures: Semantic Segmentation, Classification, and detection of Regions of Interest during endoscopic procedures, Features Extraction and Selection.	3 months	NO
Model Predictive Control in Theranostics and Interventional Radiology	Dive into advanced automation techniques tailored for guided endoscopy to enhance accuracy and responsiveness. Research the integration of predictive control methods with theranostic and interventional radiology tools.	3 months	NO

Second academic year (planned)

	Description	Period	Activity abroad
Identification of specific needs and challenges	Collaborate with medical experts and researchers to identify the specific needs and challenges associated with the development and implementation of autonomous systems for guided endoscopic navigation and theranostics.	2 months	NO
Study of DL methods and Explainable AI Techniques	A comprehensive examination of DL methods and the incorporation of Explainable AI Techniques to enhance the effectiveness and transparency of autonomous navigation systems, particularly in the field of theranostics and Interventional Radiology.	4 months	NO
Real-time Adjustment and Responsiveness	Investigate real-time adjustments during endoscopic procedures. Adaptations in response to anatomical variations during the procedure.	6 months	NO

Third academic year (planned)

	Description	Period	Activity abroad
Clinical Validation and Application	Clinically validate the solutions in real healthcare settings.	6 months	NO
Abroad project	TBD	6 months	YES

3. Training and research activities plan

First academic year planned

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Control for Optimization	November-December 2023	Yes	1
	Intelligent Control Systems	January-February 2024	Yes	2
	Multi-agent and multi-object estimation	January-February 2024	Yes	1
	Human autonomous systems interaction	March-April 2024	Yes	1
	Deep Neural Networks (ScuDo Courses)	TBD	Yes	2
	Game Theory for Controlling Autonomous Systems (ScuDo)	June-July 2024	Yes	2
B. Master's degree courses	Big Data Analytics (PoliBa)	First Semester	Yes	6
C. Soft skill courses				
D. Participation to seminars	Introduction to fault diagnosis and fault prognosis			1.5
	Introduction to dynamic control allocation			3
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**19.5**
G. Individual research activity	Research activity of intelligent frameworks suitable for real-time endoscopic navigation			35
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	TBD			5.5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			**40.5**
	TOTAL OF ECTS			**60**

Second academic year planned

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Data-driven fault diagnostic and fault prognosis	TBD	Yes	1
	TBD		Yes	2
B. Master's degree courses	Model Predictive Control (PoliBa)	TBD	Yes	6
C. Soft skill courses				
D. Participation to seminars	TBD			3
E. Participation to international	TBD			4

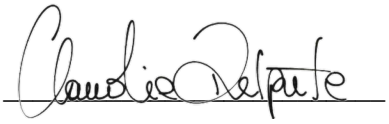
congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**16**
G. Individual research activity	Research activities focus on improving autonomous navigation systems in theranostics through DL and Explainable AI techniques. Real-time adjustments in endoscopic procedures using predictive control to enhance therapeutic precision in response to anatomical variations.			40
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	TBD			4
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			44
	TOTAL OF ECTS			**60**

Third academic year planned

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops	TBD			3
F. Presentation of research products at international congresses or workshops	TBD			3
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**6**
G. Individual research activity	Optimization and validation of the proposed model.			50
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	TBD			4
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			**54**
	TOTAL OF ECTS			**60**

4. List of the publications written by the candidate in the triennium

Dott.ssa Claudia DELPRETE



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