

INTERUNIVERSITY PH.D. PROGRAM BETWEEN  
POLITECNICO DI BARI AND UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO  
IN INDUSTRY 4.0

# **Advanced embedded systems for autonomous robots control**

## **PhD candidate**

Nikolai Svishchev

## **Cycle**

XXXVII

## **Tutors**

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## Description of the research program

The paper proposes a study to reduce the positioning error of mobile complexes in conditions of optical inhomogeneity and noisy environment, using visual odometry.

The first study directed in to the algorithm development for solving the problem of underwater dynamic noise filtering which is aimed at changing the method for searching and calculating the coordinates of a real three-dimensional (3D for short) point in a space, accordingly to obtained data from the camera and inertial measurement unit (3-axis gyroscope, 3-axis accelerometer and magnet field sensor) in the existing visual odometry system, this research will significantly increase the accuracy of the algorithm used in a tasks of underwater odometry, as well as allow to use a wide-angle lenses with spherical distortion. To do this, it is necessary to radically change the approach of the underwater camera auto-calibration method, use a different model of the camera lens that can solve the problem of finding key points in the image with spherical distortion. Moreover, to include in this system the compensation of the optical influence of the underwater environment, which in the case of standard calibration methods must be performed every time the camera is immersed under water.

Second stage is closed with the problem of visual servoing. As well as we get calibrated underwater camera model we should change trajectory calculating method in condition of underwater environment. Study propose analysis of the existing visual odometry methods by simulations in Matlab Simulink and ROS Gazebo programs for understanding the problems of underwater visual odometry system and using practical experiments on exciting underwater robot and underwater camera with online feedback system. In that case during research program we will get theoretical and practical results by implementation of empirical methods in every stage of research program.

The third stage of the study is researching the possibility of using generative adversarial network (GAN for short) for the problem of filtering dynamic structural noise on the frames of the video stream which used for visual odometry. This approach is relevant among the existing methods for recovering images from various types of interference, including prediction of the missing part of image information.

The final research in the dissertation work will focus on the overall improvement of the underwater visual odometry algorithm by optimization Simultaneous Localization And Mapping (SLAM) method and changing the graph based Simultaneous Localization And Mapping (SLAM) method, with an DPG-SLAM (Dynamic Pose Graph SLAM). This approach will make it possible to develop resistance to dynamic changes in the underwater environment, thereby increasing the accuracy of constructing a navigation map in the SLAM method, as well as the period of its relevance. Many previous SLAM approaches assume a static world such as in visual odometry method. In this work we propose incorporate the time dimension into the mapping process to enable a robot to maintain an accurate map while operating in dynamical environments. That approach will include DPG-SLAM, an algorithm designed to enable a robot to remain localized in an environment that changes substantially over time. Using incremental smoothing and mapping (iSAM for short) as the underlying SLAM state estimation engine, the Dynamic Pose Graph evolves over time as the robot explores new places and revisits previously mapped areas.

## Schedule of the research activities

### First academic year (planned)

	Description	Period	Activity abroad
<b>State of the art review and writing up a research problems</b>	Detail problems researching of the thesis	November 2021 – February 2022	NO
<b>Compilation of a literature review and bibliography on the research topics</b>	State-of-the art analysis and propose solutions	November 2021 – June 2022	NO
<b>Development of the underwater camera auto-</b>	Researching the underwater camera auto-calibration methods. Analysing	February 2022 - November 2022	NO

<b>calibration method</b>	the built camera model based on proposed method.		
<b>Research of existing methods of visual odometry on a digital camera in order to assess the positioning error</b>	Comparison of the proposed study with similar existing methods to identify benefits through experimentation and modeling	February 2022 – August 2022	NO
<b>Experiments and modeling analysis</b>	Analysing the results of experiments with visual odometry from step above, preparation of material for publication	November 2021 – July 2022	NO
<b>Modification of existing visual odometry algorithms</b>	Modification of existing visual odometry algorithms for the underwater environment by implementation of proposed solutions at the thesis, writing the code on Python and C/C++.	August 2022 – October 2022	NO
<b>Experiments and modeling analysis</b>	Conducting experiments with newly developed visual odometry methods on underwater robot and underwater camera with online feedback.	August 2022 – October 2022	NO
<b>Carrying out navigation experiments using the research results</b>	Analysing the results of experiments with visual odometry during first year study	October 2022	NO

### Second academic year (planned)

	<b>Description</b>	<b>Period</b>	<b>Activity abroad</b>
<b>Analysing the results of experiments from first year study</b>	Analysing the results of experiments with calculating the trajectory of the underwater robot's camera, preparation material for publication	November 2022 – February 2023	NO
<b>Writing the scientific and technical documentation with collaboration of DELFT</b>	Writing the scientific and technical documentation on the results of the operation of visual odometry on an underwater robot, which includes: developed software, video material, text results of experiments which will publish in article	February 2023 – March 2023	YES (DELFT University of Technology, Netherlands)
<b>Embedded system development with collaboration of DELFT</b>	Development of an adaptive controller for visual odometry based on a Generative Adversarial Network, to restore noisy images	April 2023 – May 2023	YES (DELFT University of Technology, Netherlands)
<b>Experiments and modelling analysis</b>	Conducting experiments with newly developed visual odometry methods on underwater robot	June 2023 – July 2023	YES (DELFT University of Technology, Netherlands)
<b>Changing the graph based SLAM with Dynamic Pose Graph SLAM</b>	Implementation of improved methods for constructing a trajectory based on Dynamic Pose Graph SLAM, to compensate the navigation error	August 2023 – September 2023	YES (DELFT University of Technology, Netherlands)
<b>Writing program of developed visual odometry system</b>	Writing low and higher level program of developed underwater visual odometry methods for underwater	October 2023	YES (DELFT University of Technology,

	robot		Netherlands)
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### Third academic year (planned)

	Description	Period	Activity abroad
<b>Experiments and modeling analysis</b>	Experimental testing the Dynamic Pose Graph SLAM algorithm on the developed underwater visual odometry system	November 2023 – January 2024	YES (DELFT University of Technology, Netherlands)
<b>Analysis of the thesis results</b>	Analysing the thesis results from first two years study	November 2023 – February 2024	NO
<b>Writing the thesis</b>	Writing the thesis chapters	November 2023 – October 2024	NO
<b>Preparation of an opinion, compilation of a bibliographic list of research</b>	Preparation to the dissertation defense	October 2024	NO

### Provisional training and research activities plan

Specify with the related CFU (ECTS) the training activities that you plan to carry out or have completed in the three years (e.g., courses to attend, conferences, seminars, etc.). Please refer to the *Educational regulations of the Doctoral School of Politecnico di Bari*: <http://www.poliba.it/sites/default/files/dottorati/regscudopoliba.pdf>

Specify with the related CFU (ECTS) the research activities that you plan to carry out in the three years (e.g., individual research activity, supervision of students, integrative seminars to be given by the PhD student, activity of manuscript preparation for conferences or journals, activity of patents preparation, etc.).

### First academic year (planned)

	Description	Period	Duration	CFU
<b>PhD courses</b>	Dynamics and Algorithms on Networks, International Graduate School on Control 2022	07.06.2022 – 10.06.2022	21 hours	3
	Time-series databases for sensor data analysis, SSD: ING-INF/05, Prof. Giuseppe Loseto.	18.01.2022-11.02.2022	20 hours	2
	Video Compression, SSD: ING-INF/03	-	-	2
	Complex Networks: Big Data modelling and learning, SSD: FIS/07. Prof. Nicola Amoroso.	06.06.2022 – 24.06.2022	20 hours	2
<b>Master's degree courses</b>	Model Predictive Control A.A. 2021-2022	15.11.2021 – 02.01.2022	60 hours	3
	Data Model Identification and Intelligent Control A.A. 2021-2022	15.11.2021 –	60 hours	3

		02.01.2022		
<b>Participation to seminars and international congresses or workshops</b>	International scientific and practical conference "Experience and prospects of application marine robotic systems (MRS)"	27.03.2022-28.03.2022	14 hours	2
	Competitions for the Russian Cup on underwater robotics and autonomous boats	23.03.2022-26.03.2022	4 days	2
<b>Presentation of research products at international congresses or workshops</b>	International scientific and practical conference "Experience and prospects of application marine robotic systems (MRS)"	27.03.2022-28.03.2022	-	2
	Online conference with teachers and students from Astrakhan State University	04.04.2022 – 05.04.2022	-	2
	<b>TOTAL OF CFU FOR TRAINING ACTIVITIES</b>			<b>23</b>
<b>Individual research activity</b>	Analysis of existing visual odometry algorithms in the underwater environment using a developed underwater camera and software in C and Python	02.11.2021 – 31.10.2022	-	20
	Development of software for transmission of video and telemetry via cable from an underwater camera	01.04.2022 – 09.09.2022	-	15
<b>Students' supervision</b>	Cooperative work with master degree students at the problem of modeling and control of Underwater Robotics	During 2022	-	2
	Cooperative work with master degree students at the problem of Feature and Objects Matching and Motion Estimation in computer vision tasks.	During 2022	-	2
<b>Preparation of manuscripts for conferences or journals</b>	I.M. Azhmukhamedov, P.I. Tamkov , N.D. Svishchev , A.V. Rybakov, Visual odometry in local underwater navigation problems, Journal of Physics: Conference Series 2091, Astrakhan, Russia, 2021	November 2021	-	5
	<b>TOTAL OF CFU FOR RESEARCH ACTIVITIES</b>			<b>44</b>
	<b>TOTAL OF CFU FOR YEAR I</b>			<b>67</b>

### Second academic year (planned)

	Description	Period	Duration	CFU
<b>PhD courses</b>	Physical Layer Security for wireless communication, SSD: ING-INF/02	-	-	2
	Oscillations and waves, SSD: FIS/01	-	-	2
	Equivariant Systems Theory and Observer Design for Autonomous Systems, International Graduate School on Control 2023	-	-	3
<b>Participation to seminars and international congresses or workshops</b>	International scientific and practical conference "Experience and prospects of application marine robotic systems (MRS)" or in the same international seminar	27.03.2023-28.03.2023	14 hours	2
	Competitions for the Russian Cup on underwater robotics and autonomous boats or in the same international practical seminar	23.03.2023-26.03.2023	4 days	2

<b>Presentation of research products at international congresses or workshops</b>	Presentation with thesis topic in to the 2023 IEEE 21th International Workshop on Cellular Nanoscale Networks and their Applications (CNNA) or in the same international workshop	During 2023	-	2
	Presentation of research products at the conference in ICCT 2023, Journal of Physics: Conference Series or on the same international conference	During 2023	-	2
<b>TOTAL OF CFU FOR TRAINING ACTIVITIES</b>				<b>15</b>
<b>Individual research activity</b>	Embedded system development for underwater robot with higher resolution digital camera, system propose electronic shematic with microcontroller and software for it.	02.11.2022 – 31.10.2023	-	15
	Writing the program for underwater visual odometry and approbation of it in underwater environment	01.04.2023 – 09.09.2023	-	20
<b>Integrative didactive activities</b>	Embedded System Design, laboratory work	During 2023	21 hours	3
	Embedded System Programming, laboratory work	During 2023	21 hours	3
<b>Preparation of manuscripts for conferences or journals</b>	Article at the conference in ICCT 2023, Journal of Physics: Conference Series or in any other scopus journals	During 2023	-	5
<b>TOTAL OF CFU FOR RESEARCH ACTIVITIES</b>				<b>46</b>
<b>TOTAL OF CFU FOR YEAR II</b>				<b>61</b>

### Third academic year (planned)

	<b>Description</b>	<b>Period</b>	<b>Duration</b>	<b>CFU</b>
<b>PhD courses</b>	Robust Controllability of Uncertain Systems, International Graduate School on Control 2024	-	21 hours	3
	Fundamentals of Information Theory, SSD: ING-INF/03	-	21 hours	2
	MATLAB Recipes For Measurements Data Processing, 2 CFU, SSD: ING-INF/07	-	21 hours	2
<b>Participation to seminars and international congresses or workshops</b>	International scientific and practical conference "Experience and prospects of application marine robotic systems (MRS)" or in the same international conference	27.03.2024-28.03.2024	14 hours	2
	Competitions for the Russian Cup on underwater robotics and autonomous boats or in the same practical seminar	23.03.2024-26.03.2024	4 days	2
<b>Presentation of research products at international congresses or workshops</b>	Presentation with thesis topic in to the 2023 IEEE 22th International Workshop on Cellular Nanoscale Networks and their Applications (CNNA) or in the same international workshop	During 2024	-	2
	Presentation of research products at the conference in ICCT 2024, Journal of Physics: Conference Series	During 2024	-	2

	<b>TOTAL OF CFU FOR TRAINING ACTIVITIES</b>			<b>15</b>
<b>Individual research activity</b>	Investigation of the work of visual odometry in the system of an underwater robot, conducting experiments in the water.	02.11.2023 – 31.10.2024	-	20
	Debugging the software of the underwater robot and visual odometry, analysis of the work and calculation of the trajectory error	01.04.2024 – 09.09.2024	-	15
<b>Integrative didactic activities</b>	Embedded System Design, laboratory work	During 2024	21 hours	3
	Embedded System Programming, laboratory work	During 2024	21 hours	3
<b>Preparation of manuscripts for conferences or journals</b>	Article in the Journal of Robotics and Mechatronics (JRM) 2024 or in any other scopus journals	During 2024	-	5
	<b>TOTAL OF CFU FOR RESEARCH ACTIVITIES</b>			<b>46</b>
	<b>TOTAL OF CFU FOR YEAR III</b>			<b>61</b>
	<b>TOTAL OF CFU FOR THE WHOLE PHD COURSE</b>			<b>189</b>