

FINAL REPORT

Student name: **Morris Antonello**

Cycle: **XXX**

Curriculum: **ICT**

Supervisor name: **Prof. Stefano Ghidoni**

Thesis title (final): **Semantic Models of Objects and Scenes for Industrial and Service Robotics**

PART 1 - COURSES, CONFERENCES AND MOBILITY

Courses for Ph.D. students

- *Real-Time Systems and Applications* by Prof. G. Manduchi with final mark 28/30;
- *Computational Inverse Problems* by Prof F. Marcuzzi with final mark 30/30;
- *Statistical Methods* by Prof L. Finesso with final mark A;
- *GPU Computing* by J. Pantaleoni (NVIDIA researcher) and Prof. F. Marcuzzi with final mark 28/30;
- *Cloud Computing* by Prof. T. Vardanega with final mark 26/30;
- *Bayesian Machine Learning* by Prof. G.M. Di Nunzio (only attended);
- *Introduction to Machine Learning* by Prof. F. Aioli at the Human Inspired Technology Research Center (only attended).

Short courses

- *Training course on UR10 Robot Software*, at UNIPD on Nov., 3rd, 2015.

Seminars

- *Do brains compute?* by Prof. R. Sepulchre, Dept. of Engineering, University of Cambridge, UK, at UNIPD on June, 18th, 2015;
- *Postdoctoral Research in Informatics at the Department of Information Engineering of the University of Padova*, at UNIPD on July, 18th, 2015;
- *Autonomous Mobile Robot Research at Toyohashi University of Technology* by Prof. J. Miura, Colloquia at UNIPD on Oct. 5th, 2015;
- *Semantic Image Interpretation* by I. Donadello, PhD Student at FBK Fondazione Bruno Kessler in Trento, at UNIPD on Nov. 26th, 2015;
- *Interactive Control & Learning for Robots - What we need and why!* by K. Listmann, Laboratory Group Manager at ABB in Ladenburg, at UNIPD on May 20th, 2016;

- *Pedagogical Considerations on Transparency for Student Engagement with Coding: Black-and-white Architectures, Half-baked Artefacts* by Prof. C. Kynigos, National and Kapodistrian University of Athens, at TUWien on Sept. 13th, 2016.
- *Machine Learning of Motor Skills for Robots* by Prof. J. Peters, Technische Universität Darmstadt Research Group Leader, at TUWien on Dec. 2nd, 2017;
- *Multi-camera detection, tracking and re-identification* by Prof. A. Cavallaro, Director of Centre for Intelligent Sensing, Queen Mary University of London, at UNIPD on May 3rd, 2017;
- *From Boom Cranes to Medical Robots: Research at the Toyohashi University of Technology* by Prof. K. Terashima, at UNIPD on July 17th, 2017.

Participation to International Conferences and Workshops

- BIOINFORMATICS 2015, 6th International Conference on Bioinformatics Models, Methods and Algorithms, 02-15 Jan. 2015 in Lisbon (Portugal) – Conference speaker;
- RoboBusiness Europe 2015, Exhibition and Conference, 28-30 April 2015 in Milan (Italy);
- CASE 2015, The eleventh annual IEEE International Conference on Automation Science and Engineering, 24-28 Aug. 2015 in Gothenburg (Sweden) – Conference speaker;
- IROS 2015, IEEE/RSJ International Conference on Intelligent Robots and Systems, 28 Sept.-02 Oct. 2015 in Hamburg (Germany);
- ECMR 2017, The European Conference on Mobile Robotics, 06-08 Sept. 2017 in Paris (France) – Conference speaker;
- IROS 2017, IEEE/RSJ International Conference on Intelligent Robots and Systems, 24-28 Sept. 2017 in Vancouver (Canada) – Conference speaker – PLANNED.

Participation to International Challenges

- MBZIRC 2017, 1st Mohamed Bin Zayed International Robotics Challenge, 11-21 March 2017 in Abu Dhabi (United Arabian Emirates) – **Third place in the Grand Challenge.**

Participation to European Project Meetings

- Integration week of the EU Project FibreMap at Benteler SGL Composite Technology GmbH in Ried (Austria) from Feb. 9th to Feb. 11th, 2015;
- Review meeting of the EU Project FibreMap at the European Commission in Bruxelles (Belgium) from March 23th to 24th, 2015;
- Integration week of the EU Project FibreMap in Padova (Italy) from May 26th to May 29th, 2015;
- 30th month and Business Planning Development (BPD) meeting of the EU Project FibreMap at ESI Group in Paris (France) from Feb 10th to Feb 12th, 2016;

- Integration week for the EU Project FibreMap in Padova (Italy) from Apr 26th to Apr 29th, 2016;
- 36th month meeting of the EU Project FibreMap in Padova (Italy) from July 12^h to July 13th, 2016;
- Presentation of “WP5: Accuracy evaluation results for fibre orientation measurement” and demo at the review meeting of the EU Project FibreMap in Padova (Italy) on Sep 22th, 2016.

Mobility periods

- From Sept 3th, 2016 to Sept 18th, 2016: first visit of the Vision4Robotics Group headed by Prof. Markus Vincze at TUWien, Vienna, on the topic “Multi-view 3D Entangled Forest for Semantic Segmentation and Mapping”;
- From Sept 25th, 2016 to Dec 23th, 2016: second visit of the Vision4Robotics Group headed by Prof. Markus Vincze at TUWien, Vienna, on the topic “Multi-view 3D Entangled Forest for Semantic Segmentation and Mapping”.

Teaching activities

- Laboratory support:
 1. Co-supervisor of the master student M. Pierobon. Thesis title in Italian: “Algoritmo di rilevazione di persone a terra da dati 3D per robot di telepresenza”. Thesis title in English “An Algorithm to Detect Fallen People from 3D Data for a Telepresence Robot”. Graduation date: Oct 3th, 2016;
 2. Co-supervisor of the master student G. Beraldo. Thesis title “Brain-Computer Interface for Assistive Robotics”. Graduation date: Sep. 12th, 2017.
 3. Co-supervisor of the master student T. Gagliardi. Thesis title: To Be Defined. Graduation date: To Be Defined;
- Tutor junior:
 1. 40 hours for the laboratory of the course “Fondamenti d'Informatica”, A.Y. 2015/16, by Prof. Laura Bazzanella, first semester, bachelor's degree in “Ingegneria dell'Informazione”;
 2. 60 hours for the laboratory of the bachelor course “Architettura degli Elaboratori”, A.Y. 2015/16, by Prof. Emanuele Menegatti, second semester, bachelor's degree in “Ingegneria dell'Informazione”;
 3. 80 hours for the laboratory of the bachelor course “Architettura degli Elaboratori”, A.Y. 2015/17, by Prof. Emanuele Menegatti, second semester, bachelor's degree in “Ingegneria dell'Informazione”.
- Other activities:

1. Lecture on “FibreMap project and algorithms” at the master course “Elaborazione dei Dati 3D”, A.Y. 2015/16, by Prof. Emanuele Menegatti, Dec 16th, 2016, master's degree in “Ingegneria Informatica”;
2. 12 hours as E-Tutor at the course “Architettura degli Elaboratori”, A.Y. 2015/16, by Prof. Emanuele Menegatti and Antonio Rodà for the project “Integrating technology in higher education to enhance work life balance”, second semester, bachelor's degree in “Ingegneria dell'Informazione”.

PART 2 - RESEARCH ACTIVITY

Building semantic models of objects and scenes is an important prerequisite for scene understanding and many robotics tasks. The semantics included in these models consists in the object and scene properties of interest, which can range from the color information in the most basic scenarios to the output of an object recognition algorithm in the most sophisticated ones. Building these models manually can be tedious and prone to errors. Furthermore, if a moving sensor is available, fusing the contributions of the multiple available view points in an effective way is non-trivial. During my Ph.D., I tackled these problems investigating on the best ways to build object and scene models in an automatic and accurate way, fully exploiting the vision sensors mounted on industrial and service robots. In the first 19 months, I was supervised by Prof. E. Menegatti while, in the remaining 17 months, by Prof. S. Ghidoni. During my Ph.D., I had the possibility to directly apply my research by contributing in the context of several national and international projects at the Intelligent Autonomous Systems Laboratory (IAS-Lab): the European projects FibreMap, ThermoBot and COROMA, the regional project Omitech and the international challenge MBZIRC. Finally, I had the possibility to start a collaboration with the Vision4Robotics Group headed by Prof. M. Vincze at TUWien, Vienna. In the following, I will provide a quick picture of my contributions, first, with regard to the construction of semantic object models and, second, with regard to the construction of semantic scene models.

The problem of automatically building accurate semantic object models is of great interest in the industrial field. The development of an inspection robot for the automatic and accurate quality control of carbon fibre parts like car components was of the aim of the European projects ThermoBot and FibreMap. One of tasks in ThermoBot assigned to the IAS-Lab consisted in the thermographic detection of defects in the upper layers of carbon fiber reinforced polymers. Many defects affecting their production process are due to the

wrong distribution of the thermosetting polymer in the upper layers. During the 1st year of my Ph.D, I developed a novel algorithm to detect these defects effectively by automatically analyzing the thermographic images obtained by Pulsed Phase Thermography (PPT) and comparing them with a defect-free reference. The thermographic image analysis is based on local contrast adjustment via UnSharp Masking (USM) and takes also advantage of the availability of the 3D object model and the high level of knowledge of the entire work-cell. The FibreMap task assigned to the IAS-Lab consisted in the automatic mapping of fibre orientation for draping of carbon fibre parts, in particular in the creation of an augmented model of the inspected part comprehending also accurate fibre orientation measurements. During the 1st year of my Ph.D, under the supervision of the postdoc M. Munaro, I developed novel algorithms for the image registration and mapping with translational or the 6-Degrees-of-Freedom robot motions, enabling the use of sensors that need multiple shots to perform a measurement in continuous motion. Furthermore, I developed novel algorithms for fusing the multiple views. During the 2nd year of my Ph.D, under the supervision of the postdoc M. Munaro, I have deeply tested these algorithms with complex carbon fibre parts, succeeding in reaching an industry grade accuracy (error in the angle orientation $< 5^\circ$) and making the robot scan a complete complex part in 2 minutes. Qualitatively, I have tested these methods also for multi-texturing glass fibre parts. In both projects, ThermoBot and FibreMap, the high level of knowledge of the entire work-cell is exploited. Nevertheless, this is possible only after tedious manual calibration procedures, among which the most time-consuming (about one hour) is the hand-eye calibration procedure. During the 3rd year of my Ph.D., in collaboration with the master student A. Gobbi, I have worked on its automation. The standard calibration process requires to view a calibration pattern, e.g. a checkerboard, from several different perspectives. This work extends the standard approach performing calibration pattern localization and hand-eye calibration in a fully automatic way, demonstrating that the automatic calibration reaches the same performance level of a standard procedure, while avoiding any human intervention. The source code is freely available.

The problem of automatically building accurate semantic scene models is receiving lots of attention, because of its importance in scene understanding, robotics and autonomous vehicles. Indeed, robots and autonomous cars need to understand the environment in which humans live in order to provide services like autonomous object grasping or autonomous driving in complex environments. Furthermore, this kind of methods can be

combined with text understanding techniques in order to aid machine-human interaction or support humans in every day tasks, e.g. by describing visual scenes to blind people. In this context, I tackled two well-known problems: semantic segmentation, i.e. the decomposition of a scene in its meaningful parts, and semantic mapping, i.e. the construction of 3D scene representations describing scene geometry and semantic content. During the 1st and 2nd year of my Ph.D, in collaboration with the Ph.D. student M. Carraro and the postdoc L. Tonin, we developed O-Robot, an open-source robotic platform for ambient assisted living, which proved to be a good platform for acquiring our datasets and testing our algorithms. During the 2nd and 3rd year of my Ph.D., in collaboration with the Ph.D. student M. Carraro and the master student M. Pierobon, I developed my first approach for the novel semantic segmentation and mapping of fallen people. It can detect them also in cluttered environments thanks to a two step classification (precision rate 0.80 and recall rate 0.86). Mapping and navigation are also exploited for making the detection even more robust. During the 3rd year of my Ph.D., in particular during and after my visit to the Vision4Robotics Group headed by Prof. M. Vincze at TUWien, Vienna, I worked on the development of multi-view approaches for semantic segmentation and mapping based on the fast 3D Entangled Forest Classifier. I proposed a batch approach and a novel multi-view frame fusion technique to exploit multiple views for improving the semantic labelling results. The batch approach works offline and is the direct application of an existing single-view method to scene reconstructions with multiple views. The multi-view frame fusion works in an incremental fashion accumulating the single-view results, hence allowing the online multi-view semantic segmentation of single frames and the offline reconstruction of semantic maps. Our experiments show the superiority of the approaches based on our fusion scheme, which leads to a more accurate semantic labelling.

In addition, during my Ph.D:

- I have written part of the proposal of the European Project COROMA in collaboration with the spin-off IT+Robotics. COROMA stays for “Cognitively enhanced robot for flexible manufacturing of metal and composite parts”. The project aims at applying the last findings in scene understanding also into the industrial field. It has been accepted by the European Commission and is just started;
- I have won the AI*IA outgoing mobility grant 2016. My stay in Vienna will be funded up to 2000€ if it will lead to a publication to the *Intelligenza Artificiale* journal;

- I have participated to the 1st Mohamed Bin Zayed International Robotics Challenge (MBZIRC). The challenge consisted in manually/automatically rotating a valve placed on a panel in the arena with a mobile robot and an on-board manipulator. In particular, I contributed to the sensing module and I implemented the teleoperation mode, thanks to which we scored 3rd in the Grand Challenge in collaboration with the Czech Technical University in Prague;
- I have supervised the master student G. Beraldo. She developed a novel shared control paradigm which facilitates the mental control of a mobile robot by means of Brain Computer Interface (BCI). She tested it on the Pepper robot;
- I have supervised the master student T. Gagliardi. He is developing an enhanced batch approach for building semantic scene models with the 3D Entangled Forest Classifier;
- I have won the IROS Travel Award 2017 funded by the IEEE Robotics and Automation Society. My mission at the IROS conference will be funded up to 694\$;
- I have reviewed articles submitted to the following international conferences and journals: IEEE ICRA, IEEE IROS, IEEE CASE, IEEE RAM and RAS.

PART 3 - PUBLICATIONS

List of publications on international journals

- J1. N. Castaman, E. Tosello, **M. Antonello**, N. Bagarello, S. Gandin, M. Carraro, M. Munaro, R. Bortoletto, S. Ghidoni, E. Menegatti and E. Pagello, "RUR53: an Unmanned Ground Vehicle for Navigation, Recognition and Manipulation", SUBMITTED to Journal of Field Robotics;
- J2. M. Munaro, **M. Antonello**, M. Antonello, and E. Menegatti, "Model-based Image Registration for Continuous Mapping with a Quality Inspection Robot", SUBMITTED to IEEE Transactions on Industrial Informatics;
- J3. M. Comin, and **M. Antonello**, "On the comparison of regulatory sequences with multiple resolution Entropic Profiles" BMC bioinformatics, vol.17, no. 1, pp. 130-141, March 2016. DOI: 10.1186/s12859-016-0980-2.

List of publications on conference proceedings

- C1. **M. Antonello**, D. Wolf, J. Prankl, S. Ghidoni, E. Menegatti and M. Vincze, "Multi-view 3D Entangled Forest for Semantic Segmentation and Mapping", SUBMITTED to IEEE International Conference on Robotics and Automation (ICRA) 2018;
- C2. G. Beraldo, **M. Antonello**, A. Cimolato, E. Menegatti and L. Tonin, "Brain-Computer Interface meets ROS: A robotic approach to mentally drive telepresence robots", SUBMITTED to IEEE International Conference on Robotics and Automation (ICRA) 2018;

- C3. **M. Antonello**, M. Carraro, M. Pierobon, and E. Menegatti, "Fast and Robust Detection of Fallen People from a Mobile Robot", ACCEPTED FOR PUBLICATION in Proceedings of the IEEE International Conference on Intelligent Robots and Systems (IROS) 2017;
- C4. **M. Antonello**, A. Gobbi, S. Michieletto, S. Ghidoni and E. Menegatti, "A Fully Automatic Hand-Eye Calibration System", in Proceedings of the European Conference on Mobile Robots (ECMR) 2017 (To appear);
- C5. **M. Antonello**, M. Munaro and E. Menegatti, "Efficient Measurement of Fibre Orientation for Mapping Carbon Fibre Parts with a Robotic System", in Proceedings of the 14th International Conference on Intelligent Autonomous Systems (IAS-14), pp. 757-769, Shanghai (China), July 2016. DOI: 10.1007/978-3-319-48036-7_55;
- C6. M. Munaro, **M. Antonello**, E. Menegatti and C. Eitzinger, "FIBREMAP - Automatic Mapping of Fibre Orientation for Draping of Carbon Fibre Parts.", Poster at the International CAE Conference, Pacengo del Garda (Italy), October 2015.;
- C7. M. Carraro, **M. Antonello**, L. Tonin and E. Menegatti, "An Open Source Robotic Platform for Ambient Assisted Living", 2nd Italian Workshop on Artificial Intelligence and Robotics, pp. 3-18, Ferrara (Italy), September 2015;
- C8. **M. Antonello**, S. Ghidoni and E. Menegatti, "Autonomous Robotic System for Thermographic Detection of Defects in Upper Layers of Carbon Fiber Reinforced Polymers", in Proceedings of the IEEE Automation Science and Engineering (CASE) 2015, pp. 634-639, Gothenburg (Sweden), August 2015. DOI: 10.1109/CoASE.2015.7294149;
- C9. M. Comin and **M. Antonello**, (2015), "Fast Alignment-free Comparison for Regulatory Sequences using Multiple Resolution Entropic Profiles", in Proceedings of the International Conference on Bioinformatics Models, Methods and Algorithms (BIOINFORMATICS-2015), pages 171-177, Lisbon (Portugal), January 2015. DOI: 10.5220/0005251001710177.

13/09/2017

Student signature



Supervisor signature

