PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Giuseppe Andrea Fontanelli

XXXI Cycle

Training and Research Activities Report – Second Year

Tutor: Bruno Siciliano

1. Information

Giuseppe Andrea Fontanelli, MS degree in Automation engineering, January 2014 with the thesis “Development of an 8 DOF Omnidirectional mobile robotic platform with integrated torque sensors". Now PhD student, at 2th year, XXXI-cycle in Information technology and electrical engineering at the University of Naples Federico II, with a university fellowship, under the supervision of the professor Bruno Siciliano.

2. Study and training activities

During my second year of PhD I attended the following seminars, courses, conference and summer school:

a) Courses:

- Introduction to artificial and computational intelligence, (3CFU)
  Lecturer: Fernando Burarque
- Modeling, simulation and control of collective behaviours, (3 CFU)
  Lecturer: Maurizio Porfiri

b) Seminars

- Cognitive computing and da Vinci robot, 17/02/2017 (0.4 CFU)
  Lecturer: Paolo Maresca

- IBM cognitive computing, 17/02/2017, (0.4 CFU)
  Lecturer: Pietro Leo

- Icelandic centre of neurophysiology: aims, projects and opportunities for biomedical engineers’ student, 20/04/2017 (0.4 CFU)
  Lecturer: Paolo Gargiulo, Mario Cesarelli

- Assessment, monitoring, prediction and decision making: different application from multimodal analysis, 20/04/2017 (0.4 CFU)
  Lecturer: P. Bifulco

c) Summer school

- Hamlyn winter school 2016, (3CFU), Imperial college of London, the final project presented was runner-up for the best project award,
  http://hamlyn.doc.ic.ac.uk/winterschool/

- 8th surgical summer school Montpellier SSSR 2017, (5 CFU), http://www.lirmm.fr/sssr-2017/

d) Conference

- ICINCO 2017 in Madrid, Spain (2 CFU). Paper presented: A. Petit, F. Ficuciello, G.A. Fontanelli, L. Villani, B. Siciliano, "Using Physical Modeling and RGB-D Registration for Contact Force Sensing on Deformable Objects",
- CRAS workshop 2017 (1.9 CFU). Three papers accepted, and two papers presented by the candidate. https://www.cras-eu.org/cras-20167

3. Research activity

My research field is surgical robotics. Minimally Invasive Robotic Surgery (MIRS) holds a fundamental role in modern surgical procedures. In details, a better sense of visual immersion and comfort for the surgeon, the less post-operative pain and recovery time with respect to the classical open or laparoscopic surgery, are just some of the benefits of using robots in minimally invasive procedures.

During my second year, I had the opportunity to follow two schools specialized in robotic surgery. More in details I follow the Hamlyn winter school focusing on Imaging in robotic surgery (the final project presented was runner-up for the best project award). The second was the 8th summer school on surgical robotics SSSR 2017. Moreover, I attended the CRAS workshop and the ICINCO conference 2017 during which I had the possibility to present three of my recent works.

During this year I also started a collaboration with the University La Sapienza of Rome working on the problem of suturing needle tracking. A preliminary result has been presented at CRAS workshop 2017 and a Journal extension is work in progress.

Moreover, I had the opportunity to work in the new MUSHA project, (principal investigator Fanny Ficuciello) on the development of a multifunctional, miniaturized and underactuated hand for MIRS.

My research activities of this year have focused on the mechatronics design of new devices for the da Vinci robot and on the development of advanced control strategies to help the surgeon during tedious and time demanding procedures.

More in details follows are reported the major activities of my second year:

a) Modelling and Identification of the da Vinci research kit robotic arms dynamics using the toolbox developed during my first year and an LMI based approach. The results of this work have been presented at the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2017) and during a poster section in the IROS 2017 Workshop on Shared Platforms for Medical Robotics Research. A journal extension of the work is in writing.

b) Development of the first prototype of the trocar force sensor. This sensor allows the estimation of two force components by measuring the displacement between the surgical instrument and the fixed trocar. This opens the way for a chap, disposable and plug and play force sensor for the da Vinci robot. This device is a big improvement with respect the state of the art because allows the force measure without any modification on robot's arm and with full adaptability to different robot platforms and surgical instruments. The preliminary results of this work have been presented at the CRAS workshop 2017 (the paper was the finalist for the best paper award). More detailed results of this work have been presented at the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2017). A journal extension of the work is in writing.

c) Design of a new suturing needle driver that allows the in hand rolling of a suturing needle. These devices promise to allow the surgeons during the suturing procedure. In fact, during suturing the surgeons must find the correct orientation of the suturing needle by continues and tedious bimanual manoeuvres. The presented instrument, on the contrary, permits a continuous needle reorientation. A first plastic prototype of the instrument has been realized to test the working principle. Furthermore, a simulator of the instrument has been developed to test the enhanced manipulability and dexterity due to the presence of the additional degree of freedom. A patent for this instrument is under submission. Moreover, the design and the simulation results have been submitted to RAL + ICRA 2018 (under revision).

d) Mechatronic design of a multifunctional, miniaturized and underactuated robotic hand. The MUSHA project focus on the development of advanced devices human-inspired with the goal to improve the surgeon manipulation capabilities. During the first year of the project, I have worked on the mechatronic design of a three-finger miniaturized hand for MIRS. A mechanism was developed to allows the hand reconfiguration. This serves to make the hand multifunctional allowing different control modalities. Moreover, a novel Bragg-based force sensor integrated directly in the hand distal phalanges has been designed and is under testing. The first prototype in scale was developed and actuated by servomotors to validate the design characteristics. Moreover, a simulated model was developed using the syn-grasp software to evaluate the best underactuation modality using the synergies paradigm.

e) Development of an algorithm to needle detection and tracking based on Kalman filtering to combine visual information from a monocular camera with the robot kinematics. Besides providing a fast and reliable needle pose estimation, the proposed method is robust with respect to scene variations as in case of partially needle occlusion or of needle re-grasping operation, as well as external disturbances perturbing the needle pose. In addition, the covariance matrices can be adapted taking into account the particular task that is being performed. The preliminary results of this work have been presented at the CRAS workshop 2017 and the paper was accepted for a journal extension to IJCARS.

f) Testing of a method for contact force estimation using a vision-based approach. I collaborated with the Post Docs Antoine Petit and Fanny Ficuciello on the development and testing of a new approach for contact force estimation on deformable objects using an RGB-D sensor and the object FEM. This approach was tested in a simplified environment and the results have been presented during the ICINCO conference 2017. Moreover, the method has been tested in the surgical scenario using the da Vinci robot.

g) Development of a state classification algorithm using force information in MIRS. The preliminary results have been presented during the CRAS workshop 2017.

h) Design of a methodology to flexibly adapt Virtual Fixtures while guaranteeing the passivity of the overall system. During robotic-aided surgical interventions the surgeon can benefit from the application of shared control techniques based on the use of virtual fixtures (VFs). To comply with the unstructured environment and with the surgeon intentions, both the VFs geometry and the constraint enforcement parameters need to be adapted on line. This online parameter adaptation could affect the stability of the system and hence a passivity-based approach method has been designed to preserve the system stability. The proposed method has been validated through experiments involving multiple dissection tasks on the da Vinci Research Kit. The results have been submitted to ICRA 2018 and are under revision.

i) On October 2017 I started my abroad period to the Hamlyn centre, Imperial college, under the supervision of the professor G.Z Yang. My topic is automatic suturing using a novel suturing instrument and a supervisory control paradigm.

4. Products

a) Journal paper submitted:

1. **G. A. Fontanelli**, M. Selvaggio, L. R. Buonocore, F. Ficuciello, L. Villani, and B. Siciliano, "A New Surgical Instrument Designed for In-Hand Rolling" Robotic and Automation Letters + ICRA 2017, **under revision**
2. V. Lippiello, **G.A. Fontanelli**, "Image-Based Visual-Impedance Control of a Dual-Arm Aerial Manipulator" Robotic and Automation Letters 2017, **under revision**
3. L. R. Buonocore, J. Cacace, A. Donaire, F. Ficuciello, **G.A. Fontanelli**, V. Lippiello, A. Petit, F. Ruggiero, A. C. Satici, D. Serra, B. Siciliano, L. Villani, "Nonprehensile manipulation of deformable objects: Achievements and perspectives from the RoDyMan project", IEEE Robotic and Automation Magazine, **accepted**

b) Conference paper:

1. F. Fazioli, F. Ficuciello, **G.A. Fontanelli**, B. Siciliano, L. Villani, "Implementation of a Soft-Rigid Collision Algorithm in an Open-Source Engine for Surgery Realistic Simulation, ROBIO 2016
2. R. Caccavale, M. Saveriano, **G.A. Fontanelli**, F. Ficuciello, D. Lee, A. Finzi, "Imitation Learning and Attentional Supervision of Dual-Arm Structured Tasks", EPIGEN 2017
3. A. Petit, F. Ficuciello, **G.A. Fontanelli**, L. Villani, B. Siciliano, "Using Physical Modeling and RGB-D Registration for Contact Force Sensing on Deformable Objects", ICINCO 2017
4. **G.A. Fontanelli**, F. Ficuciello, L. Villani, B. Siciliano, "Modelling and identification of the da Vinci Research Kit robotic arms", IROS 2017
5. **G.A. Fontanelli**, L.R. Buonocore, F. Ficuciello, L. Villani, B. Siciliano, "A Novel Force Sensing Integrated into the Trocar for Minimally Invasive Robotic Surgery", IROS 2017
6. **G.A. Fontanelli**, F. Ficuciello, L. Villani, B. Siciliano, "A Novel Force Sensor Integrated into the da Vinci Trocar for Minimally Invasive Robotic Surgery", CRAS workshop 2017, **finalist best paper award**
7. M. Selvaggio, **G.A.Fontanelli**, F.Ficuciello, L. Villani, B. Siciliano, "Task Classification of Robotic Surgical Reconstructive Procedures using Force Measurements", CRAS workshop 2017
8. M. Ferro, **G.A.Fontanelli**, F. Ficuciello, B. Siciliano, M. Vendittelli, "Vision-based suturing needle tracking with Extended Kalman Filter", CRAS workshop 2017
9. M. Selvaggio, **G.A. Fontanelli**, F. Ficuciello, L. Villani, B. Siciliano, "Passive Virtual Fixtures Adaptation in Minimally Invasive Robotic Surgery", ICRA 2018, **under revision**

c) Patent: An Italian patent for a new laparoscopic tool that allows in hand manipulation of a suturing needle is under submission.

	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**		6			8	7	**21**	**10**	3	3	2	0	0	5	**13**	**0**							**0**	**34**	**30-70**
Seminars	**5**	1,6	0		1	0	3,3	**5,9**	**5**	0	0.8	0.8	0	2	1.9	**5.5**	**0**							**0**	**11**	**10-30**
Research	**35**	8,4	4	10	9	2	2	**35**	**45**	7	6.2	7.2	10	8	3.1	**42**	**60**							**0**	**77**	**80-140**
	60	10	10	10	10	10	12	**62**	**60**	10	10	10	10	10	10	**60**	**0**	0	0	0	0	0	0	**0**	**122**	**180**