PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Sunny Katyara

XXXIV Cycle

Training and Research Activities Report – Second Year

University of Naples Federico II

Tutor: Bruno Siciliano

Co-Tutor: Fanny Ficuciello

Italian Institute of Technology

Tutor: Darwin Caldwell

Co-Tutor: Fei Chen

Università degli Studi di Napoli Federico II

1. INFORMATION

I am Sunny Katyara, M.Sc Control Engineering – Wroclaw University of Science and Technology Poland – July 2018. Currently, I am a joint PhD student between Università di Napoli Federico II, supervised by Prof. Bruno Siciliano and co-supervised by Dr. Fanny Ficuciello, and Istituto Italiano di Technologia (IIT), supervised by Prof. Darwin Caldwell and co-supervised Dr. Fei Chen.

2. STUDY AND TRAINING ACTIVITIES

Courses:

Lecture/Activity	Type	Credits	Certification	Notes
Mathematics of Finite Element Methods	Ad hoc module	4.0	×	PhD course by ITEE UNINA
Design and Implementation of AR Software Systems	Ad hoc module	4.0	×	PhD course by ITEE UNINA
Strategic Orientation for STEM Research and Writing	Ad hoc module	6.6	×	PhD course by ITEE UNINA
C++ Programming Techniques	Ad hoc module	6.0	×	PhD course by UNIGE
Grant Writing	Ad hoc module	5.0	×	PhD course by UNIGE
Regularization Methods for Machine Learning	Ad hoc module	2.0	×	Summer school by UNIGE

Seminars:

Lecture/Activity	Type	Credits	Certification	Notes
Computational biology	Seminar	0.5	×	UNINA seminar
Large Scale Training of Deep Neural Networks	Seminar	0.5	×	UNINA seminar

External Courses:

None

3. RESEARCH ACTIVITY

My major research direction is learning control for fine manipulation tasks. Manipulation tasks involve dexterous multi-fingered hands and are exceedingly complex due to the dynamics and under actuation of hands and challenges associated with non-prehensile manipulation.

In order to reduce the controller complexity of dexterous hands, the idea of postural synergies is widely adopted. The postural synergies however form a reduced subspace of control variables, are exploited to control the coordinated motion of anthromorphic robot hands, similar to humans. However, the motivation of using postural synergies shadows down with the increasing complexity of manipulation tasks and thus requires to use more number of synergistic components to perform certain task. Moreover, enabling robots to acquire human-level capabilities necessitates to exploit multi-sensory information for autonomous complex contact interactions during grasping and manipulation tasks.

To alleviate such problems, at first, the probabilistic form of postural synergies is obtained by evolving corresponding synergistic components over the duration of demonstrations and is then kernelized to preserve their grasping and manipulation properties globally, thus resulting into a new framework called kernelized synergies. Further, for adaptive interaction with environment, the model of soft synergies is used which introduces compliance into the kernelized synergies. Moreover, for autonomous interaction with object, the perception pipeline and tactile feedback are integrated into proposed framework for object detection and run-time force/torque adaptation respectively.

In addition to this, for learning control policies with force/torque profiles in an incremental way, the Imitation Learning (IL) and Reinforcement Learning (RL) together can be used as optimizer for cost function that measures the success of different grasping and manipulation tasks. For learning different control policies, initially position control is initialized through kinesthetic demonstrations and then augmenting these policies with force/torque profile to be controlled in combination with kernelized synergies through RL

To summarize, the key objectives of my PhD research work are;

i. To perform a detailed literature survey on different taxonomies of synergies, robust grasping, dexterous manipulation, robot learning and active perception.
ii. To generate a data set of grapevines for training a deep neural network for complex agricultural manipulation task i.e, winter pruning using autonomous robot system.
iii. To develop a new framework, called Kernelized synergies by amalgamating postural synergies together with force-closure quality index and kernelized movement primitives (KMP) for human-inspired robotic manipulation tasks.
    a. To perform different daily life tasks i.e, pouring coffee, closing jar, opening latches, squeezing lemon, mounting bulb, spraying cleanser and many others
    b. To evaluate the performance of proposed framework by comparing it with other state of art techniques using two different metrics i.e, primitive accuracy and normalized square error.
iv. To integrate visual perception into kernelized synergies framework using RANSAC model approximations and SVM classifier for semantic segmentation and object detection respectively. Further, to augment kernelized synergies with tactile feedback for run-time force/torque adaptation during robot-object interaction.
v. To learn control policies with desired force/torque profile for manipulation tasks on compliant robot through reinforcement learning algorithm [Policy Improvement through Path Integral (PI^2)]. Finally, to demonstrate and test the learnt control policies for different fine manipulation tasks i.e, assembling 3D printed gears, organizing abacus, turning a tap and in-hand manipulation of cube.

In the first year, I spent my first quarter on making thorough study **(first objective)** about probabilistic motion planning, human-robot collaboration, synergistic control of anthropomorphic hands, robust grasping and dexterous manipulation and robot interactive learning, to get the complete insight of existing research gaps and highlight the issues to be solved and addressed henceforth. In the next two quarters, to acquire the required set of skills needed for highlighted research problems, different tools i.e, Quadratic Programming (QP) path planar for whole body motion control, ROS for real-time communication with robot controllers, OpenAI Gym for robot interactive learning, Mujoco and Pybullet simulators for Sim2Real skill transfer, Blender and Unity frameworks for designing different test scenarios, Syngrasp toolbox for synergistic grasp evaluation, imitation learning for trajectory planning, markov decision processes (RL) for policy learning etc were learnt and exercised. Finally, in the last quarter, to test the learnt skills, a complex manipulation task i.e, robot pruning under VINUM project at APRIL Lab IIT, was chosen as case study for learning manipulation with the aim of Sim2Real skill transfer. For training the deep model for possible spur detection and pruning point localization, 3D models of grapevines were constructed in blender engine **(second objective)**. The trained network successfully classified spurs not only in simulated environment but also in laboratory setup and later for performing required cuts on the designated locations; the QP was used for path planning of robot system. From such analysis, a paper is accepted at 13th Workshop on Human Friendly Robotics (HFR) 2020 and is given **Best Research Paper Award by Franka-Emika, Germany** and also being selected for publication into **Springer Proceedings on Advanced Robotics (2020)**.

In the second year, during first two quarters, a new framework called **kernelized synergies** was developed **(third objective)**. For learning robotic control from demonstrations, the synergistic subspace of anthropomorphic robot hand was calculated using principle component analysis (PCA) by tele-operating the robot hand for given objects in the training dataset. The resultant synergistic coefficients evolved over duration of demonstrations to obtain the corresponding synergistic trajectories, which were then approximated with Gaussians using GMM and a reference trajectory was generated by GMR for the robot hand to be followed for reproducing the taught tasks. Further, the idea of KMP was exploited to adapt to the shape and size of new objects which act as environment descriptors i.e, via/end points for the KMP. The inherent use of kernel trick in KMP preserved the probabilistic grasping and manipulation properties of computed synergistic subspace, which enables it to be reused for new tasks as well. From this investigation, a paper is submitted to SCI journal **IEEE Transactions on Cognitive and Development systems (2020).**

In the last two quarters, the kernelized synergies framework was initially upgraded **(fourth objective)** to include visual sensory information for object detection and pose estimation. A simplified perceptual pipeline, using RANSAC algorithm together with Euclidean clustering was used for detecting objects in the scene and then SVM classier, trained on different daily life objects, was used for object classification. With the object being classified, its pose was enumerated locally from its centroid and was given to kernelized synergies for autonomous object interaction. In the next step, the tactile information using sponge based pressure sensor was used for contact detection and run-time force adaptation during object integration. Both i.,e visual and tactile sensory information enable the kernelized synergies to perform either human like manipulation tasks or in collaboration with them. From this analysis, one paper has been already submitted to **IEEE International Conference on**

Robotics and Automation (ICRA)-2021 while the second paper is in write-up process and will be submitted **to IEEE Robotics and Automation Letters (2020)**.

In the third year, in the first quarter, more 3D models of grapevines will be constructed and analyzed on the basis of their key properties i.e, deformability, geometry, texture etc. The resultant models will be made online for the community as a dataset for training deep networks **(second Objective)**. In the next two quarters, the parameters from kernelized synergies will be used to initialize the RL loop for improving the learnt control policies under different states of the actions with error and trial on the basis of rewards function **(fifth Objective).** Once the policies are learnt efficiently, they will be tested on simulated and real robot for different manipulation tasks. In the final quarter, thesis write-up will be done to comply with the given deadlines.

All the research activities have been carried out between PRISMA LAB (UNINA) and APRIL LAB (IIT).

4. PRODUCTS

Publications (published/submitted):

i. **S. Katyara**, F. Ficuciello, D. Caldwell, F. Chen, and B. Siciliano "Reproducible Pruning System on Dynamic Natural Plants for Field Agricultural Robots" **Springer Proceedings in Advanced Robotics, (2020).** [Best Paper Award]

Abstract: Pruning is the art of cutting unwanted and unhealthy plant branches and is one of the difficult tasks in the field robotics. It becomes even more complex when the plant branches are moving. Moreover, the reproducibility of robot pruning skills is another challenge to deal with due to the heterogeneous nature of vines in the vineyard. This research proposes a multi-modal framework to deal with the dynamic vines with the aim of sim2real skill transfer. The 3D models of vines are constructed in blender engine and rendered in simulated environment as a need for training the network. The Natural Admittance Controller (NAC) is applied to deal with the dynamics of vines. It uses force feedback and compensates the friction effects while maintaining the passivity of system. The faster R-CNN trained on 3D vine models, is used to detect the spurs and then the statistical pattern recognition algorithm using K-means clustering is applied to find the effective pruning points. The proposed framework is tested in simulated and real environments. (Link: https://www.youtube.com/watch?v=kZ6yIm0REYM)

ii. **S. Katyara**, F. Ficuciello, D. Caldwell, B. Siciliano, and F. Chen "Leveraging Kernelized Synergies on Shared Subspace for Precision Grasp and Dexterous Manipulation" **IEEE Transactions on Cognitive and Development Systems, 2020** [In review process]

Abstract: Manipulation in contrast to grasping is a trajectorial task that needs to use dexterous hands. Improving the dexterity of robot hands, increases the controller complexity and thus requires to use the concept of postural synergies. Inspired from postural synergies, this research proposes a new framework called kernelized synergies that focuses on the re-usability of the same subspace for precision grasping and dexterous manipulation. In this work, the computed subspace of postural synergies is parameterized by kernelized movement primitives to preserve its grasping and manipulation characteristics and allows its reuse for new objects. The grasp stability of the proposed framework is assessed with a force closure quality index. For performance evaluation, the proposed framework is tested on two different simulated robot hand models using the Syngrasp toolbox and experimentally, four complex grasping and manipulation tasks are performed and reported. The results confirm the hand agnostic approach of the proposed framework and its generalization to distinct objects irrespective of their shape and size. (Link: https://www.youtube.com/watch?v=rjQ8BpvhY4U)

iii. **S. Katyara**, F. Ficuciello, F. Chen, B. Siciliano, and D. Caldwell "Vision Based Adaptation to Kernelized Synergies for Human Inspired Robotic Manipulation" **IEEE International Conference on Robotics and Automation (ICRA), 2021** [In review process]

Abstract: Humans in contrast to robots are excellent in performing fine manipulation tasks owing to their remarkable dexterity and sensorimotor organization. Enabling robots to acquire such capabilities, necessitates a framework that not only replicates the human behaviour but also integrates the multi-sensory information for autonomous object interaction. To address such limitations, this research proposes to augment the previously developed kernelized synergies framework with visual perception to automatically adapt to the unknown objects. The kernelized synergies, inspired from humans, retain the same reduced subspace for object grasping and manipulation. To detect object in the scene, a

simplified perception pipeline is used that leverages the RANSAC algorithm with Euclidean clustering and SVM for object segmentation and recognition respectively. Further, the comparative analysis of kernelized synergies with other state of art approaches is made to confirm their flexibility and effectiveness on the robotic manipulation tasks. The experiments conducted on the robot hand confirm the robustness of modified kernelized synergies framework against the uncertainties related to the perception of environment. (Link: https://www.youtube.com/watch?v=SL2SkRvTmSY)

Publications (in preparation):

i. **S. Katyara**, F. Ficuciello, F. Chen, B. Siciliano, and D. Caldwell “Augmenting Kernelized Synergies with Visuo-Tactile Sensing for Collaborative Human-Robot Manipulation” **IEEE Robotics and Automation Letters (IEEE RAL) [deadline: 15th December 2020]**

ii. **S. Katyara**, F. Ficuciello, F. Chen, B. Siciliano, and D. Caldwell “Winter Grapevine Plants for Deep Model Training: A Constructive Data-set“ **International Journal of Robotics Research (IJRR) [deadline: 5th February 2021]**

5. CONFERENCES AND SEMINARS

- Submitted paper and attended virtually “13th Workshop on Human Friendly Robotics (HFR)”, Innsbruck, Austria, October 22-23, 2020

6. ABROAD ACTIVITY

None

7. TUTORSHIP

None

8. SUMMARY OF CREDITS

Student: Sunny Katyara sunny.sunny@unina.it

Tutor: Bruno Siciliano bruno.siciliano@unina.it

Cycle XXXIV

	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	15			6	6.6			13	25			2	8	13	5	28								0	40	30-70
Seminars	5			0.8		0.8	0.8	2.4	2			0.5	0.5			1	7	1	1		2	2	1	7	10	10-30
Research	40	6	7	6	7	9	9	44	50	5	5	6	10	10	10	46	50	5	5	10	10	10	10	50	140	80-140
	60	6	7	13	14	9.8	9.8	59	77	5	5	8.5	19	23	15	75	57	6	6	10	12	12	11	57	191	180

Year	Lecture/Activity	Type	Credits	Certification	Notes
1	Robotics for Bio-Engineering	MS Module	6	x	
1	Machine Learning	Ad hoc module	4.2	x	
1	Methods for Explainable Machine Learning	Ad hoc module	2.4	x	
1	Active perception and robot Interactive learning	Seminar	0.4	x	
1	Robotics in medical applications	Seminar	0.4	x	
1	Complexity trade-offs for robot motion and manipulation skills	Seminar	0.4	x	
1	Development of non-contact measurement techniques for qualification of additive manifactured robotic components	Seminar	0.4	x	
1	Continual learning for robotics	Seminar	0.4	x	
1	Identification and model based control of robots	Seminar	0.4	x	
1	Robotic cognitive adaptive system for teaching and learning	Seminar	0.4	x	
2	Mathematics of Finite Element Method	Ad hoc module	4	x	
2	Design and Implementation of AR Software Systems	Ad hoc module	4	x	
2	C++ Programming Techniques	Ad hoc module	6	x	
2	Strategic Orientation for STEM Research and Writing	Ad hoc module	6.6	x	
2	Grant Writing	Ad hoc module	5	x	
2	Computational Biology	Seminar	0.5	x	
2	Large Scale Training of Deep Neural Networks	Seminar	0.5	x	
2	Regularization Methods for Machine Learning	Summer Schhol	2	x	