PhD inInformation Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Sunny Katyara

XXXIV Cycle

Training and Research Activities Report – First Year

University of Naples

Tutor: Bruno Siciliano

Co-Tutor: Fanny Ficuciello

Italian Institute of Technology

Tutor: Darwin Caldwell

Co-Tutor: Fei Chen

1. INFORMATION

I am Sunny Katyara, M.Sc Electrical 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 Darwin Caldwell and co-supervised Dr. Fei Chen.

2. STUDY AND TRAINING ACTIVITIES

Courses:

Lecture/Activity	Type	Credits	Certification	Notes
Robotics for Bioengineering	M.S module	6.0	×	Regular Master studies course
Machine Learning	Ad hoc module	4.2	×	PhD course by ITEE UNINA
Methods for explainable machine learning	Ad hoc module	2.4	×	PhD course by ITEE UNINA

Seminars:

Lecture/Activity	Type	Credits	Certification	Notes
Active perception and robot interactive learning	Seminar	0.4	×	ITEE UNINA seminar
Robotics in medical applications	Seminar	0.4	×	ITEE UNINA seminar
Complexity trade-offs for robot motion and manipulation skills	Seminar	0.4	×	ADVR IIT Seminar
Development of non-contact measurement techniques for qualification of additive manufactured trabecular	Seminar	0.4	×	ADVR IIT Seminar

structures of robotic components				
Continual learning for robotics	Seminar	0.4	×	iCUB IIT Seminar
Identification and model based control of robots	Seminar	0.4	×	ADVR IIT Seminar
Robotic cognitive adaptive system for teaching and learning	Seminar	0.4	×	iCUB IIT 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 of hands, challenges associated with non-prehensile manipulation and the under actuation of hands.

In order to operate safely in the human environments, the actuation and control of manipulator need to be complaint. However, the manipulation tasks imply complex contact interactions with external environments and require information about contact forces and torques. Hence, the motion planning under contact conditions is usually impractical due to computational complexity and lack of precise dynamic models of the environments. Therefore, the trajectory planning algorithms are ineffective and lead to alternative solutions to learn manipulation skills through trial and error.

For learning control policies with force/torque profiles in an incremental way, the Imitation Learning (IL) and Reinforcement Learning (RL) together can used as a optimizer for cost function that measures the task success. 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 trajectory planning through RL.

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

i. Systematic Literature Review (SLR) on robot learning techniques

ii. To use moment primitives either KMP, DMP, ProMP or TP-GMM together with synergies to learn human centric demonstrations for higher dimensional tasks and time-driven trajectories

iii. To learn control policies with desired force/torque profile for manipulation tasks on compliant robot through reinforcement learning [Demo – Augmented Policy Gradient (DAPG) method or Policy Improvement through Path Integral (PI^2)]

iv. To demonstrate and test the learnt control policies for different fine manipulation tasks on simulated and real mobile manipulator (Franka Panda arm mounted on MP-500 base equipped with dexterous hand) i.e, soft objects, manipulating abacus, pruning, turning valve etc

v. To integrate visual perception in movement primitives for dynamic manipulation tasks (To formulate a new technique called Visual Moment Primitives (VMP))

vi. To develop a C++ library for whole body motion control dealing with holonomic and non-holonomic constraints simultaneously.

The last year, I dedicated my initial six months on literature review(first objective) about learning control policies from imitation to reinforcement learning, to get the complete insight of existing research gaps. In order to acquire expertise on required set of skills, different tools i.e, OpenSOT for whole body motion control, ROS for communicating with robot controllers, OpenAI for learning control policies, Mujoco and Pybullet simulator for Sim2Real skill transfer, Blender and Unity frameworks for rendering different environments etc are learnt. The next step is to test the skills for a complex manipulation task.

One of the key issue with fine manipulation tasks is the modeling of contacts and learning of interaction controllers i.e, impedance and admittance controllers for different environmental conditions. Thus, under one of the work packages of current VINUM project at APRIL Lab IIT, the pruning scenario as a case study is chosen to do Sim2Real skill transfer on mobile manipulator. With the chosen manipulation case, the pruning of dynamic vines using interaction controller (Admittance controller) has been evaluated. For motion planning, OpenSoT is applied, which is a C++ library used for inverse dynamics, inverse kinematics, contact-force optimization and motion planning based on quadratic programming. The models of three different kinds of vines are created in Blender engine and rendered in simulated environment for further analysis. The spur detection and pruning points location algorithms are applied to find the cutting poses on respective vine branches. From such analysis, two papers are written and submitted to International Conference on Robotics and Automation (ICRA) 2020.

For learning robotic control from human demonstrations, different low level and high level techniques have been proposed so far. Low level techniques are based on mapping the dynamics and kinematics of humans to robots., while the high level methods define the human demonstrations in terms of basic building blocks called motor primitives (second objective). In order to learn the initial control policies and also to reduce the search space for RL algorithm, different movement primitives are used for motion control. In our research work, Dynamic Movement Primitives (DMP) and Kernalized Movement Primitives (KMP) have been used and preliminary results on robot arm have been verified. The next step is to test them for high dimensional inputs with human robot interaction (HRI).

The parameters from movement primitives will be then used to initialize the RL loop for improving learnt control policies under different states of the actions with error and trial on the basis of rewards function (third Objective). Once the policies are learnt efficiently, then will be tested on simulated and real robot for different tasks (forth objective). The fifth and sixth objectives deal with the development of motion learning and motion planning methods. From the SLR, it has been found that all the proposed Movement Primitives (MP) algorithms are based on kinesthetic learning rather than visual demonstrations which affects the autonomy of all developed MP algorithms in terms of run time adaptation. In order to enhance the robustness, automation and reliability of movement primitives, the new methods called Visual Movement Primitives will be developed having similar capabilities to humans learning. The humans have abilities to improve their actions on run time according to the new states of the environment on basis of their visual feedback (fifth Objective).

Motion planning is one of the key factors in robotics control and many planning libraries have been proposed so far commercially such as; Moveit, OpenRAVE, OpenSoT, MoveBase etc for whole body motion control of mobile manipulators, humanoids, quadrupeds, bipeds etc. All of these developed libraries can either control holonomic robots or non-holonomic robots, but not both of simultaneously. Therefore, in order to have single uniform framework dealing with all the constraints it has been wished to develop motion library for whole body motion control of different robots (sixth objective).

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

4. PRODUCTS

Publications (under review):

i. **S. Katyara**, L. Lugli, F. Ficuciello, D. Caldwell, F. Chen "Towards reproducible pruning system on dynamic natural plants for field agricultural robots" International Conference on Robotics and Automation (ICRA) 2020.

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 plant branches are moving. Moreover, reproducibility of robotic pruning skills is another challenge to deal with due to the heterogeneous nature of vines. This research proposes a methodology to deal with dynamic vines using Natural Admittance Controller (NAC) during pruning. The NAC uses force feedback and compensates the friction effects while maintaining the passivity of system. The 3D models of vine branches as a need for sim2real skill transfer are reconstructed in blender engine and rendered in simulated environment. An algorithm based on statistical pattern recognition using K-means clustering is applied to find the pruning points on the vines. The OpenSoT library is used for whole body motion control of mobile robot.

ii. L. Lugli, **S. Katyara**, D. Caldwell, F. Chen "Towards statistical pattern recognition graph morphometry applied in agricultural robotic vineyard pruning" International Conference on Robotics and Automation (ICRA) 2020.

Abstract: Computational systems employed in Precision Agriculture (AP) currently provide relative sampling, precision and level of data processing required by agricultural practices, which were not common to early conventional agriculture, raising production costs and research aimed at sensing remote, mapping and inspection of planting lines, assisting farmers' activities during all planting stages of a particular crop. Given this information and relating the level of investment and development of these technologies, this research aims to apply statistical-based image analysis referred to a graph morphometry agricultural scenario with robotic mobile manipulator assigned to vines' pruning. Such task is necessary so that the spur pruning process is carried out autonomously, verifying parameters and technical/real characteristics of pruning and also the vine itself. Within an initial potential pruning region detection, through a residual neural network R-CNN architecture, a merged statistical pattern recognition-based method with Naive-Bayes, KNN, and K-Means provided reliable results when identifying pruning points

by a graph-based morphometry in each branch. This research is part of a multidisciplinary project namely VINUM.

Publications (in preparation):

i. **S. Katyara**, F. Ficuciello, D. Caldwell, F. Chen, B. Siciliano "Kernalized treatment of synergies for in-hand manipulation tasks" Robotics and Automation Letters (IEEE RAL) 2020

Abstract (tentative): Manipulation of different objects with anthropomorphic hand-arm mounted on mobile base is one of the most complex tasks in robotics due to their coordinated control with increased degrees of freedom. In this research work, the synergy concept is exploited to represent the grasping and manipulation tasks as trajectories connecting suitable configuration based on human hand demonstrations. With RGB and depth information for 3D motion capture, the grasping and manipulation postures are recorded and mapped to the kinematics of robot hand and then PCA is applied to find the relative grasping and manipulation synergies. For teaching motion patterns to arm and to deal with unpredictable situations (i.e, obstacles and external perturbations), the Kernalized Movement Primitives is applied, which allows the arm to adapt to learned motor skills and fulfil the task constraints. For generalizing the computed synergies for unknown objects, the kernel treatment is extended from arm to hand with synergies as a reference to GMM/GMR. The 3D graph based vision SLAM is used to control the movement of mobile base.

ii. **S. Katyara**, F. Ficuciello, D. Caldwell, F. Chen, B. Siciliano "Run-time adaption of trajectories with DMPs using perceptual learning "Robotics, Science and Systems (RSS) 2020.

Abstract (tentative): Dynamic movement primitives (DMPs) are the motion building blocks suitable for real world robotic tasks which require interaction with dynamic environments. Improvement in the execution of different tasks mainly depends upon learning of relative movement primitive parameters. The DMP has shape and meta parameters which are dealing with spatial shape of movement and overall movement progression respectively. A continuous mapping of task parameters to DMP parameters with visual servoing can be used for fast adaption to changes in task requirements. This research work proposes a framework for run time mapping of task parameters with DMP parameters. For learning the mapping deep neural networks and kernel estimation are used. Principal Component Analysis (PCA) is applied to exploit and improve the learning outcome. The framework is demonstrated and the learning methods are compared for high dimensional 3rd Hand Task, which is based on robot arm assisting human hands in completing soldering task.

5. CONFERENCES AND SEMINARS

None

6. ABROAD ACTIVITY

None

7. TUTORSHIP

None

8. SUMMARY OF CREDITS

Student: Name Surname sunny.sunny@unina.it **Tutor: Name Surname** fanny.ficuciello@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								0								0	13	30-70
Seminars	5			0.8		0.8	0.8	2.4								0								0	2.4	10-30
Research	40	6	7	6	7	9	9	44								0								0	44	80-140
	60	6	7	13	14	9.8	9.8	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	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	