TITLE: "Learning Contact Forces for Humanoid Trajectory Generation"	
GUIDANCE	
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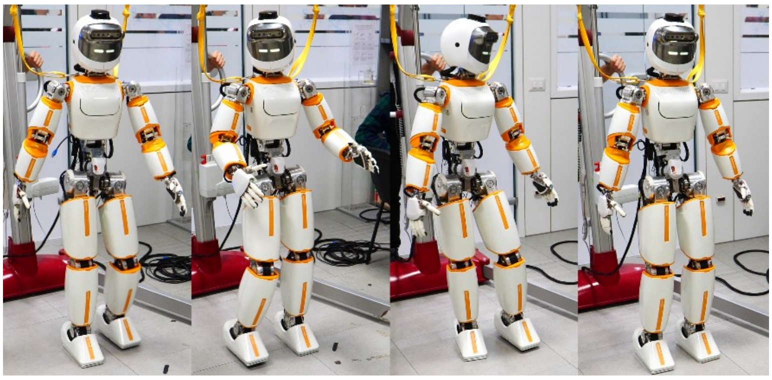
• **Thesis location(s)**	• **IIT, Genoa, Italy (primary)** • PoliTo, Turin, Italy
KEYWORDS	
• **Robot Learning** • **Physics-Informed Neural Networks** • **Learning Contact Forces** • **Robot Trajectory Planning**	
CONTEXT	



This thesis project is proposed by the Artificial and Mechanical Intelligence (AMI) Lab at Istituto Italiano di Tecnologia, - Center for Robotics and Intelligent Systems located in Genoa, in collaboration with the VANDAL Laboratory at Politecnico di Torino.

The project will focus on incorporating the learning of contact forces and contact status of the feet of the humanoid ergoCub robot. The ergoCub robot is a 150 cm tall, 55.7 Kg heavy robot intended to be used for purposes which improve the ergonomy of human workers' tasks. Some examples of its use cases include collaborative lifting and autonomous navigation.

Currently, the lab is using the ADHERENT framework [1] to generate learned walking trajectories for the robot, based on the MANN learning architecture [2]. This approach uses data collected by a human wearing a sensor suit to train the network. The learned parameters include various information about the state of the robot, but despite the robot being equipped with contact force sensors, the existing trajectory generation framework does not currently take advantage of this data.

Contact information can be extremely useful for making generated trajectories smoother, and also opens up the possibilities for walking on rough terrain or adapting to external disturbances [4]. Use of recorded force data is nontrivial as it requires the conversion of the forces associated with the human on which the data is taken to the expected forces on the robot for a similar motion.

The student may also find it helpful to investigate physics-informed learning methods [5] for improving the quality of the learned forces. Physics-informed learning is a branch of machine learning that focuses specifically on injecting physics information into the learning architecture, either by 1) shaping the dataset, 2) modifying the architecture, or 3) involving the ODEs/PDEs that govern the system in the loss function.

All these methods are designed to help the learning converge to outputs that mimic the training data and follow known physical laws.

REFERENCES

[1] P. M. Viceconte, R. Camoriano, G. Romualdi, D. Ferigo, S. Dafarra, S. Traversaro, G. Oriolo, L. Rosasco, and D. Pucci, "ADHERENT: Learning human-like trajectory generators for whole-body control of humanoid robots," IEEE Robotics and Automation Letters, vol. 7, no. 2, pp. 2779–2786, apr 2022.
[2] Zhang, He & Starke, Sebastian & Komura, Taku & Saito, Jun. (2018). Mode-adaptive neural networks for quadruped motion control. ACM Transactions on Graphics. 37. 1-11. 10.1145/3197517.3201366.
[3] D. Holden, "Encoding Events for Neural Networks," theorangeduck.com. https://theorangeduck.com/page/encoding-events-neural-networks.
[4] Tsounis, Vassilios & Alge, Mitja & Lee, Joonho & Farshidian, Farbod & Hutter, Marco. (2020). DeepGait: Planning and Control of Quadrupedal Gaits Using Deep Reinforcement Learning. IEEE Robotics and Automation Letters. PP. 1-1. 10.1109/LRA.2020.2979660.
[5] Cuomo, Salvatore & Schiano Di Cola, Vincenzo & Giampaolo, Fabio & Rozza, Gianluigi &

Raissi, Maziar & Piccialli, Francesco. (2022). Scientific Machine Learning Through Physics–Informed Neural Networks: Where we are and What's Next. Journal of Scientific Computing. 92. 10.1007/s10915-022-01939-z.

GOAL

The goals of this thesis are the following:

1. Collect human locomotion data with force information using the iFeel sensor suit and force-sensing shoes.
2. Retarget (process) the data from the human onto the ergoCub robot model.
3. Use event encoding strategies to allow the ADHERENT framework to learn the contact information in addition to the existing parameters.
4. Evaluate the success of the resultant trajectories trained using force data in both simulation and on the real robot.
5. (Optional) Improve quality of learned contact trajectories using phsyics-informed learning.

METHODOLOGY

The first part of the thesis will be devoted to performing a literature review on the following topics:

- Methods of learning contact forces for locomotion (quadruped, biped, etc.)
- Event encoding in machine learning [3]
- (Optional) Physics-informed machine learning techniques

The student who accepts the proposed project should first focus on the gathering and processing of contact data, using the iFeel sensor suit and shoes. The student will then incorporate the learning of force information into the existing trajectory generation framework. Some options for how to do this include designing another, parallel network to learn the contact information, or encoding the contact information such that it can be learned effectively.

Once the chosen method is implemented, the student will evaluate the efficacy of the approach and the accuracy of the learned force information on the simulated robot as well as test the generated trajectories on the real ergoCub robot.

PROFILE	
• Prior knowledge and coursework on supervised Machine Learning are required • A background or interest in working with robots is highly appreciated • Excellent programming skills are required (Python) • Attitude for and interest in carrying out research-driven projects are a plus • Availability to relocate for an extended period for working with the real-world humanoid robot and sensing systems at Istituto Italiano di Tecnologia national research center in Genoa, Italy, is required. Expected activities breakdown: • Literature and study – 20% • Implementation – 60% • Experiments – 20%	
# for Students	1