1. Advanced robot manipulation skills acquired via human demonstrations

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Description:

Humans excel in the manipulation of everyday objects or tools, especially when learning new manipulation skills, or when adapting already acquired skills to different tasks. Such an expert ability to use the hands for manipulation results from a life-long learning process that draws upon the observation of other humans as well as ourselves, as we discover how to handle objects first hand.

Today's manipulation capabilities in robots are unable to achieve such high level of dexterity in comparison to humans, and acceptable results are obtained only in very specific application scenarios and use cases [1]. In order for robots to operate reliably in environments *made by humans and for humans*, They must be capable of manipulating a wide variety of unknown objects modulating different parameters, such as contact strength, motion dexterity, and grasp stability. Furthermore, an object or tool may be considered (and therefore perceived) not only for its physical features, but also for the possibilities it entails, i.e., its *affordances*.

The need arises to provide robot hands with high-end behavioural capabilities, and specifically to deal with real-world uncertainties in perception and action, to represent heterogenous, multi-modal (visual and haptic) object features, and to generalise previously acquired manipulation skills to new objects and tools, and for new tasks.

This PhD proposal aims at (i) understanding how humans perform in-hand object manipulation, and at (ii) replicating the observed skilled movements with dexterous artificial hands. The work will merge the concepts of reinforcement and transfer learning to generalise in-hand manipulation skills to previously unknown objects, tools, and tasks, starting from well-known experiments as those done in the Open AI Gym scenario[1], which will be considered as a simulation platform in this PhD research proposal. An abstract representation of previously acquired knowledge,

[1] For instance, see the Open AI page https://gym.openai.com/envs/HandManipulateBlock-v0/ for block-like object manipulation, and https://gym.openai.com/envs/HandManipulatePen-v0/ for a pen-like object.

e.g., based on logic-based or belief-space frameworks [2], will be fundamental for reproducing acquired (learned) skills to different robot hand's mechanical shapes. The learning process will use heterogeneous, multi-modal data that will be collected, annotated and assembled into a large dataset, using an ad-hoc setup involving different sensing modalities [3]. The data and the methods developed throughout the PhD research period will be shared with the whole research community to allow for testing against open benchmarks and reproduction of results.

The core objectives of the PhD proposal are:

1. to build a visuo-haptic multi-modal robot perception architecture that extracts data about object manipulation via human demonstration;
2. the creation of a multi-modal dataset of in-hand manipulation tasks including re-grasping, reorienting and fine repositioning;
3. the development of an advanced object modelling and recognition method, including the characterisation of object's physical properties and their affordances;
4. to autonomously learn and precisely imitate human strategies in manipulation tasks.

The PhD student will work within an engaging, stimulating, and multi-cultural environment. He or she will be involved in the activities carried out by the TheEngineRoom team. This will involve also helping the team supervise MSc students in their thesis work, most notably students from the UniGe's Robotics Engineering program. To conduct the research activities, the PhD student will use state of the art dual arm manipulators (a Baxter robot from Rethink Robotics and Tiago++ from PAL Robotics, the latter provided with a dexterous 10-DOF hand), a network of RGB-D devices, motion capture systems (two combined OptiTrack systems), wearable devices (both commercial and custom IMUs, custom data gloves), AR/VR equipment (an Oculus Rift, a Hololens2), as well as advanced computational machinery.

This work will be done in the context of the H2020 CHIST-ERA collaborative project InDex. The student will have the opportunity to spend research periods abroad at Aston University (UK), Sorbonne University (France), TU Wien (Austria), and the University of Tartu (Estonia).

Requirements:

- Notions related to machine learning, data analysis, trajectory and motion planning.
- Software development in C/C++.

References:

[1] L. Seminara, P. Gastaldo, S. J. Watt, K. F. Valyear, F. Zuher, F. Mastrogiovanni. Active haptic perception in robots. Frontiers in Neurorobotics, vol. 13, 53, 2019.

[2] A. Thomas, F. Mastrogiovanni, M. Baglietto. MPTP: Motion-Planning aware Task Planning for navigation in belief space. Robotics and Autonomous Systems (accepted), 2021. Preprint at: https://arxiv.org/pdf/2104.04696.pdf.
[3] A. Carfì, F. Foglino, B. Bruno, F. Mastrogiovanni. A multi-sensor dataset for human-human handover. Data in Brief 22, 2019.

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