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Ecole doctorale SMAER
Sciences **M**écaniques, **A**coustique, **E**lectronique, **R**obotique

Thesis subject 2020

Laboratory : Institute for Intelligent Systems and Robotics

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Title of the thesis: Theoretical and experimental assessment of a sensorimotor approach to space perception

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Thesis's summary (abstract):

The ability for a naïve agent to build, by itself, a representation of its interaction inside its environment is a key requirement to make robots able to adapt themselves to an unpredictable world. Multiple strategies can be exploited to reach such a goal. Among them, sensorimotor approaches constitute promising approaches since most of them require minimal a priori on the agent knowledge. In this framework, we proposed different theoretical contributions aiming at understanding how and why the sensorimotor flow –made of proprioceptive and exteroceptive data mixed together—can be used to extract knowledge about the agent body, its peripersonal space, or even its surrounding environment. Most of these developments have been mainly tackled from a formal point of view, considering the agent as a way to gather sensory data from which information could be extracted by considering the interlink between action and perception.

But the theoretical world, often ideal or at least considered as a simplified version of a realistic environment, does not guarantee that what has been proven so far can be actually applied on a real robot, with real sensors, noises, repeatability issues, etc. The main objective of this thesis is to leverage the existing theoretical developments proposed by our team and to generalize them to realistic conditions. This might require to introduce new formal aspects like topology considerations, or stochastics processes, inside the already developed theory. The other objective is to extend the proofs of concept of these theoretical aspects to real robotic agents, with all their limitations. This will require to work with real robot platforms endowed with multiple sensors (like tactile, vision, etc.) so as to assess the developments.

Subject

Perception and actions are two fundamental, complementary, tasks in Robotics. One is not possible without the other. Traditionally, these two components are linked together by the robotician knowledge, modeling the sensors, the actuators and the mechanical properties of the robot to be able to make it realize a given task. But would it be possible for a naïve agent, to discover and learn the structure of its own interaction with its environment, without any a priori knowledge given by the engineer? Then, taking the internal point of view of the agent, the only data that are accessible are made of its own sensors outputs, possibly mixed together and generally non directly interpreted, and a copy of its own motor commands. All these data constitute the sensorimotor flow of the agent, and it is all the agent can use to infer the properties of its interaction in the unknown, outside, environment.

As already stated, classical approaches to perception in robotics are often based on models (of the robot, of the environment, etc.). For these traditional models, action is often --or even always-- considered as a consequence of the perception. In such frameworks, an a priori goal is provided to the agent ("reach this red ball") and the knowledge of the agent body structure and sensors can be exploited to compute the next step towards this external goal. The ability to perceive is thus given a priori by the engineer, and the perception is then a passive act mostly decoupled from the action of the system. But this point of view is questioned when considering works like sensory substitution, demonstrating that action and perception cannot be split this way, proving the tremendous importance of action when acquiring or adapting sensory capabilities [5]. In this vein, the sensorimotor contingency theory [2] has been introduced about 20 years ago by K. O'Regan to support the idea that an agent can learn to perceive the world in which it is evolving only on the basis on the sensorimotor flow, i.e. without any a priori data given to the agent. This theory also questions very old mathematical works by Henri Poincaré [1], who demonstrated how the dimensionality of geometrical space could be recovered only from data internally accessible to the agent.

Multiple development in this field have been since conducted, mostly oriented toward space understanding [3], sensory prediction, body schema estimation, etc. We recently proposed a formal way to understand how all these knowledges could be actually embedded inside the sensorimotor flow of a naïve agent. As a first step, we developed a theory based on motor quotient spaces and topology induced by a statistical exploration of the agent environment to (i) represent the interaction of an agent with its own body (by self-exploration) [6], and (ii) build a representation of its peripersonal space [4, 7]. All these developments were mostly formal, supported by realistic simulations, but still far from representing a real interaction of a real robot in its environment. We are also now working on a new variational approach of these aspects, explicitly including actions acting on the actuator states, as a way to structure sensory prediction together with the set of actions. Again, simulations have been conducted as a proof of concept of the theoretical developments. The objective of this thesis is to extend the obtained formalism and results to more realistic cases, where the sensors are possibly noisy, where the environment is intrinsically dynamic, and where actions are not strictly repeatable. This ambitious goal will have to be tackled from a theoretical point of view, with the objective the mathematically prove properties of this realistic interaction. This might require to introduce new formal aspects like topology considerations, or stochastics processes, inside the already developed theory. But differently from our previous works, real robotic platforms, endowed with various sensory capabilities (with tactile skin, cameras, microphones, etc.), will be used to gather sensorimotor data. The aim is to assess how the proposed theory can be used on real platform, together with the evaluation of how the multimodality can help in this process.

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[6] Marcel, V. and Argentieri, S. and Gas, B. (2017). Building a Sensorimotor Representation of a Naive Agent's Tactile Space. IEEE Transactions on Cognitive and Developmental Systems. Vol 9 No 2 Pages 141-152.

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