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GUEST EDITORIAL

Cognitive Robotics Systems

Concepts and Applications

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While current robotic systems are getting closer to repeating a carefully-coded set of actions, they are still far from human's versatility and adaptivity. Cognitive Robotics Systems (CRS) need to reach a level of cognition that will allow them to understand and effectively operate in household and industrial environments, interact with humans, and adapt their actions to an ever growing range of situations. They are expected to be able to predict the perceptual changes that result as a consequence of human actions and replicate human activities, taking into consideration their own capabilities and limitations. In essence, robots are expected to be capable of *understanding*, *generalizing*, *empathizing* and *replicating* human behavior to achieve autonomous learning in the fullest sense of the word. More precisely, understanding can be achieved through sensing and encoding, generalizing by extracting higher-level understanding from low-level sensing data, empathizing by developing a sense of context-dependent interpretation, and replicating by regenerating observed behaviors even in novel contexts.

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This special issue draws inspiration from these themes, as addressed and discussed in the series of IROS workshops CAS-2012: "Cognitive Assistive Systems: Closing the Action-Perception Loop" and CRS-2013: "Cognitive Robotics Systems: Replicating Human Actions and Activities". The vivid discussions during these workshops revealed the importance of CRS, as well as the diversity of approaches toward their realization. The open call for papers for this special issue resulted in 37 submissions, out of which 11 high quality papers were finally accepted for inclusion.

While there is probably not an all-satisfying answer to what cognition is, certain topics keep reoccurring when discussing about cognitive systems. CRS need to communicate with people for them to coexist and collaborate in human living and working environments. As a result, *symbiotic interaction* between robots and humans becomes a very important aspect of such systems. Kim and Rosen in "Predicting

Redundancy of a 7 DOF Upper Limb Exoskeleton Toward Improved Transparency between Human and Robot" present a control strategy for a 7 degrees of freedom upper limb exoskeleton used as a human-robot interface. In order to improve the transparency between the robot and the human, the redundancy resolution of the human arm is provided as a closed form solution for the robot control algorithm. Redundancy is expressed mathematically as a function of the operator's wrist pose using the reference swivel angle and the swivel angle offset. Apart from the theoretical foundation, an experimental setup for validation is considered. However, such a symbiosis requires *learning by demonstration* mechanisms for CRS to be taught new tasks or given instructions. Pedersen and Krueger in "Gesture-Based Extraction of Robot Skill Parameters for Intuitive Robot Programming" present a teaching by demonstration approach for interactive programming of mobile manipulators in real-world industrial scenarios. This work describes the skill model, the human tracking and gesture recognition system and other components that are combined to form an easily programmable mobile industrial robot. Then, programming of robot tasks is treated as a manual selection and sequencing of required robot skills, while individual skill parameters are specified using a gesture-based human-robot interface. Koropouli et al. in "Generalization of force control policies from demonstrations for constrained robotic motion tasks" propose two policy generalization approaches employed for generalizing motion-based force control policies. The goal of this work is to learn control policies from demonstrations and to allow for constrained motions in presence of new motion-dependent external forces. The proposed approaches are evaluated in real-world robot constrained motion tasks by using a linear-actuated, two degrees of freedom haptic device. Rekabdar et al. in "An Unsupervised Approach to Learning and Early Detection of Spatio-Temporal Patterns Using Spiking Neural Networks" deal with the issue of unsupervised pattern classification, be it gestures or other human actions. They examine the use of a spiking neural spatio-temporal pattern recognition system and show that it can cope with small training sample numbers and allows for early classification of the pattern from observing only a fraction it.

While collaboration between robots and humans is undoubtably a very interesting topic, the *interactions between multiple robots* aiming to achieve common goals are of equal importance for cognitive systems consisting of multiple agents. Maia and Goncalves in "Intellectual Development Model for Multi-Robot Systems" incorporate ideas and theories from psychology to deal with the issue of multi-agent cooperation. The authors consider groups of robots and propose a learning formalism for them to coordinate and allow assimilation and accommodation of knowledge through experience exchange. The proposed model is theoretically grounded, mathematically formalized and experimentally validated. Dragone et al. in "Robotic Ubiquitous Cognitive Ecology for Smart Homes" present a framework for heterogeneous robotic devices to cooperate autonomously and adaptively in smart home environments. The proposed ecology is able to teach and improve itself so as to perform useful tasks and pro-actively assist people. A broad review of the communication, learning, cognitive and control abilities of the architecture is presented and experiments are performed to validate the efficacy of the architecture.

Visual perception and representation of 3D information is another essential ability a cognitive robot needs to possess. De Luca et al. in "A Depth Space Approach for Evaluating Distance to Objects" propose that instead of using the Cartesian space, distances can be rather computed in the native representation of depth sensors, the depth space. This space allows distance estimation by considering also the frustum generated by the pixel on the depth image, which takes into account both the pixel size and the occluded points. The authors explore a human-robot collision avoidance case study and show that the proposed method is effective and fast to compute. Cui et al. in "Analysis of Different Sparsity Methods in Constrained RBM for Sparse Representation in Cognitive Robotic Perception" present an approach to the Restricted Boltzmann Machine (RBM) with sparse constraints using a generalized optimization problem. The approach is applied to visual images for sparse feature representation. Three variants of sparse RBMs are proposed based on the L_1, L_2, and $L_{\frac{1}{2}}$ norms.

What makes CRS special compared to other advanced systems is their ability to physically interact with the environment and perform useful tasks. Toward this direction, *grasping* as well as *manipulation of tools and objects* are required skills. Chen et al. in "Uncertainty-Aware Arm-Base Coordinated Grasping Strategies for Mobile Manipulation" present an approach for grasping that simultaneously considers and uses the base and arm of a mobile manipulator. The system takes into account uncertainties in object location and decides the best grasp strategy taking into account grasp success probability and task execution time. For this purpose, the use of a Dynamic Motion Primitives controller and a Markov Decision Process approach is proposed. If the uncertainty is small, the system uses a pre-shape adaptation, while if the uncertainty is large a push and grasp strategy is preferred. The importance of *motion planning and motion generation* is highlighted by Mericli et al. in "A Case-Based Approach to Mobile Push-Manipulation". This work presents a push-manipulation framework that enables a robot to interact with objects in order to move them to some predefined target pose. The authors adopt a data-driven approach where the robot learns the effect of pushes from self experience. A variant of a Rapidly-exploring Random Trees planner is used for generating the sequence of pushes to reach the goal. The proposed method is shown to generalize the learned cases and adapt to novel situations. Elbanhawi et al. in "Continuous path smoothing for car-like robots using B-spline curves" present an approach for generating motion paths with continuous steering for car-like mobile robots. The planning of the robot motion satisfies path continuity and maximum curvature for nonholonomic robots. The efficiency of the presented work allows real-time planning, while the use of B-spline curves provides robust models of the vehicle's path.

Realizing CRS will require advances along the complete processing pipeline, from sensing through learning to acting. While the constituent technologies seem to progress and get more mature, it is not yet evident how they can be combined into a single CRS that would be robust enough for deployment in real household, industrial or outdoor environments. Such a challenging task is likely to require step changes in current state of the art capability. We, the guest editors of this special issue, believe that it sheds some light on the recent advances around CRS and we hope it serves as a motivation to other researchers to further pursue the ultimate goal of implementing and integrating truly cognitive robots.