2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
September 24–28, 2017, Vancouver, BC, Canada

Hybrid Adaptive Control of Industrial Robots for Surface Exploration of Arbitrary Objects

Danial Nakhaeinia, Pierre Payeur, and Robert Laganière

Abstract— Industrial robots rapidly gained popularity in manufacturing as they can perform tasks quickly, repeatedly and accurately in static environments. However, in modern manufacturing, robots should also be able to safely interact with arbitrary objects in unstructured environments and dynamically adapt their behavior to various situations. The large masses and rigid constructions of classical industrial robots prevent them from easily being re-tasked and considerable cost and effort is required for providing a suitable workspace for these blind machines [1]. Therefore, repurposing of them for alternate tasks and applications requires precise control of forces and motion, and cannot be fully accomplished without a comprehensive set of sensing modalities that monitor the position, orientation, shape, surface characteristics and even objects transformation under external constraints. For that matter, it is essential to develop innovative integrated sensing and control methods to provide next generation robots with increased versatility that will make them perform closer to what human beings achieve.

In order to extend the usability of industrial robots, they should be made able to react and adapt their behavior to changes in the environment. As such, flexible and adaptive interaction with various objects in arbitrary positions raises new challenges for reactive interaction and exploration (surface following) tasks that may involve physical contact. This work addresses the two key issues of flexibility and adaptability for reactive interaction with arbitrary objects through the use of a custom-designed compliant wrist and an original hybrid switched motion control approach that is proposed which utilizes multimodal sensory information for offline trajectory planning and online path adaptation.

To minimize the complexity of the task, the problem is divided into four interaction motion modes, respectively defined as: free, proximity, contact, and a blend of those. The free motion mode guides the robot towards the object of interest using information provided by a remote RGB-D sensor. The latter is used to collect raw 3D information on the environment, which is then processed to segment and construct a rough 3D model of an object of interest in the scene, which is in turn used to guide the robot in free motion mode. In order to completely explore the object, a novel coverage path planning technique is proposed using a dynamic 3D occupancy grid method to generate a primary (offline) trajectory. However, RGB-D sensors provide only limited accuracy on depth measurements and are very sensitive to lighting. In order to update the sensory information, a custom-designed instrumented compliant wrist [2] is mounted on the robot end effector which provides means for collecting extra measurements on objects either in proximity to, or in contact with, the tool plate, while also adding a degree of compliance to the robot [3]. Two model-free self-tuning adaptive controllers are designed that allow the robot to dynamically interact with arbitrary objects and adapt to their surface as the robot approaches or touches them, using live proximity and contact feedback provided by the sensors embedded in the compliant wrist. The adaptive controllers neither require precise mathematical models of the robot and the environment, nor force/torque calculation and learning procedure. This enables the robot to perform fast reactive interaction in close proximity to (proximity motion mode), or contact with (contact motion mode), arbitrary objects.

To achieve seamless and efficient integration of the sensory information and smoothly switch between different interaction modes, a hybrid switching scheme is also proposed. This hybrid switching scheme originally utilizes a supervisory (decision making) module which applies a mixture of hard and blend switches that allow data fusion from heterogeneous sensing sources. It combines pairs of the main motion modes (into a blend motion mode), and data from the related sensing stages, in a structure that will be detailed in the poster. Furthermore, in order to validate and demonstrate the performance and efficiency of the proposed method, experiments corresponding to free motion, proximity, contact and hybrid (sequences of free motion, proximity and contact) interactions are carried out using an industrial 7-DOF CRS-F3 robotic manipulator equipped with the designed instrumented compliant wrist [4].

This research provides original contributions to the fields of multimodal sensing and adaptive control in robotics. More specifically, a hybrid switched motion control approach is introduced that allows classical industrial robots be adapted and made flexible enough to permit reliable reactive interaction, such as surface following, with unmodeled objects in their environment. The results provide innovative ways to support robotic applications in inspection, cleaning, painting, welding, and particularly security screening, where close inspection of vehicles, containers or parcels requires rapid adaptation to and accurate coverage of complex surfaces.

Danial Nakhaeinia, Pierre Payeur, and Robert Laganière are with the School of Electrical Engineering and Computer Science, University of Ottawa, 800 King Edward, Ottawa, ON, Canada; e-mail: [dnakhaei, ppayeur, laganier]@uottawa.ca.

REFERENCES

[1] C. Heyer, "Human-robot interaction and future industrial robotics applications", *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2010, pp. 4749-4754.

[2] P. Laferrière, and P. Payeur, "Instrumented Compliant Wrist with Proximity and Contact Sensing for Close Robot Interaction Control", *MDPI Sensors*, vol. 17, 1384, 14 June 2017.

[3] M. Laffranchi, N. Tsagarakis, and D. Caldwell, "CompAct Arm: a compliant manipulator with intrinsic variable physical damping", *Robotics: Science and Systems*, vol. 8, pp. 225-232, 2013.

[4] D. Nakhaeinia, P. Laferrière, P. Payeur, and R. Laganière, "Safe close-proximity and physical human-robot interaction using industrial robots,"*12th Conference on Computer and Robot Vision*, Halifax, NS, 2015, pp. 237-244.