2013 IEEE/RSJ International Conference on
Intelligent Robots and Systems (IROS)
November 3-7, 2013. Tokyo, Japan

Provably-Correct Robot Control with LTLMoP, OMPL and ROS

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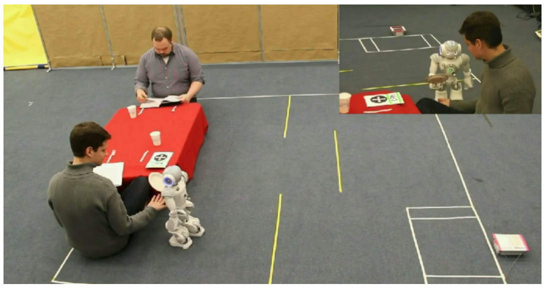

Fig. 1. Nao delivering a plate to a customer

I. Introduction

This video illustrates the Linear Temporal Logic MissiOn Planning (LTLMoP)[1][1] toolkit. LTLMoP is an open source software package that transforms high-level specifications for robot behavior, captured using a structured English grammar, into a robot controller that guarantees the robot will complete its task, if the task is feasible. If the task cannot be guaranteed, LTLMoP provides feedback to the user as to what the problem is.

Due to its modular nature, users can control a variety of different robots using LTLMoP, both simulated and physical, with the same specification. This video shows an example robot waiter scenario, with LTLMoP controlling both a PR2 in simulation (using Gazebo), showcasing the interface between LTLMoP and the Robot Operating System (ROS)[2], as well as an Aldebaran Nao humanoid in the lab.

Fig. 1 shows the the restaurant environment used for this video and Listing 1 contains the specification for the scenario in the structured English grammar used by LTLMoP.

II. Controller Synthesis

The specification in Listing 1 cannot be fulfilled in all environments, so LTLMoP alerts the user to the fact that the specification is unsythesizable. LTLMoP allows the user to run an analysis of the specification [2], which helps the user pinpoint the problem. In this case, the robot is required to deliver food whenever it gets an order, but there is no guarantee that the food will actually be available. To solve the problem, we add the assumption "infinitely often food_ready" to Listing 1, which states that food will always eventually be ready for pickup in the kitchen. By adding this line, the specification becomes synthesizable.

This work is supported by NSF CNS-0953365 and NSF ExCAPE

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[1]Available online at http://ltlmop.github.com/

[2]http://www.willowgarage.com/pages/software/ros-platform

Listing 1 Structured English Specification

```
robot starts with false

### How to get food ###
carrying_food is set on kitchen and pick_up and reset on
    deliver
if you are not sensing food_ready then do not pick_up

### We can only carry one thing at a time ###
if you are activating carrying_food then do not pick_up

### We need food to deliver ###
if you are not activating carrying_food then do not
    deliver

### Satisfy all orders ###
after each time cam_order, go to Cam and deliver
after each time spyros_order, go to Spyros and deliver
```

III. Controller execution

This video shows the same task and specification executed by two different robots. First a simulated Willow Garage PR2 running inside the Gazebo simulator is controlled with LTLMoP using ROS. We have interfaced LTLMoP with ROS so any robot running under ROS can be easily controlled through LTLMoP. Here, we use the PR2 with a modified version of the Pick And Place Autonomous Demo[3] to locate the can on the table and pick it up using the PR2's gripper.

During the simulation, the motion planning between adjacent regions is conducted using the Open Motion Planning Library (OMPL)[4] which is integrated with LTLMoP. LTLMoP currently supports a variety of two-dimensional and three-dimensional motion planning algorithms in OMPL, including different versions of Rapidly-Exploring Random Tree (RRT), Expansive Spaces Tree (EST) and Probabilistic Roadmap Method (PRM).

Finally, a physical experiment with the Nao humanoid robot was run with a Vicon motion capture system providing pose information. The Nao's built-in vision system was used to recognize two patterns representing the order from Spyros and Cam respectively. Nao grasps the dish given by the chef and delivers it to the customers. OMPL is used here as well for the motion planning between regions.

References

[1] C. Finucane, G. Jing, and H. Kress-Gazit, "LTLMoP: Experimenting with language, temporal logic and robot control," in *IEEE/RSJ Int'l. Conf. on Intelligent Robots and Systems*, 2010, pp. 1988 – 1993.

[2] V. Raman and H. Kress-Gazit, "Automated feedback for unachievable high-level robot behaviors," in *ICRA*. IEEE, 2012, pp. 5156–5162.

[3]http://www.ros.org/wiki/pr2_pick_and_place_demos/

[4]http://ompl.kavrakilab.org/