Briding the Gap between Operator Intent and Robot Execution with Automated Whole-Body Planning and Perception

Bridging the gap between Operator Intent and Robot Execution with Automated Whole-body Planning and Perception

Maurice Fallon[1]

I. Introduction

The number and type of situations where robotic systems have been deployed continues to grow. From bomb disposal situations (with complete human interaction at the joint level) to simple maintenance of robotic vacuum maintenance, human intervention is still required to achieve sufficient performance and flexibility — especially when the system developed by the robotic system designers is used outside the scope for which it was designed.

From our experiences in the DARPA Robotics Challenge we have learned important lessons about a) what approaches are effective in human-robot teaming in unexpected environments and (2) what is needed to achieve sufficient performance improvements so as to justify the usage of humanoids in challenging disaster situations.

II. Reflections on 2013 DRC Trials

In the DRC Trials (December 2013 in Homestead, Florida) our team competed in outdoor competition against 15 other teams in a landmark demonstration of humanoid capability. Our task was to develop a humanoid system to execute 8 manipulation and locomotion tasks themed around disaster relief — complete with realistic communication and using on-board sensors.

As a "Track B" entry we were provided with a 28 degree of freedom, 160 kg humanoid manufactured by Boston Dynamics called Atlas to compete with. Thus, our focus was on the development of software to pair the robot with our operator(s).

[1]Maurice Fallon is with the Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, USA and the Department of Informatics, University of Edinburgh, UK. mfallon@mit.edu

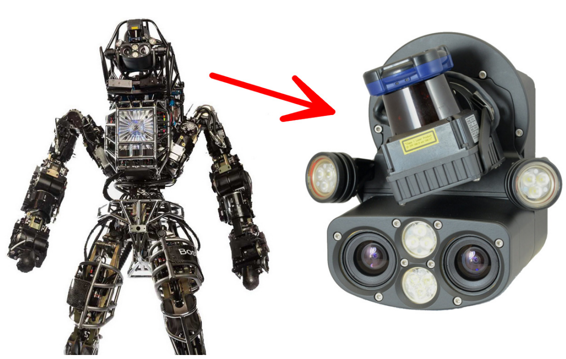

Fig. 1. The Boston Dynamics Atlas robot used by our team in the DARPA Robotics Challenge (photo credits: Boston Dynamics and CRL)

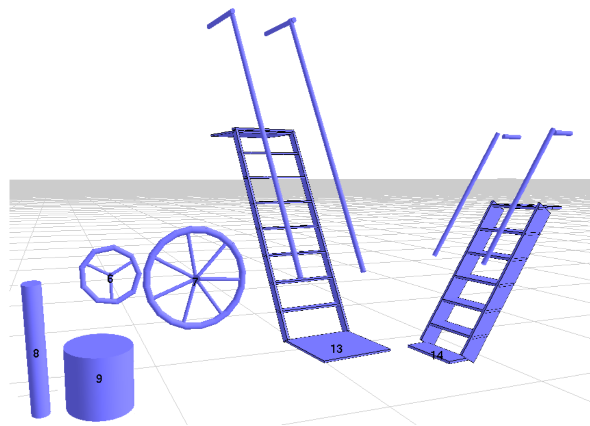

Fig. 2. High level affordances parameterized in XML. Using a URDF-like representation the robot could be commanded to execute valve turning, ladder climbing at a functional level. Using the parameterization of these affordances; such as radii, step spacing, hand rail positioning.

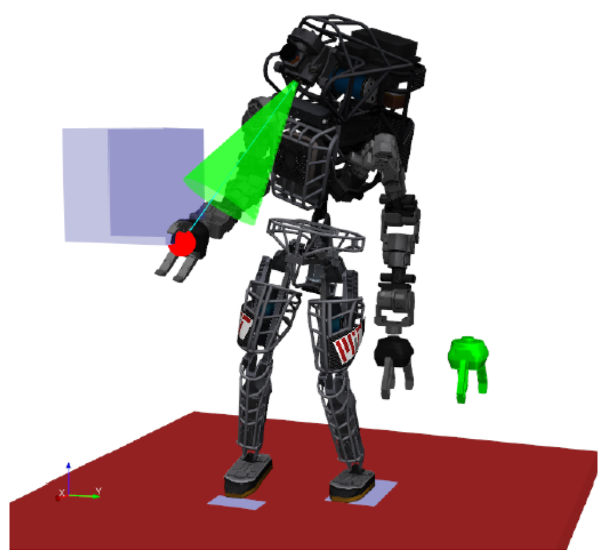

Fig. 3. Motion Planning represented as a series of constraints. For example The left foot and the right foot toes are constrained to lie within the shaded regions. A point (red sphere) on the right hand is constrained to be within the shaded bounding box. The head camera gazes at the right hand.

In our upcoming article, [1], we describe in detail our approach, instead here we will briefly discuss some initial reflections from the competition:

Framing of objects in the robot's 3D environment by its kinematic model (which we described as an affordance) is an important step which centered our manipulation about affecting change to these objects. However to do so requires a significant degree of forward kinematic precision, manipulators that are capable of accurate joint and force sensing. The former was achieved through repeated calibration while the latter issues will only be improved upon by a new revision the Atlas robot in Dec 2015. As a result we only partly succeeded in leveraging the high level approach illustrated in Figure 2.

Manipulation planning focused on motion planning of the robot's kinematic model combined with that of the affordance of interest. Our approach uses trajectory optimization [2] to plan kinematic sequences that are quasi-statically stable, but their description is also close enough to be used at a functional level — for example bi-handed manipulation requires maintaining a relative position constraint between the two hand links of the robot.

However in the challenge, high level manipulation of of complete actions such as "drill the wall" was at too high a level to be executed.

While our user interface framed all manipulation as positing of the robot's 'hand' link, there was little flexibility to support more varied inputs such as a 5-DOF pointing constraint. Simple kinematic execution does not capture the subtly required to, for example, connect a hose to a spigot with an imprecise end–effector nor does it express contact points or forces.

Instead we have redesigned our approach to reduce the distance between the description of the steps required to execute a task and the code necessary to execute it. We believe that this separation should be as short as possible — without becoming entirely specific.

Object Fitting algorithms: We paired the affordance representation with simple reliable fitting algorithms. This was been hugely beneficial in enabling rapid development of action sequences which could be autonomously executed on the robot — without unrepeatable and inconsistent human interaction. Illustrated in Figure 4 is an example annotation which the human could provide to fit an object of interest.

Finally, we recognize that human manipulation is very different from a robotic system: with relative perception–aided motions using subtle cues such as shadow or texture. Without high-rate tracking of texture-less small objects, in the presence of occlusion, a human-inspired approach to manipulation can only be useful when the human is tightly in the loop.

III. Conclusion

In summary while we have seen significant demonstration of capability before and during the DRC Trials proving that the robotic hardware is very capable. However operation speed and efficiency remains low, thus both the duty cycle of operation and the speed of execution needs to be improved — as well as achieving the repeatability.

To achieve either of these goals requires the development of mature planning systems which deeply captures the full intent of the operator while retaining a high level of generality.

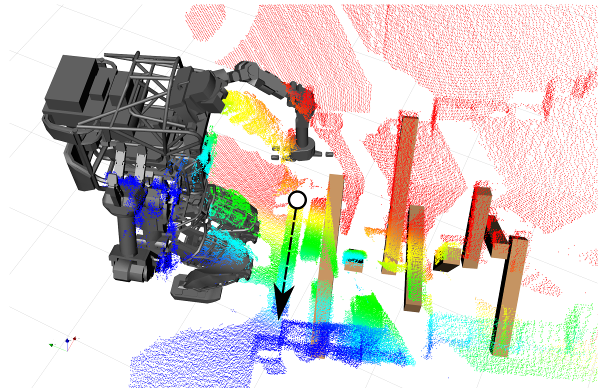

Fig. 4. Efficient fitting of a board. A line annotation (arrow) defines a search region that is used by a segmentation algorithm to fit a 2"x4" board affordance to the 3D point cloud data.

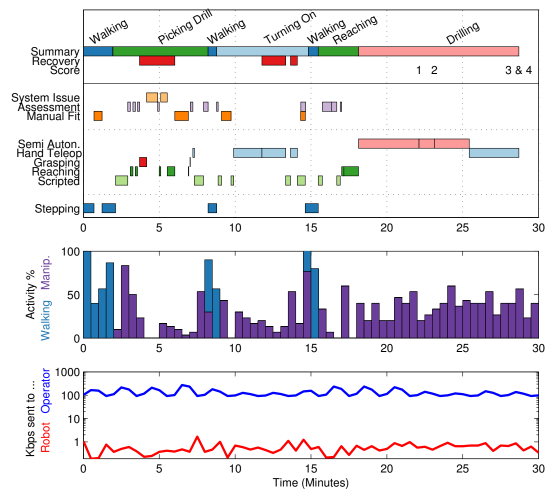

Fig. 5. Analysis of the Drilling Task from the DRC Trials. **Top:** Analysis of operating time. From top to bottom: summary of task components; time spent primarily stationary while the operators considered the situation and manually fit objects; various manipulation task and walking. **Center:** Portion of time the robot spent moving integrated over 30 second intervals. **Bottom:** Data transmission rates from robot to operator (blue) and vice versa (red).

Videos over-viewing of our team's work since the Trials competition as well as references to work mentioned in this document can be seen here: `http://drc.mit.edu`

References

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[2] H. Dai, A. Valenzuela, and R. Tedrake, "Whole-body motion planning with simple dynamics and full kinematics," in *Proc. IEEE Int. Conf. Humanoid Robots*, Madrid, Spain, 2014.