Affordance Templates for Shared Robot Control

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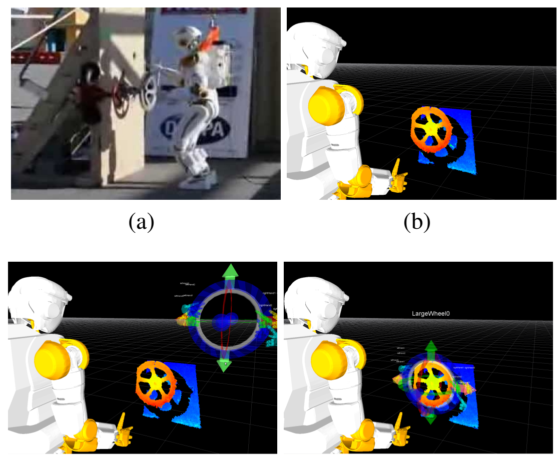
Introduction

This paper introduces the Affordance Template framework used to supervise task behaviors on the NASA-JSC Valkyrie robot at the 2013 DARPA Robotics Challenge (DRC) Trials. This framework provides graphical interfaces to human supervisors that are adjustable based on the run-time environmental context (e.g., size, location, and shape of objects that the robot must interact with, etc.). Additional improvements, described below, inject degrees of autonomy into instantiations of affordance templates at run-time in order to enable efficient human supervision of the robot for accomplishing tasks.

The Affordance Template Framework

Recent advances in human-robot interface design have led to a number of useful tools for interacting with complex systems. Specifically, the abundance of RGBD and LIDAR devices have resulted in the development of 3D visualizations of robot environments that reflect state of the robot in a virtual space with the aggregate data delivered by these devices. One such environment is RViz, which enables seemless use with the Robot Operating System (ROS). While RViz delivers a significant amount of off-the-shelf situational awareness to a human supervisor along with a standard point-and-click interface for teleoperation (Gossow et al. 2011), it does not inherently provide the tools for directing robots to accomplish more complex tasks. Affordance templates, introduced here, have been developed to provide such task-level structure.

An *affordance* describes a place or object in the world that affords an action by a particular agent. If an area of the perceived environment affords "sitting" it is not that that area is a chair, but rather that it has a surface that the agent could sit on (without falling off), whether it be a chair, a stool, a rock, or the ground, and is inextricably linked to the agent (robot) doing the acting. The concept of affordances was initially introduced in the psychological literature by Gibson (Gibson 1977) as a means of describing cognitive structures that assign functional merit to the environment. It is therefore readily applicable for programming robots; embodied agents that must perform actions to achieve some discernible objective (Stoytchev 2005; Hart and Grupen 2013).



(a) (b) (c) (d)

Figure 1: Placing a wheel-turning template in RViz.

An *affordance template* is a graphical construct that exists in a 3D immersive environment (such as RViz) to provide human-adjustable robot task goals (spatial end-effector waypoints, contact points for interaction, force magnitudes) and parameters (object scales, locations) in object-centric coordinate frames. If a template is placed in such an environment alongside a robot avatar and its aggregate sensory data, a supervisor can move the template to an appropriate location (a location that affords the task behavior) and adjust the template goals and parameters as necessary, appropriate for the current run-time context.

Figure 1 shows the placement of a wheel-turning affordance template in the immersive RViz environment. In (a), Valkyrie is shown standing in front of a valve. In (b), the RViz display window shows the robot avatar and the point cloud data received from Valkyrie's head-mounted Ensenso sensor. From this view, a supervisor can clearly identify the valve in the robot's workspace, and can manually register the wheel affordance template to the location of the valve, seen in (c). Additionally, the wheel template allows the supervisor to adjust the hand pre-grasp, grasp, and turn-goal waypoint locations (shown as different color hands, displayed

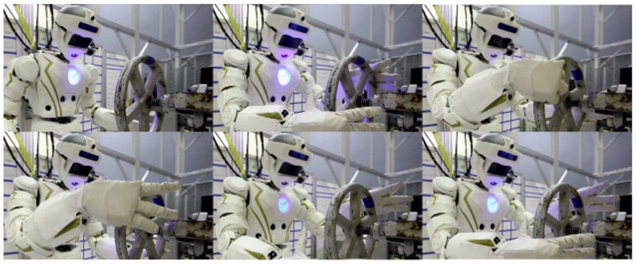


Figure 2: Turning a valve using an affordance template.

in the wheel reference frame). When the goal locations are finalized, they can be sent to the robot's control system to accomplish the task (Figure 2).

Template parameters (*e.g.* controller reference, object poses, navigational way-points) are meant to capture the key degrees of freedom of the task in an efficient representation suitable for control over unreliable and/or unknown networks. It is the fact that these parameters exist, however, that an affordance template is only a template. These parameters must be set in order to provide sufficient information for the task to be accomplished. As a result, affordance templates follow a methodology of shared control, which lets the supervisor and robot control different signals simultaneously, rather than on traded control, which assumes direct teleoperation or full autonomy. A number of affordance templates were developed for use on the Valkyrie robot including templates for door opening, walking, hose mating, valve turning, and ladder and stair climbing.

Ongoing Work

The Affordance Template framework follows a supervisory control paradigm of *Plan, Teach, Monitor, Intervene, and Learn* (PTMIL) (Sheridan 1992). Currently, the framework supports only the PTMI steps of this paradigm as it only allows the supervisor to place a template in an appropriate location, adjust certain parameters, and execute the resulting plan to the robot (intervening if necessary). However, allowing the robot to *learn* from this experience is ongoing work. Currently, the framework is being extended along multiple dimensions.

- **Planning:** Integration of motion planning tools such as MoveIt! (`http://moveit.ros.org`) will allow extra levels of verification, intelligence, and visualization for the supervisor concerning the robot's expected motion for accomplishing the goal(s) of the affordance template. Moreover, the ability to determine whether a waypoint goal is reachable after the supervisor adjusts that goal, could provide preliminary feedback on whether the task is accomplishable in the current context. More sophisticated uses of robot planning could also be used to eliminate the necessity for the supervisor to set *all* task parameters as is currently necessary, or to chain affordance templates together to accomplish multiple extended behaviors (walk up to an object, pick it up, use it for some purpose, etc.)
- **Learning:** Either in the absence of, or in conjunction with, more sophisticated planning techniques, affordance templates could monitor the parameter values over the course of multiple executions of a task and provide statistical feedback on whether those values are likely to lead to task success. The metric of success could be supervised (let the supervisor indicate task outcome after execution) or unsupervised depending on the task's requirements.
- **Perceptual Registration:** Rather than relying on the supervisor to register templates with sensor data (as in Figure 1), autonomous point cloud registration techniques could be used. In fact, the robot could monitor its environment and provide "guesses" about likely affordances, "dropping in" corresponding affordance templates with pre-adjusted parameter settings into the virtual environment.
- **Force-Based Tasks:** Currently existing affordance templates only allow the supervisor to set spatial parameters (object locations, end-effector waypoints, etc.). However, force- or contact-based goals (apply a force along an axis of a certain magnitude, turn the wheel with a desired torque, etc.) could also be set in the framework. Such specifications will ultimately be necessary for guiding a robot to accomplish sophisticated manipulation tasks in real world industrial or service contexts. The visualization of these parameters in a 3D spatial environment is an interesting problem on its own terms, and currently various approaches are under investigation.

Although some of these extensions individually may require significant research contributions, the affordance template framework provides an efficient representation for aggregating this functionality together in a unified structure. By keeping the supervisor "in the loop" and phasing in more autonomy as appropriate—whether in terms of planning, perception, or learning—the framework supports multiple levels of intervention that can ensure task success in multiple contexts.

Acknowledgments

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