Video survey of pre-grasp interactions in natural hand activities

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The first step in many manipulation actions is object acquisition, where the hand is formed around the object to achieve a task-specific grasp. A large body of the previous research has investigated object acquisition in the context of reach-to-grasp actions. The primary focus has been on the motor coordination of the upper limb and hand shape in the process of reaching toward the object which is grasped. In many of the reach-to-grasp actions studied previously, the target of the coordinated reach and preshape motion is a presented object whose placement is considered fixed in the environment.

In several natural task settings, however, the object is movable in the environment, and the task does not require the object to be grasped exactly from its presented placement. The object interaction during acquisition may be more complex, such that the object is moved prior to the complete formation of the desired grasp. This pre-grasp interaction may serve to adjust the object configuration to improve the goal grasp. For example, a person may use non-prehensile contact to slide and re-orient a mug on a table before grasping it by the handle. When grasping a pen off of a table, the fingers may quickly pivot the pen to orient the tip for the subsequent writing task.

Our previous work [Chang *et al.*, 2008, 2009] has investigated preparatory object rotation as a specific example of pre-grasp interaction. In preparatory object rotation, the object is pivoted in the plane of the support surface in order to re-orient the object handle prior to grasping, as in the mug example above. Instead of completely re-planning a new direct reach-to-grasp action for novel object orientations, a preparatory rotation strategy first adjusts the object orientation with pre-grasp interaction and then completes the hand formation of the final desired object grasp.

The present work surveys the broader class of pre-grasp interaction strategies beyond the specific example of preparatory rotation. Our goal was to develop a taxonomy for classifying the variety of pre-grasp action primitives which are integrated into complex reach-to-grasp tasks. We were specifically interested in surveying human hand activity in natural settings in contrast to instructed tasks within a laboratory environment. In this way, we could capture the richness of pre-grasp interactions beyond the direct reach-to-grasp actions studied previously in the literature.

In the video survey of human hand activity, we filmed people performing manipulation tasks in natural settings such as the home or place of occupation. All participants provided informed consent. In all observations, the participants performed manipulation skills which had been practiced previously as part of their regular occupation. There were a total of 10 sessions of both individual and group manipulation activities, such that overall 38 people were filmed. The sessions covered activities for housekeeping, food preparation, office work, and mechanical repair. Specific tasks include sorting office supplies, washing dishes, and moving furniture.

We found that there is indeed a broad class of pre-grasp interactions where the object is not grasped directly from its presented placement in the environment. Our framework describes the survey examples according to two main aspects of the pre-grasp interaction. The first aspect is the type of object re-configuration resulting from the interaction. The second aspect is the underlying intent of the interaction to improve the posture quality or grasp quality of the manipulation action.

First, the object reconfiguration is classified by a taxonomy based on the degrees of freedom which were adjusted by the pre-grasp interaction (Fig. 1). The object motion may be completely comprised by planar displacement. This is common in examples of non-prehensile pre-grasp interaction where the object is primarily supported on a horizontal surface. Alternatively, for a bulky

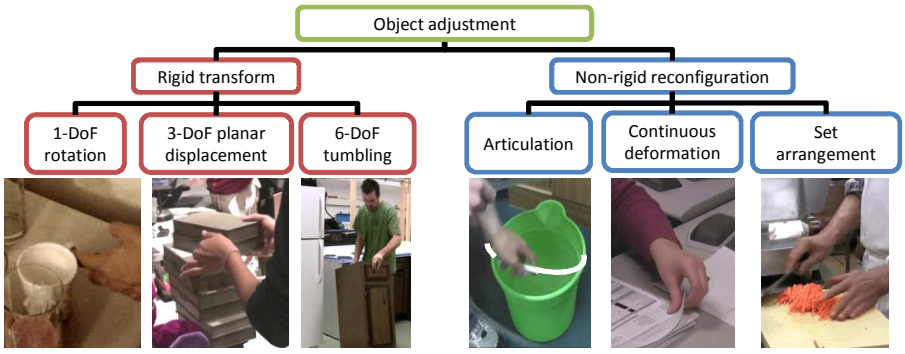

Figure 1: Taxonomy for the object reconfiguration aspect of pre-grasp interaction. Examples of rigid planar transformations included rotation of a cup by its handle and sliding books off the top of a stack. General rigid tumbling was used to achieve a whole body grasp of a bulky piece of furniture. Pre-grasp interaction was also observed for non-rigid objects. A hinged bucket handle was rotated to achieve a cylinder grasp, and a piece of paper was curled to achieve a pinch grasp. Multiple objects were also rearranged as a set, such as in the scooping interaction with a pile of peelings.

piece of furniture, the pre-grasp tumbling interaction may result in general 6-degree-of-freedom rigid displacement. In more complex cases, the pre-grasp interaction may cause a morphological reconfiguration of a deformable or articulated object, such as a bucket with a hinged handle.

Second, the pre-grasp interaction is described by the intent of the object adjustment in relation to the final grasp. The presented configuration of the object in the environment could be suboptimal for direct reach-to-grasp object acquisition due to preferences for a particular body posture and/or grasp. When the handle on a cooking pan is oriented away from the person, a direct grasp of the handle may be feasible but could require lifting the heavy pan from an uncomfortable body posture with limited lifting capability. In other scenarios, the intent of the pre-grasp interaction may be to improve the grasp quality rather the posture quality. This is especially relevant to situations where environmental clutter occludes the desired grasp contact surfaces, as in the case of a shelved book where only the spine is exposed in the initial task condition. The observed examples suggest that the intent of pre-grasp interaction was often a combination of preferences for both posture quality and grasp quality, and potentially other optimization metrics.

The presented pre-grasp interaction framework suggests several approaches for improving the dexterity of robotic manipulators. Taking advantage of object movability may extend the effective workspace by changing the environmental constraints when direct reach-to-grasp actions are of insufficient posture and/or grasp quality. Non-prehensile pre-grasp interaction could reduce the load on the manipulator by using shared support with the work surface during the initial interaction with the object. Moreover, the expense of tuning control parameters for complex manipulators can be reduced if pre-grasp object reconfiguration enables the reuse of a single well-tuned grasp action for multiple initial placements. Finally, because pre-grasp strategies are part of natural human manipulation, incorporating them in the repertoire of assistive or teleoperated manipulators could facilitate more intuitive control for human operators.

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