Multi-sensor Segmentation of Human Grasping and Manipulation Tasks

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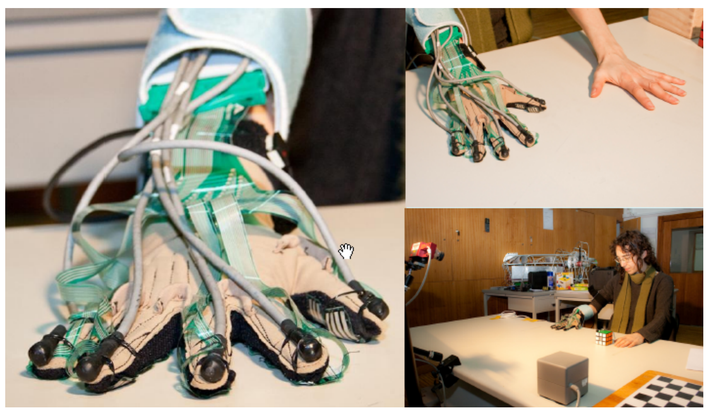

Figure 1: *Multi-sensor recording setup: 6-DOF Polhemus sensors on each finger-tip and the hand base, Cyberglove, and Tekscan Grip tactile-sensor.*

1. Introduction

The capacity of the human hand to grasp and manipulate objects, known or unknown and of widely different sizes, shapes and materials is unmatched. Despite recent progress in the design and control of multi-finger robot hands, their use in service-robotics is still limited by the complexity of finding and applying grasp movements for any given task. So far, theoretical approaches to the grasping problem have proven difficult in practice. The HANDLE project attempts to **record human manipulation** tasks with a unique multi-sensor experiment setup. Later analysis steps, of which **sequence segmentation** and corresponding **annotation** are the first, are supposed to improve our understanding of motion sequences and their transfer to robotic hands.

2. Multi-sensor Experiment Setup

Precise recording of the human hand during grasp and manipulation tasks is particularly challenging, because external sensors suffer from occlusion problems, while sensors mounted onto the hand must be very small and flexible to avoid restraining the finger movements.
For HANDLE, a complex multi-sensor setup was designed which includes stereo cameras and magnetic or optical trackers as the external sensors:

- **stereo cameras**, used both for an overall view of the scene and also to gather depth-maps for hand tracking and object recognition (Videre systems STDC)
- **magnetic tracker**, up to six sensors, each providing absolute and accurate 6D position and orientation data (Polhemus [4])
- **data-glove** for the recording of hand posture and finger positions (Cyberglove [5])

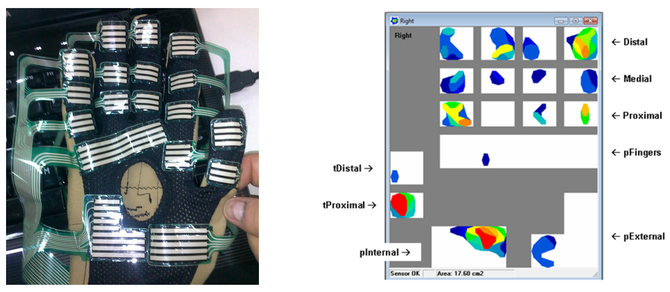

Figure 2: *The Tekscan Grip system mounted on a right-handed Cyberglove, and the visualization software.*

3. Tactile sensing

To record the contact forces applied during the experiments, a Tekscan Grip system [6] has been stitched onto a standard Cyberglove [5]. The Tekscan Grip system consists of a set of matrix sensor elements using force-sensitive resistive material and connected by a flexible circuit board. The layout of the sensors is shaped to match the human hand, with three groups of sensors (distal, medial, proximal) on each finger, two groups on the thumb, and three groups on the palm of the hand.
Despite the extra weight and some restrictions on finger positions caused by the stiffness of the glove and sensors, many manipulation tasks can be performed well.

4. Instrumented objects

Custom instrumented sensing objects are another keystone of our experiment setup. The sensors in the object measure orientation, accelerations, and grasp forces to complement the data gathered from the glove and hand itself.
The first instrumented sensing object is a custom-built cube equipped with tactile sensors (Handle D6, 2010). Every face of the cube consists of a small circuit board carrying an array of 3x3 resistive force sensors and one 3-axis accelerometer. Six boards are interconnected, with a CAN-bus interface to the host computer. The faces have been colored identically to the original cube, see figure 3.

5. Experiments

We are currently recording a number of typical tasks involving everyday objects in order to compile the database of basic human manipulation strategies. In this section, we present initial experimental results.
As a typical example of our experiments, the video images shown in figure 4 correspond to key phases of a simple manipulation task. The experimenter was asked to pick up the instrumented Rubik cube, using a precision grasp with the thumb and index-finger only, — but intentionally off-center, resulting in significant grasp forces. Next, the cube was allowed to slide down a bit, and then set down.

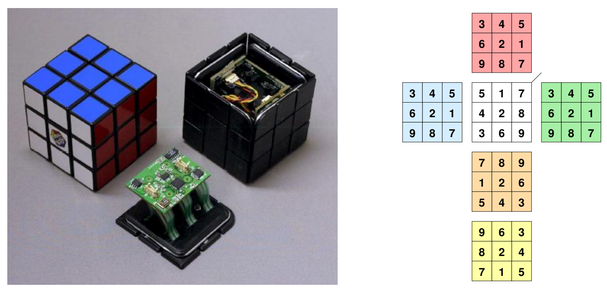

Figure 3: *Picture of an original and the instrumented Rubik cube, and visualization of the force sensors.*

The second and third rows in figure 4 show the visualized grasp-forces, measured by the TekScan Grip and the Rubik cube. Initially, the cube rests on the green face, resulting in sensor response on that face. Then, the cube is grasped with the index finger at cell W1 and the thumb on cell Y1. The sliding phase starts near $t = 8.6$ seconds. Finally, the cube is set down on its orange face.
Our automatic segmentation is based on the gradients of the accumulated forces as recorded by the sensors, see figure 5. For the TekScan, only the distal phalanges of the thumb and index finger are shown. The traces show that the thumb is first to make contact with the object, closely followed by the index finger at t =5.0 seconds. The forces increase rapidly and force-closure makes it possible to lift the cube. Once in mid-air, the forces are slightly reduced and remain roughly constant. At $t = 8.6$ seconds, the test subject releases the grip force for a moment, and the cube rotates under the influence of gravity. At $t = 11$ seconds, the cube is put on the table again.

References

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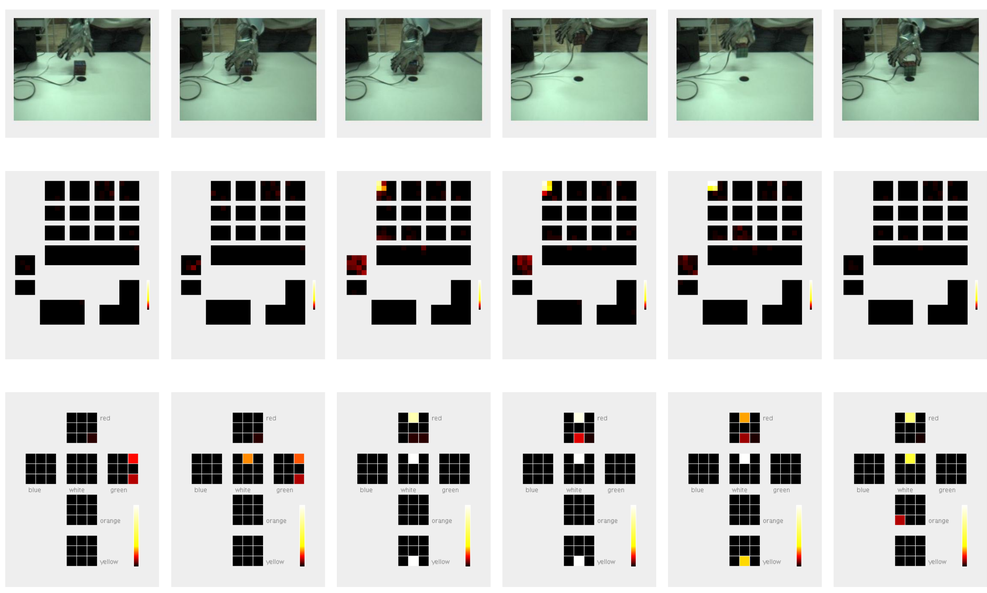

Figure 4: *Picking up the Rubik cube: The photos in the upper row show the left-image of the recorded stereo-image pairs during the experiment, with the corresponding force-signatures from the Tekscan glove in the middle and the forces from the Rubik cube in the bottom row: (a) approach (b) first contact (intentionally off-center of the object) (c) lift-off, precision grasp with thumb and index finger only (d) reducing the finger forces to let the cube slide down (e) finger forces remain low, because the cube is now stabilized by gravity, (f) setting the cube on the table. Compare the figure on the right for a plot of the recorded finger forces vs. time.*

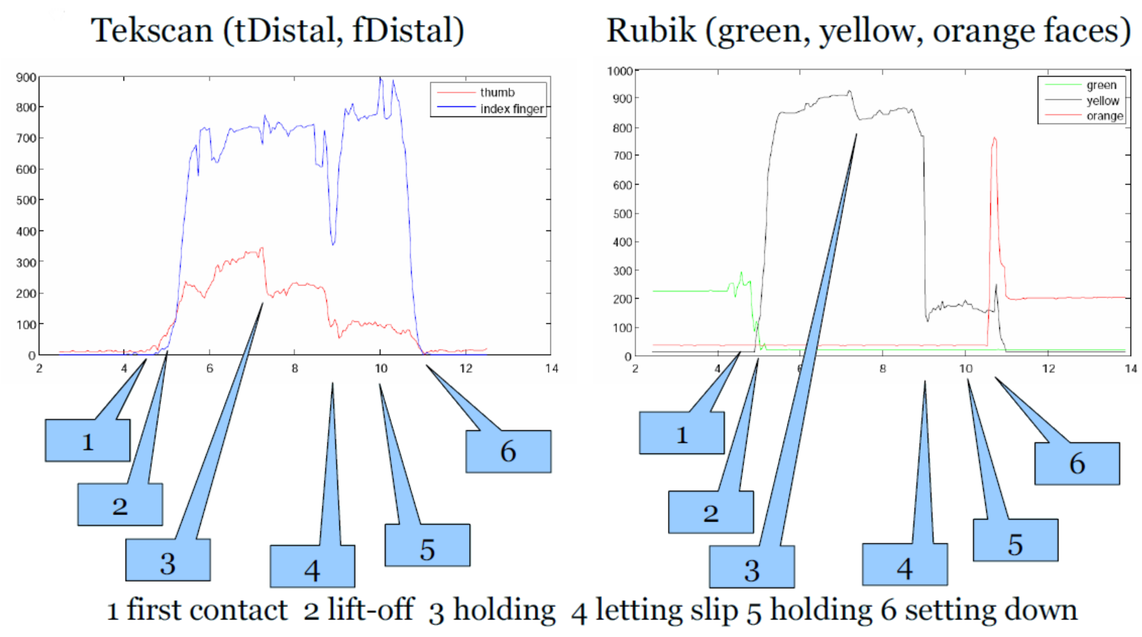

Figure 5: *Plots showing accumulated grasp-forces recorded by the TekScan system on the index-finger and thumb (left), and corresponding forces recorded by the instrumented Rubik cube sensor (right). The **different phases** of the manipulation task are clearly visible: initial approach, lift-off at 5 sec, stabilization, swing at 8.6 sec, stabilization, drop-off at 11 sec. Forces are not scaled and correspond to the raw data values. Note that the experimenter intuitively reduces the thumb forces once the Rubik cube is pointed downwards and kept stable by gravity.*