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1 Teaching a robot to cook

Imagine that we want to build a robot that can be installed in a household kitchen to cook meals from raw ingredients and we are not constrained by cost. In order to prepare the meal we require a means of manipulating ingredients and tools. Humans use their hands for this. You could argue that a special purpose manipulator should be built for the task but consider the following argument: The space of possible meals that a robot can prepare is defined by the manipulator it uses. If we want to span the space of all meals humans cook, the manipulator design approaches the human hand. The number of digits on your manipulator may not need to be exactly five, but for simplicity, lets assume we will use a biomimetic robotic hand with five digits. We can allow the manipulator to achieve an arbitrary pose in the kitchen by means of a robotic arm with the necessary degrees of freedom and a gantry mechanism if required.

At this point, we have introduced nothing that is not already commercially available. There are a number of appropriate robotic arms (Universal Robots' UR5 or Kuka's IIWA) and biomimetic robotic hands (Shadow's Shadow Hand). So why does such a robot not exist? The problem lies in providing the appropriate commands to the manipulator. I will call the process of sending commands to a humanoid manipulator to perform an arbitrary task accomplishable by humans dexterous manipulation.

Definition 1.1 (Dexterous Manipulation)**.** Sending commands to a humanoid manipulator to perform an arbitrary task accomplishable by humans.

Dexterous manipulation, at the time of writing, is an unsolved problem in robotics. For example, it is not known how to produce a set of commands that will allow a robotic hand to peel an onion, julienne carrots, or roll sushi. To determine how we can send these commands, let us consider how humans perform such a task.

Humans are able to perform the above tasks because of our sense of touch. You may argue that vision is of primary importance but consider this: Many skilled tasks can be performed without vision, such as cutting onions, peeling carrots, tying knots etc. In fact, during such tasks most of the object is occluded by the hands, even when vision is used. Human depth perception is actually remarkably bad without feedback from touch, as can be demonstrated by experiments in VR. An argument often posed to me against touch is the following: it is possible to teleoperate a robot to perform

complicated tasks such as surgery and the robot does not require a sense of touch. However, the process in the surgeons brain by which the commands to the joystick are being produced are using touch sensation of the joystick as an input. I would imagine the surgeon would be hesitant to perform such a surgery with aneasthetized hands.

If we believe that touch, rather than traditional vision, is the appropriate sensory modality for manipulation, how do we use it to produce the necessary joint commands for dexterous manipulation?

2 Human Touch

There are a number of neuron types collectively called Low Threshold Mechanoreceptors or LTMRs. They are subdivided in to 7 categories:

1. Slow Activation I (SAI-LTMR): Indentation
2. Slow Activation II (SAII-LTMR): Stretch
3. Rapid Activation I (RAI-LTMR): Skin movement, hair follicle deflection
4. Rapid Activation II (RAII-LTMR): Vibration
5. A-delta (Ad-LTMR): Hair follicle deflection
6. C (C-LTMR): Hair follicle deflection
7. High Threshold Mechanoreceptors (HTMRs): Noxious mechanical

3 Algorithm