Modelling Grip Point Selection in Human Precision Grip

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Humans are capable of extremely fine hand and finger movements to interact with objects. Vision plays a fundamental role in the planning and execution of these motor actions. Precision grip (Forssberg et al., 1991) is one such fine action, in which a relatively small object is held between thumb and index finger. How humans select the thumb and index contact points on an object during precision grip is unclear (Kleinholdermann et al., 2013).

In robotics, grasp point section is typically solved by searching for contact points that satisfy certain heuristics, the most important of which is *force closure* (Nguyen, 1986). A force closure grip guarantees that arbitrary forces and moments may be applied to an object by pressing the fingertips together. Another common heuristic is the minimization of net torque acting on the object (Mangialardi et al., 1996). There is evidence that humans may combine such heuristics with constraints arising from the shape and degrees of freedom of the arm and hand to select where to grip 2D objects (Kleinholdermann et al., 2013).

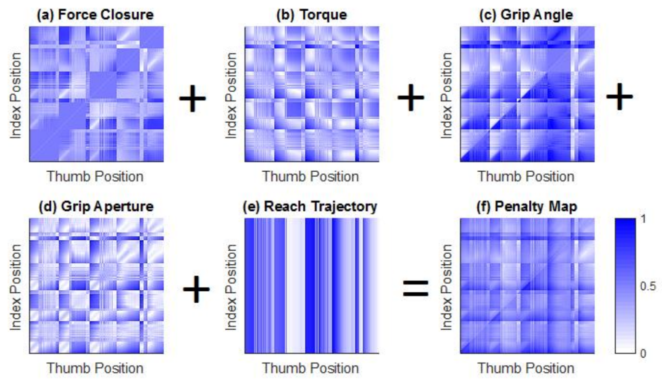

Figure 1. Penalty maps for thumb and index grip locations. (a-e) Penalty maps for individual heuristics. (f) Final penalty map obtained as linear sum of the individual heuristics. In all cases low color saturation represents regions of low penalty (i.e. good grip locations), whereas high color saturation represents regions of high penalty (i.e. bad grip locations).

Here we take a similar approach to predict grasp locations on 3D objects, comparing against recordings of grasps applied to real objects made of wood. The task of selecting contact points that will lead to a successful grip may be accomplished by first constructing a penalty function that combines multiple constraints derived from the object geometry and properties of the arm and hand. To grip a given object, the combination of thumb and finger contact points that minimizes this penalty function is selected. We investigate plausible heuristics that the visuomotor system may employ to construct such a penalty function. In addition to force closure and torque minimization, we include heuristics based on minimizing grip apertures and hand rotations away from natural hand posture, and on minimizing the length of the reach trajectory.

Figure 1f shows a penalty map computed for the object in Figure 2a. This penalty map is the linear sum of penalty functions that punish deviations from force closure (fig.1a), minimum torque (fig.1b), minimum unnatural grip angles (fig.1c) and grip apertures (fig.1d), and minimum reach trajectory (fig.1e). Figure 2(a) shows grip points selected by human subjects on one 3D object. Figure 2(b) shows the same grip selections overlaid on the penalty map computed for the same object. A majority of the human grip locations selected do indeed align with minima of the map. Optimal grip locations selected from the minima of the penalty map (fig.3a) cover the same area (fig.3b) of the object as the human grip points.

Thus, this approach produces a promising model of human grip point selection which takes into account object geometry and the physical constraints of the human arm and hand. This model produces testable hypotheses about which computations the visual and motor planning systems perform to execute reaching and grasping hand movements. The model can be tested against more general approaches such as searching for the grip point configuration that minimizes the forces necessary for static equilibrium ($\sum F=0$; $\sum M=0$, Abel et al., 1985), and against novel robotic architectures based on closed-loop training of deep convolutional neural nets (Levine et al., 2016). Determining whether and how the brain computes and minimizes these penalty functions directly from the visual input will likely include computational steps to estimate both the shape and the material properties of the objects to be gripped. Thus, we compare the model against human grasp locations as object shape and material are varied. Understanding how humans select grip points from the visual input may provide key insights into the perception and action loop, with real world applications in both humanoid robotics and upper limb prosthetics.

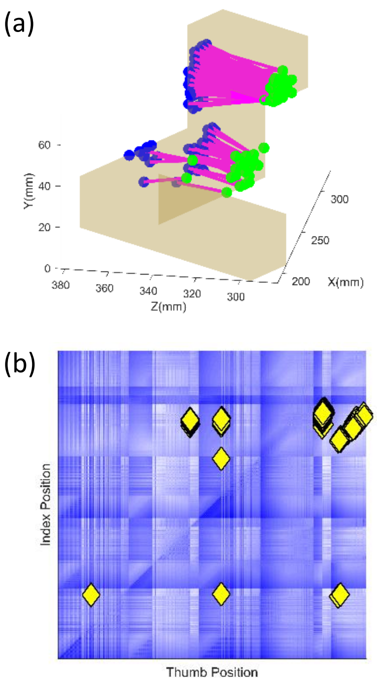

Figure 2. Human grip point selection. (a) Thumb (green dots) and index (blue dots) contact points selected by human subjects when gripping a 3D object. For each individual grip, thumb and index fingers are connected by magenta vectors. (b) The same grip point couples from (a) projected as yellow diamonds onto the penalty map computed for the specific 3D object shown.

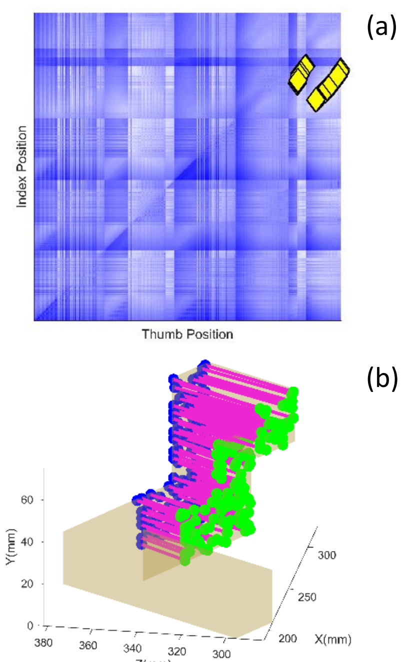

Figure 3. Grip locations selected by the model. (a) Grip point couples (yellow diamonds) selected from the two deepest local minima of the penalty map. (b) Same thumb (green dots) and index (blue dots) grip point couples projected onto the 3D object. For each individual grip, thumb and index fingers are connected by magenta vectors.