16-848 Reference List for April 10, 2024

We began by talking about contact models – especially hard finger and soft finger contact with Coulomb friction. These are very popular in the grasp analysis literature, but they are point contact models – they assume that the robot makes contact with an object at a single point.

Not only do we know that for human hands contact often occurs over a substantial area, but also working with single point contact can create discontinuities in predicted contact force as a contact slides across an edge, when in reality, that force may vary fairly smoothly.

Area contact can be simulated fairly well with finite element techniques. However, these techniques are still slow and are not widely used in grasp optimization and planning. Multiple area-based contact models exist however. We took a quick look at one of these – hydroelastic contact -- described in this blog:
https://medium.com/toyotaresearch/rethinking-contact-simulation-for-robot-manipulation-434a56b5ec88

We then went into some of the math for grasping, including the Grasp matrix and the Jacobian. I used the second half of this paper for reference. This paper also contains a quality metric – one that takes into account the kinematic structure of a robot hand (in this case the human hand) and a specific set of tasks that the hand is required to accomplish.

Li, Ying, Jiaxin L. Fu, and Nancy S. Pollard. "Data-driven grasp synthesis using shape matching and task-based pruning." *IEEE Transactions on visualization and computer graphics* 13, no. 4 (2007): 732-747. https://ieeexplore.ieee.org/abstract/document/4293017

You can find a very clear discussion of key terms such as Force Closure, Form Closure, Grasp Matrix, and other fundamental properties in this entry from the Springer Handbook of Robotics:

Prattichizzo, Domenico, and Jeffrey C. Trinkle. "Grasping." *Springer handbook of robotics* (2016): 955-988. https://link.springer.com/chapter/10.1007/978-3-319-32552-1_38

We then talked a little bit more about what makes a grasp a good one – many things go into it!

One of the most well-cited and most-used quality metrics is the Ferrari and Canny grasp quality metric (wrench space ball).

Ferrari, Carlo, and John Canny. "Planning optimal grasps." In *Robotics and Automation, 1992. Proceedings., 1992 IEEE International Conference on*, pp. 2290-2295. IEEE, 1992.
https://people.eecs.berkeley.edu/~jfc/papers/92/FCicra92.pdf

The following paper describes seven grasp quality metrics that have appeared in the literature over the years. The authors carried out a large number of experiments with real three-fingered robot hands to test the predictive value of each of them.

Rubert, Carlos, Daniel Kappler, Jeannette Bohg, and Antonio Morales. "Predicting grasp success in the real world-A study of quality metrics and human assessment." Robotics and Autonomous Systems 121 (2019): 103274.
https://www.sciencedirect.com/science/article/abs/pii/S0921889019300247

This paper used a physics simulation to evaluate grasp quality:

Kim, Junggon, Kunihiro Iwamoto, James J. Kuffner, Yasuhiro Ota, and Nancy S. Pollard. "Physically based grasp quality evaluation under pose uncertainty." *IEEE Transactions on Robotics* 29, no. 6 (2013): 1424-1439.
http://www.cs.cmu.edu/afs/cs/Web/People/junggon/publications/2013_IEEE_TRO_evalgrasp.pdf

.. and this one uses a weighted A* algorithm to identify globally optimal grasps of objects from their geometric meshes (using the wrench space ball grasp quality metric):

Hang, Kaiyu, Johannes A. Stork, Nancy S. Pollard, and Danica Kragic. "A Framework for Optimal Grasp Contact Planning." *IEEE Robotics and Automation Letters* 2, no. 2 (2017): 704-711. http://www.csc.kth.se/~kaiyuh/pdfs/hang2017a.pdf

We quickly looked at the video from this work as a contrasting point of view. In this line of research, quality of a grasp is estimated from the image alone, based on large amounts of data gained from experience.

Levine, Sergey, Peter Pastor, Alex Krizhevsky, Julian Ibarz, and Deirdre Quillen. "Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection." The International Journal of Robotics Research 37, no. 4-5 (2018): 421-436.
https://journals.sagepub.com/doi/full/10.1177/0278364917710318?casa_token=SDSRQ32qfM8AAAAA%3AkqNr2-QBXTlZNOr3QIegTAhPvUDLP8pNwH6cv3CQgYbfg4fCQQilzarxe4-znb8flf6UBzLhCxhgfg

https://kargarisaac.medium.com/paper-review-learning-hand-eye-coordination-for-robotic-grasping-with-large-scale-data-collection-a858d69d83b8

Here are some other works along similar lines:
https://www.youtube.com/watch?v=oSqHc0nLkm8
https://deepmind.google/discover/blog/rt-2-new-model-translates-vision-and-language-into-action/