6.4212 Project Proposal

# Apple Picking Robot

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**Motivation**

Many attempts have been made to build robots capable of performing agricultural harvesting tasks, but none come close to matching human capabilities across different crop families. Agriculture presents a challenging environment for robots to operate in, with complicated obstacles. Robots must navigate uneven terrain and pass through foliage without damaging crops, though some allowable deformation of foliage is often required to complete a particular harvesting task. The task itself may require fine manipulation of an object that is easily damaged if applied forces are too great. This problem presents challenges across perception, motion planning and control.

**Project**

This project will focus on the sub-problem of motion planning in the context of apple picking. Concretely, given a model of an apple tree, and a rigidly mounted Kuka iiwa next to the tree, the completed system should be able to perform perform the necessary movements to pluck an apple off the tree. This will involve planning a path through foliage and branches, which may require deformation of some branches to be completed successfully, followed by trajectory execution that limits the contact forces applied to the tree and apple.

The tree will be modelled as randomly generated "tree" of rigid links connected by compliant spherical joints. Leaves and apples will be modelled as similar rigid links. Different branches will have different joint stiffness - some will tolerate deformation more than others, and some will be too stiff for the iiwa to deform. Progress on the simulated tree is shown in Fig 1.

**Motion Planning**

A two-pass approach to motion planning will be explored. In the first pass, a trajectory will be generated that ignores collisions with more compliant branches and foliage, using some sensible threshold for compliance. In the second pass, for each compliant branch that was previously ignored, a modification will be made to the initial trajectory that involves "nudging" that branch out of the way.

Simplifying assumptions will be made to make this problem more tractable, but these can be relaxed depending on project progress. For example, as each branch is deformed, the overall tree will deform, which may introduce new collisions into the planned path, and move the target apple away from its expected location. One solution would be to perform repeated iterations of motion planning during execution. This approach is expected to be reasonably computationally efficient, unlike strategies that require detailed modelling of deformation during the motion planning stage (see Prior Work below.)

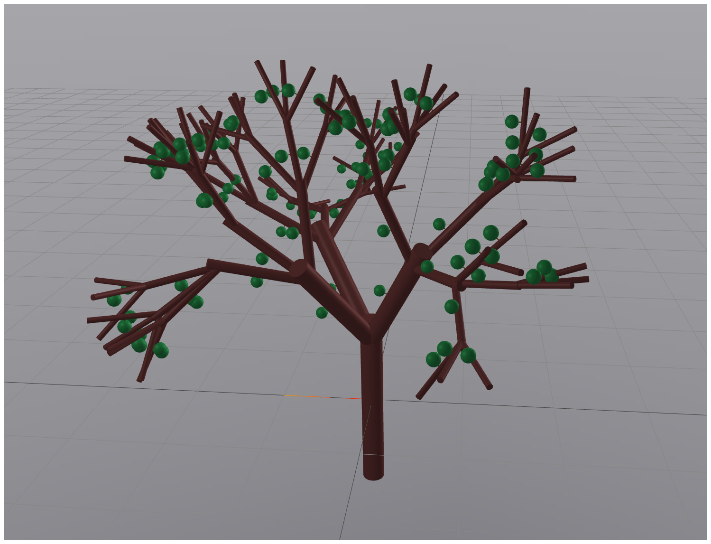

Figure 1: Procedurally generated apple tree in Drake

**Control**

The project will use simple position-based control to execute the planned trajectory. Depending on progress, there is much follow up work to explore here. For example, instead of the two-pass motion planning approach, we could define a straight-line Cartesian trajectory to the target apple, and then use a control strategy which attempts to explicitly regulate contact forces across the iiwa's surface (replicating the work of Jain and Kemp [2]). This does not require any prediction of where those contact forces might arise - i.e. no prior knowledge of the position or compliance of individual branches. The performance of this approach could be compared with the two-pass motion planning position control approach from above.

The two approaches could combined: use the two-pass motion planning strategy to generate a trajectory that a) avoids overly stiff tree branches, and b) includes segments that explicitly deform particular branches in a desired direction. Then, during trajectory execution, use contact-force-regulating-control to ensure actual contact forces remain below acceptable limits.

**Picking**

The 'pick' action will require a torque to be applied along an axis aligned with the apple's stalk. Force applied to the apple's surface should remain below some threshold. This project aims to use the SCHUNK WSG gripper to perform the picking action. The gripper trajectory required for the pick will be included as part of motion planning.

**Perception**

The perception problem will be ignored for in this project. It will be assumed that the precise location and compliance of each branch is always known by the motion planner. Again, depending on project progress, this assumption could be relaxed. Deep learning could be applied to identify individual branches and estimate their compliance, as well as the pose of apples from RGB-D data. A resulting complexity would be the development of occlusion as the trajectory was executed - previously occluded branches would be uncovered, which could require updates to the remaining trajectory.

**Prior Work**

The 2022 review paper of harvesting robots from Zhou et al.[5] examines three categories of work: overall system design (e.g. choice of mobile base, quantity and design of manipulators, fruit storage strategy), perception, and fruit detachment method. Only passing mention is given to the problem of motion planning through branches and foliage, with work focusing on optimizing mechanical design of end-effectors to minimize collisions[4].

More relevant prior work is found around manipulation through deformable clutter, like that of Jain [2]. Jain's approach to contact-aware control is particularly relevant due its reliance on contact force information rather than an accurate map of the environment. An (admittedly ambitious) stretch goal of this project is to replicate Jain's control strategy. Other approaches involve generating computationally expensive models of how the environment will deform [1], [3] and including deformation in subsequent trajectory optimization. These approaches are likely not extensible to real-world applications, due to the difficulty in accurately modelling a complex, heavily occluded object like a tree.

**Planned Timeline**

| Date | Milestone | Notes |
|---|---|---|
| Nov 10th | Complete tree model | Including plausible mass/stiffness parameters |
| Nov 17th | Straight line trajectory | Include iiwa in environment, identify target apple and execute straight line motion plan, disabling collisions with branches |
| Nov 24th | Pluck action | Augment straight line trajectory with motion to pluck apple - approach pose, grasp pose, and deformation needed to 'break' the joint. Simulate detachment of apple from tree. |
| Dec 1 | Branch deformation | Re-enable branch collisions. Augment trajectory with segments to deform invidual branches as needed. |
| - | Stretch Goals | Explore contact-force-aware control |

# References


[1] Barbara Frank et al. "Using Gaussian Process Regression for Efficient Motion Planning in Environments with Deformable Objects". In: *Proceedings of the 9th AAAI Conference on Automated Action Planning for Autonomous Mobile Robots*. AAAIWS'11-09. AAAI Press, 2011, pp. 2–7.

[2] Advait Jain et al. "Reaching in clutter with whole-arm tactile sensing". In: *The International Journal of Robotics Research* 32.4 (2013), pp. 458–482. DOI: 10.1177/0278364912471865. eprint: https://doi.org/10.1177/0278364912471865. URL: https://doi.org/10.1177/0278364912471865.

[3] Sachin Patil, Jur van den Berg, and Ron Alterovitz. "Motion Planning Under Uncertainty In Highly Deformable Environments". In: June 2011. DOI: 10.15607/RSS.2011.VII.033.

[4] Satoshi YAMAMOTO et al. "Development of a Stationary Robotic Strawberry Harvester with a Picking Mechanism that Approaches the Target Fruit from Below". In: *Japan Agricultural Research Quarterly: JARQ* 48.3 (2014), pp. 261–269. DOI: 10.6090/jarq.48.261.

[5] Hongyu Zhou et al. "Intelligent robots for fruit harvesting: recent developments and future challenges". In: *Precision Agriculture* 23.5 (Oct. 2022), pp. 1856–1907. ISSN: 1573-1618. DOI: 10.1007/s11119-022-09913-3. URL: https://doi.org/10.1007/s11119-022-09913-3.