Pick and Place Simulation of Parallel End Effector Grasping Fruits

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***Abstract*— This project aims to develop a simulated model of a parallel end effector grasping a piece of fruit. This model should allow for the analysis of how various applied forces affect the deformation of the fruit. The model should simulate the contact forces between the gripper and the fruit surface in order to predict the "squeezing" of the fruit.**

I. INTRODUCTION

The usage of robotics to automate the agricultural industry is a developing field. A key element of automating crop harvesting is the picking up and placing of various crops. This is a complex task to automate, as the amount of force applied to the crop has to be precise enough to grasp the crop without damaging it [1]. In order to test various forces applied to various crops, a simulation model is needed. This project shall develop a simulation that can be used to test different forces applied to a fruit model.

II. BACKGROUND

Key research exists on the modeling of parallel end effectors. A study published in the *Mechanism and Machine Theory* journal details the development and modeling of a compliant gripper with parallel movement jaws [2]. The researchers successfully developed a compliant gripper that uses a parallel movement mechanism combined with a bistable mechanism to enhance grip stability and energy efficiency. The bistable mechanism allows the gripper to be stable in both its open and closed jaw states. This mechanism allows the gripper to maintain its hold without continuous energy input. The study also includes mathematical models of gripper behavior which would be useful in simulation development.

Research in the *Information Processing in Agriculture* journal has even applied a robotic end effector in the harvesting of a common fruit, the kiwi [1]. Unlike the previous parallel gripper, this study used bionic fingers to grasp and pick the kiwi in order to minimize damage. The study determined the static friction coefficient between the kiwi and the rubber gripper and the separate force needed to pluck the kiwi from its stem. The procedures used to calculate both of these values will be applicable in creating a simulation for the parallel end effector. Similarly, research in the *Frontier Robotics and AI* journal has also applied robotic end effectors in the harvesting of fruit [3]. This research highlights the struggles of developing a gripper that accurately picks fruit without damage. It ultimately proposes the design of a pneumatic soft robotic structure to grasp the fruit.

III. PROJECT OBJECTIVE

The primary objective of this project is to develop a simulated model of the robotic harvesting of a piece of fruit. This model should be composed of a parallel end effector which closes in on the piece of fruit in a linear motion. This model should accurately simulate the contact forces between the robot gripper and the fruit. It should also predict the fruit deformation caused by applied forces. This simulation shall be developed in a 3 stage process. The first stage will create a 2D simplified model of a gripper closing on a circular fruit model. The second stage will further this model by adding complexities to both the gripper and fruit geometries. The final stage will expand this simulation into a 3D model. The final simulation should facilitate the analysis of forces from a soft gripper geometry applied to a fruit. This will help prevent the crushing and dropping of fruits in real world robotic harvesting applications, which will improve the quality and efficiency of harvesting.

IV. IMPLEMENTATION

Under the constraint of time, this project will focus on the successful implementation of this project through stages of increasing complexity. Stage two of the project will be the main objective for analysis of force distributions from gripper geometries. Further analysis may be done within 3D situations for varying numbers of gripper prongs and positioning of the fruit specimens.

First Stage: 2D Gripper

Within this project, the first milestone would be to create a simulation for a 2D robotic gripper for proof of concept, with the following simplifications below:

- Gripper within 2D plane
- Gripper prongs are treated as rods
- Fruit modeled as a block of constant width

These simplifications are seen below in figure 1. Actuation of the gripper would be represented with the deformation of the rod between the two gripper prongs of a constant rate of deformation between different simulation iterations

With the following simplifications, the main outcome of this stage of the project will be the functional implementation of an algorithm to represent contact between the gripper and fruit. This will be done with investigation into algorithms such as Incremental Potential Contact model and the Implicit Contact Model. This stage of the project will begin with an implementation of the Implicit Contact model first, where the felt normal force and friction would be derived from the gradient of energy from contact points. As this proposed model for friction was made primarily for applications with

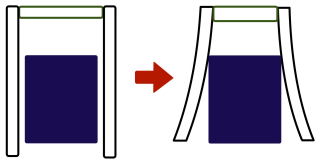

Fig. 1: Schematic of simulation within the initial stages of the project

rods, the source code would likely be readily applicable for this stage, but further modifications will have to be made to include simulations with 2D and 3D meshes [4]. Time permitting, implementation of the Incremental Potential Contact model could also be done to obtain comparisons/validations of future simulations for the project [5].

A simplified model of the contact between the fruit between the gripper will also be used within the energy calculations. A proportional linear relation between the the deformation of the fruit surface will initially be used when obtaining contact forces between the surfaces. To simulate contact with the fruit, it also may be acceptable to first assume rigidity of the fruit's body, as the material of the robotic gripper would practically be significantly more prone to deformation.

Second Stage: Gripper Geometry

Building off the initial stage of the project, the second stage of the project would introduce complexity into geometry used within the gripper and fruit specimens. The following lists simplifications and adjustments to the physical simulation:

- Gripper within 2D plane
- Gripper prongs with varying patterns of geometry
- Introduction of curvature into fruit surface

Figure 2 below represents the changes to the simulation setup from the first iteration. Actuation of the gripper would still be represented with the deformation of the rod between the two gripper prongs of a constant rate of deformation.

From this stage of the project, the main objective is the accurate representation of the contact force with varying geometry from the fruit and end effectors. Thus, the same contact algorithms from the first stage will be implemented, but the prongs of the gripper will be treated as 2D shells, from the cross-sectional area of the gripper. If forming gripper geometry with 2D meshes becomes too complex for this project, a simplified gripper represented with a curved rod could also be used to complete this stage of the project. Similarly, the fruit geometry will be varied to introduce varying degrees of curvature in the surface contacts. The same relation between contact force and deformation of the fruit will be utilized, but more complex versions such as those from may be implemented time permitting [6].

Reach Stage: 3D Gripper

This stage includes reach goals of this project to achieve if time allows. More complex forms would be used to represent

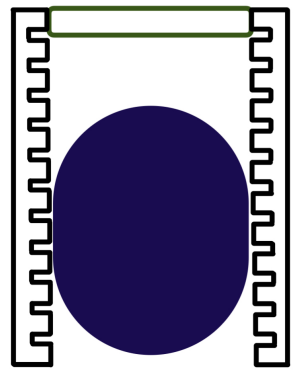

Fig. 2: Schematic of more comprehensive version of the initial stage

contact force from gripping the fruit, and a 3D representation would potentially be used for this stage. Below lists reach goals for the current project:

- Gripper and fruit represented within 3D space
- Test implementation of varying number of gripper prongs
- Gripper prongs with varying patterns of geometry
- Complex fruit geometry and contact force representation

The main objective of this project is the representation and analysis of the pick-and-place action within agricultural applications, so this stage would practically be representative of a vertical action of the manipulator to move fruits and other crops. As the fruit specimen wouldn't be perfectly symmetric and may also be off center within grippers, a gripper in 3D would be more representative of practical pick and place situations within agricultural robotics.

To build off this project, future iterations can include simulations of movement of the manipulator in different directions during and after gripping the fruit, to analyze how the gripping force from the end effector may have to be adjusted to account for inertial effects from the movement. While not within the scope of the project, one may also further investigate the control required for the movement of the end effector when moving or harvesting fruits and vegetables.

V. ANTICIPATED CHALLENGES

Within this project, one of the challenges will be accurately representing contact between complex surface geometries. Between the two algorithms under consideration for simulating surface contact, there exists a trade-off between convergence time and penetration errors. When implementing with complex shapes for the grippers, formation of the mesh would need more nodes. This then calls for increased computation time for the simulation, and it would potentially need more analysis to find a proper resolution for the mesh necessary to gain representative results without excessive resolution in the grippers.

Accurate depiction of the behavior of the surface of fruits and crops would also be an important consideration within this project. As contact force and friction are directly related through the usage of coulomb friction calculations, simulated force distributions would vary with models used to represent the surfaces of crops. The gripper also may be unable to pick up the fruit without damaging the surface depending on the constraints imposed by the model for the fruit's surface.

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