Bite Acquisition of Soft Food Items via Reconfiguration

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***Abstract*— This paper focuses on bite acquisition of soft food items by reconfiguring them using a set of pre-acquisition manipulation actions before bite acquisition. A key challenge in acquiring soft food items is that a manipulation action such as vertical skewering often fails due to their unique physical properties. Our key insight is that in such cases, using pre-acquisition actions to reconfigure the food items may help in bite acquisition. Here, we develop a framework using which a robot can search in the joint space of acquisition actions and the pre-acquisition manipulation actions to maximize the success rate of bite acquisition. We showcase this using robot experiments to acquire leaves in a salad bowl.**

I. Introduction

Feeding is an important activity of daily living (ADL) and losing the ability to self-feed can be devastating [1] as is the case for 1.0 million people with mobility impairments according to a survey in 2010 [2]. Robotic systems can potentially help these people gain control and independence [3]. A robot-assisted feeding system needs to acquire a bite and feed a person. Based on a taxonomy in our previous work [4], we developed robot manipulation strategies for acquiring a variety of food items [5], [6]. However, despite these recent successes, bite acquisition of soft and slippery food items still remains challenging because a vertical skewering action often fails due to the high deformability and slipperiness of these food items. In this work, we focus on the problem of bite acquisition for soft food items.

Previously [4], we found that humans sometimes reconfigure (push, flip) soft, slippery, round, and continuous or granular food items to stabilize or clump them before acquisition. A dataset [6] collected with real-world robot bite acquisition trials corroborated that food position on a plate and its surrounding environment indeed affects bite acquisition success rates. For example, a sliced banana near the edge of a plate (wall) or a stack of lettuce has higher probability of successful acquisition than when they are isolated. Thus, pushing these items to the edge to provide support or to clump them could be essential. Unlike our previous work which assumes that food items are in their best possible configurations and focuses only on the immediate bite acquisition actions, this work aims to develop pre-acquisition manipulation strategies for reconfiguring these food items in a plate or bowl before bite acquisition.

Our key insight is that a robot can search in the joint space of acquisition actions and the pre-acquisition manipulation actions to maximize the success rate of bite acquisition.

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Fig. 1: A JACO robotic arm skewering food items in different configurations in a plate using a *Vertical* (left), *Tilted-Vertical* (middle), and a Tilted-Angled (right) skewering acquisition actions.

Given a target item on a plate, the robot uses a *task-driven perception module* that not only segments each food item but also predicts the success rate of an acquisition action in the current configuration. From the data, we also build a *configuration generator* which puts the target item in various potential candidate configurations that affects its acquisition success rates. The robot then searches for a sequence of manipulation actions which can reconfigure the target item from its current configuration to one of these candidate configurations that maximizes the bite acquisition success rate.

Based on this insight, we build a set of parametrized skewering and scooping actions for acquisition and propose a model for predicting how soft food items deform and move by pushing reconfiguration actions. Using this set of actions and the proposed model, we build a closed-loop perception-planning-execution framework that searches for the best combination of reconfiguration and acquisition actions. We showcase the system using a robot performing a simple combination of pushing and acquisition action on lettuce.

We make the following contributions:

- Parameterized skewering and scooping actions for soft food items with data-driven parameters
- A model to predict how various soft food items deform by pushing actions, e.g. mashed potato or salad leaves
- A framework which utilizes a task-driven perception module to search for a sequence of pre-acquisition and acquisition actions to successfully acquire soft food items on a plate

II. Approach

A. Parametrized manipulation actions

We developed parametrized manipulation actions for skewering as well as scooping. For skewering, we considered three variants (see Figure 1). In *Vertical Skewering*, a robotic arm holding the fork approaches a food item vertically. In *Tilted-Vertical Skewering*, the robotic arm approaches the food item at an angle while keeping the fork tines vertical, especially useful for food items with uneven surfaces and

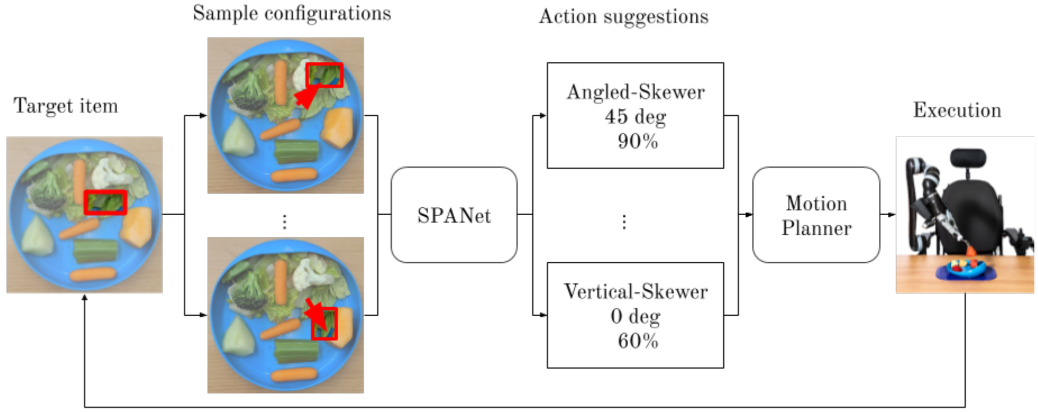

Fig. 2: An overview of our framework.

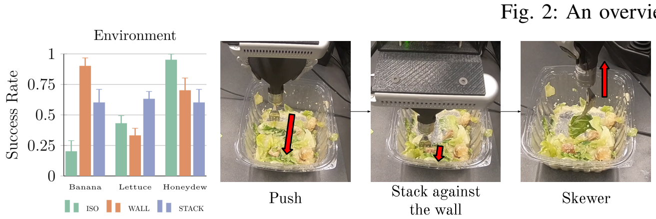

Fig. 3: *Left chart:* Food configuration matters [6]. Acquiring a lettuce is most successful when stacked. *Middle to Right:* Preliminary results with our *Push-then-Skewer* experiment validates that pushing helps in stacking the lettuce thus helping in acquiring it from the salad bowl.

high curvature. In *Titled-Angled Skewering*, the robotic arm also approaches the food item at an angle but while keeping the fork tines almost horizontal, thus leveraging gravity to increase friction to prevent slippery food items from slipping off. For scooping, we constructed a 2D trajectory with the trajectory height as a function of horizontal position from the edge of the plate as a 3rd-order polynomial using simple boundary conditions - angle and height at the start and end of the trajectory. We considered two variants: *sideways* and *forward* scooping.

B. Prediction model

We developed a model that can predict what manipulate actions to take to reconfigure or reposition a target food item from a current configuration to a goal configuration. For this extended abstract, we developed a simple instantiation of this model using a robotic pushing manipulation action that pushes a target food item from any current configuration to a position near the edge of an extruded plate / bowl. We discretized the pushing action space into eight pushing directions with an interval of $45°$ between two adjacent directions. We used haptic feedback to detect whether the pushing action successfully reconfigured the target food item near a wall. In future, we plan to extend this to a more general data-driven model where, given the images of a target configuration and the current configuration, the model can generate a sequence of actions with directions and forces required to perform the reconfiguration.

C. Framework

Figure 2 shows our framework. Given a target food item (which can come from a user), our *configuration generator* generates candidate configurations that could affect bite acquisition success rates. Our prediction model then predicts the sequence of pre-acquisition actions necessary to reconfigure the food item to each of these candidate configurations. Parallely, our developed SPANet [6] predicts success rates and the corresponding most successful bite acquisition action for each of these candidate configurations. Our framework then chooses the candidate configuration for which the probability of successfully executing the sequence of pre-acquisition actions predicted by our model and the bite acquisition action predicted by SPANet is the highest. This set of actions are then passed to our motion planner for successful bite acquisition.

III. Preliminary Results

We performed a preliminary experiment showcasing how food reconfiguration can help in bite acquisition. We used a 6-DoF JACO robotic arm [7] with a wrist-mounted Intel Realsense D415 RGBD camera and holding a fork instrumented with a 6-axis ATI F/T sensor for the experiments. We used leaves in a salad bowl for the experiments. Using the experiments, we found that using a vertical skewering bite acquisition action fails to pick up isolated pieces of lettuce in the bowl but when these lettuce pieces were pushed near the edge of the bowl, they got stacked which helped in acquiring these items using the same vertical skewering action (See Figure 3).

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