Behavior Planning for Pruning with Robotic Arms

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***Abstract*— Pruning is an essential agricultural practice for orchards. Properly pruning an orchard can promote healthier growth and optimize fruit production over the lifespan. Robotic arms are developed as an automatic solution for such a repetitive task, which typically requires seasonal labor with specific skills. While previous works mainly addressed the challenges of perception, we focus on the planning problem in pruning. Specifically, pruning poses a motion planning problem within environments that have complex collision issues. In this work, we formulate the planning problem for a high-dimensional robotic arm in the pruning scenario and discuss the potential solutions. In the experiment, we demonstrate that more comprehensive planning methods can enhance the performance of the robotic arms in the pruning task. As a result, this motivates future research and development on planning in pruning.**

I. Introduction

Pruning is a crucial procedure in cultivation, as it involves the removal of dead and unproductive branches and stubs, creating space for new growth. Manual pruning demands a considerable number of seasonal laborers and involves an extensive workload [1], [2]. However, manual pruning demands a considerable number of seasonal laborers and involves an extensive workload. To address this challenge, automated pruning has been introduced to reduce labor and save time. Currently, the prevalent method in automated pruning mechanization is non-selective pruning, commonly known as hedging. This approach decides which branches to trim solely based on the distance between the tree and the trimming bar [1]. However, this crude method may lead to damage, as productive outlying branches may be inadvertently cut off, thereby reducing the cumulative yield per tree [2]. Selective pruning with high-dimensional robotic arms offers an agile alternative for the pruning task. Thanks to the redundant Degrees of Freedom (DoF), the robotic arms have the flexibility to avoid branches while still reaching the desired goal position effectively [3]. Robotic pruning demands that the robot possesses various skills, including branch detection, cutting sequence decision-making, and collision-free motion planning. These abilities are crucial for ensuring efficient and accurate pruning operations. Previous efforts have primarily focused on tree detection using computer vision technologies, such as 2D image segmentation [3] and depth image mapping [4]. However, the planning problem has often been neglected or simplified, given that the structure of target plants is relatively simple and uniform. Nevertheless, planning for tree pruning requires multiple levels of reasoning to achieve both safety and efficiency in execution. We consider the hierarchical planning task to be a hierarchical behaviour planning problem with several unique challenges specific to the pruning context such as intricate obstacles, changing collision environment, and holistic planning. The paper is intended to support future research in this area, as discussed in the concluding section. It aims to advance the field of agile robotic pruning and contribute to the development of more efficient and effective pruning techniques.

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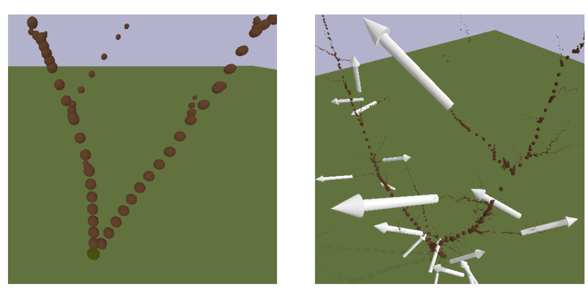
II. Methodology

Pruning planning poses a complex domain characterized by continuous spaces and intricate constraints. Successfully addressing this planning problem entails creating models for the intricate collision environments and implementing a hierarchical system capable of comprehensively considering various levels of constraints.

A. Tree Modeling

The tree is represented using a topological structure consisting of vertices and edges [5], as illustrated in Figure 1a. The cutting points are described by vectors containing position and normal direction information, as depicted in Figure 1b. The sequence of updated tree models can be observed in Figure 2.



(a) (b)

Fig. 1. The visualization showcases the tree represented as a series of spheres, each sphere having radius (thickness) information, effectively depicting the different parts of the tree. Additionally, the cutting vectors are visualized as white arrows, indicating the precise position and orientation where cutting actions will be performed.

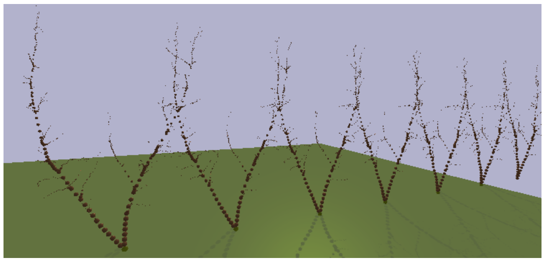


Fig. 2. A tree's collision model undergoes changes after each pruning execution. During the pruning planning, the obstacle structure continuously evolves as the pruning progresses.

B. Hierarchical Behavior Planning

The planning problem for a pruning task is inherently multi-level, and need to be considered comprehensively: (1) In order to finish all the cutting goals, the robot must follow a goal sequence because of the limitation and optimization reasons such as spatial obstructions among branches and collisions between the robot and obstacles. (2) The cutting pose determines the approach and cutting of a branch by specifying the pose (position and orientation) of the end-effector. The visualization of the position and orientation pose samples can be seen in Figure 3. (3) The motion planning can be implemented with well-studied sampling-based method such as Rapidly-exploring Random Tree (RRT) or its variants. The feed-back to the other levels can be sampling time, or the number of samples which contains the information of how difficult the motion in the task can be planned.

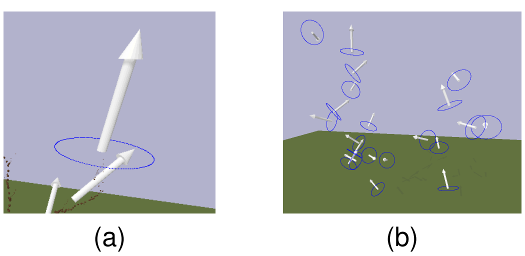


Fig. 3. The cutting position for cutting vectors in the simulation. (a) For each cutting vector we generate cutting poses on a circle around it. Every blue points on the circle represents one possible position of the end-effector. (b) Repeat this process for all the cutting vector.

III. Experiments

In this section, we conduct experiments to demonstrate the importance of agility in robotic pruning. The experiments involve a comparison between the pruning motions commonly used in most systems such as [3], where branches are consistently approached from the same direction (see Figure 4a), and our system, which takes collision into account and plans poses and motions accordingly (see Figure 4b). In Figure 4, the obstacles are visually represented in red to highlight the branches that could potentially obstruct the robot's motions during the pruning process. The simulation results show that the robot can achieve better agility by using a multi-layer of planning method.

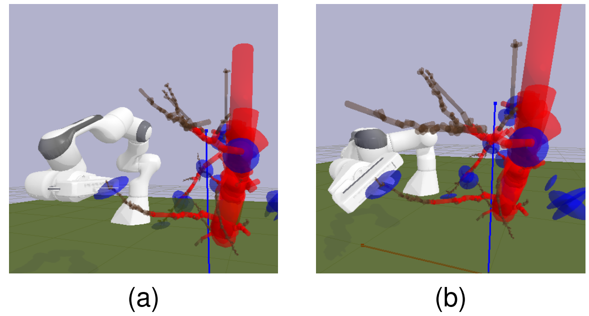


Fig. 4. The cutting poses comparison. The red parts of the tree indicate the obstacles. (a) The traditional cutting strategy always approaches the cutting point with the same direction. (b) The cutting pose with planning. The cutting pose is able to adapt with the direction of the branches and achieves a more flexible cutting pose.

IV. Conclusion

In this paper, we addressed the planning problem associated with pruning tasks utilizing high-dimensional robotic arms. For future research, the focus should be on designing a complete system that encompasses all levels of planning to fully realize the potential of robotic pruning. By integrating comprehensive planning strategies, we can further advance the efficiency and effectiveness of robotic pruning techniques.

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