CONCEPT DESIGN OF A ROBOTIC PRUNER FOR APPLE TREES

Azlan Zahid, Md Sultan Mahmud, Long He, Daeun Choi, Paul Heinemann, James Schupp
The Pennsylvania State University, University Park, PA

WHAT WE LEARNED

- The concept of integrating cartesian and rotational joints robot showed promising results for apple tree pruning
- The path planning algorithms successfully generated the collision-free paths for reaching the targeted pruning points
- Perpendicular to limb cutting posture may not be suitable for all limb angles → alternate cutting postures are suggested
- A camera vision system and pruning cut sequencing are still required to identify and reach the targeted branches automatically

BACKGROUND

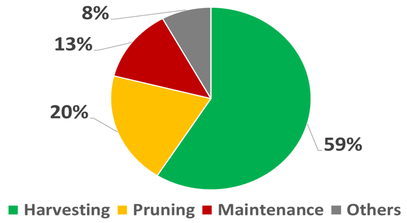

Fig.1. Labor costs for apple production

- Pruning ~ 20% of total labor costs
- ~ 80 to 120 working hours per hectare

Available labor decreasing!

OBJECTIVES

- Design an integrated 6 degrees of freedom (6DoF) pruning robot for apple trees
- Kinematic dexterity, collision-free path planning, and field tests for the reachability of the robotic pruner

ROBOT DEVELOPMENT

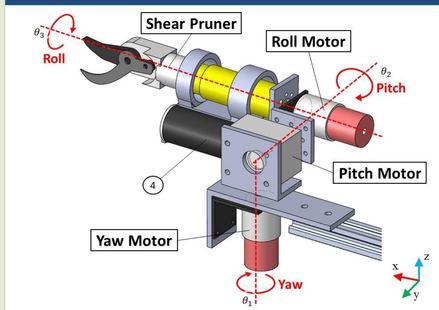

Fig.2. Pruning end-effector model

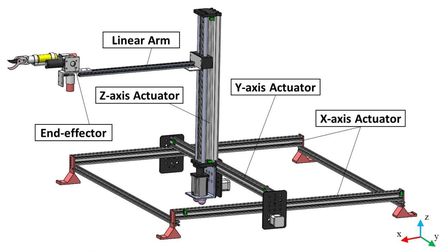

Fig.3. Integrated pruning robot model

- Yaw-pitch-roll (θ_1, θ_2, and θ_3) for rotation along z, y, and x-axis respectively
- Modified shear pruner was integrated to the last joint (θ_3) as a pruning tool
- The maximum rotation limits for θ_1, θ_2 , and θ_3 was 240°, 360°, and 360° respectively
- Cartesian robot with a square platform was developed to reach targets
- The pruning end-effector was attached to a rigid linear arm
- Integrated Arduino-Matlab control system with a user interface was developed

DEXTERITY ANALYSIS

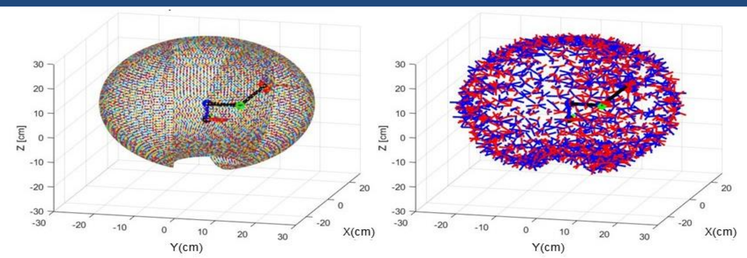

Fig.4.(a) Robot reachable workspace; (b) Cutter orientations in workspace

- Cutter displays a spherical reachable workspace of diameter 240 mm
- At every point in workspace, multiple cutter orientations are possible (cutter face: blue-red lines represent z-x axes, refer to Fig.3)

PATH PLANNING

Tree Model Development

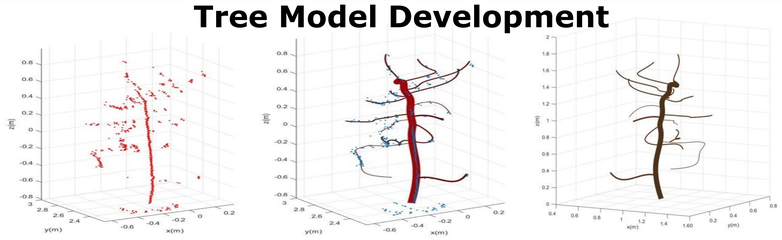

Fig.5.(a) LiDAR point cloud; (b) Branch reconstruction; (c) Tree model

- Point cloud of the apple tree was collected using a 3D LiDAR sensor
- Trunk and branches were segmented for 3D reconstruction of the tree
- The tree model consists of a tree trunk and 14 primary branches

Collision-free Path Finding

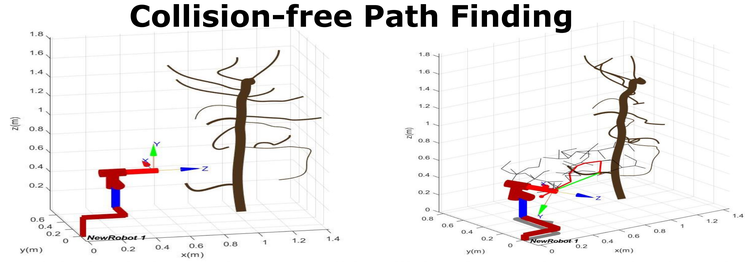

Fig.6.(a) Simulation environment; (b) Collision-free path to reach a branch

- Simulation environment including the robot kinematic model and tree model, was established for collision-free path planning
- Rapidly-exploring random tree (RRT) algorithm was implemented along with path smoothing method for obtaining collision-free paths (green line)

FIELD TESTS

Fig.7.(a) Experimental setup in the field; (b) Robot end-effector

- Fuji apple trees trained to trellis fruiting wall were selected
- Ten trees were selected, and 8 to 10 branches selected from each tree
- A total of ~ 100 pruning cuts were applied. The coordinates (x, y, and z axis) of the targeted pruning points were added to the robot

Table.1. Data (subset) collected during field tests

Test	Branch Diameter (mm)	Angle θ_1 (deg)	Angle θ_2 (deg)	Angle θ_3 (deg)	Cut Point Coordinates (x, y, and z)
1	19	30	40	25	(480, 525, 390)
2	17	65	75	10	(615, 475, 410)
3	23	45	55	15	(420, 645, 535)
4	21	20	25	15	(340, 325, 265)
5	23	45	70	10	(388, 415, 492)
6	19	15	40	45	(362, 690, 425)
7	15	75	45	20	(380, 546, 365)
8	25	40	65	00	(315, 590, 405)
9	17	65	75	15	(315, 435, 545)
10	18	35	20	45	(605, 240, 380)

- The pruning cutter reached all the selected branches in a collision-free manner and made the pruning cut successfully
- The mean collision-free path finding time was 13 s per target branch
- Maximum branch diameter of the successful cut was 25 mm
- The joint limits for θ_1, θ_2, and θ_3 were validated. No collision, and physical interferences were observed during the tests

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