Automatic Pruning System for Shrubs in the median strip of highways

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***Abstract*—Pruning is important in the maintenance of trees and shrubs and is a task which demands labor. Hence, an innovative automatic pruning system is proposed to prune the shrubs grown in the median strip of highways. The challenges associated with manual pruning in highways are considered and addressed. The system possesses image processing algorithms to identify the shrub boundary and provide navigational assistance to the robotic arm with an end effector to carry out the trimming process. The real time data is employed and pruning action is implemented accordingly. This report portrays the proposed solution as simulations and files in MATLAB which can be utilized for further developments in the industry.**

***Index Terms*—pruning, automatic, highways, shrubs, MATLAB**

I. Introduction

Highway landscaping is a major part of highway construction which ensures driver safety, relieves visual fatigue, and provides an aesthetic appeal [1]. In addition, it promotes environmental sustainability by reducing noise and air pollution present in urban areas. Explicitly, the technical objective of planting shrubs in the median strip of highways is to prevent the opposite lane traffic affecting a person driving a vehicle [2]. These shrubs act as a barrier between the two opposing lanes of the highway especially in the night. The additional aspect that comes with this is the maintenance of the shrubs without causing obstacles for the vehicles on the highways. Hence, the importance of periodical pruning or trimming of shrubs needs to be taken care of.

Pruning of a shrub adjusts the shrub shape, alters the top or root ratio, and changes the density of the shrub. Moreover, a balanced, synchronized, and harmonic dissemination of sunlight and nutrients for all branches happens by pruning [3]. For smaller shrubs, a manual hedge trimmer is generally used to clip shrub stems while for larger shrubs, a gasoline-powered hedge trimmer is used. The manual process is slow, repetitive and can even be dangerous for the laborers. To accelerate the process, increase the quality of shrub pruning and ensure the safety of the laborers, an automatic system is suggested. The automatic system is capable of withstanding longer shifts and providing pruning of higher caliber than a human pruner at a faster rate.

Automated pruning can be divided into two major categories: Non-selective mechanical pruning and Precise robotic pruning [4]. Mechanical pruning performs hedging which trims the shrubs or plants in a non-selective methodology whilst Robotic pruning selectively cuts branches using an end-effector like a blade or anvil. According to [4], mechanical pruning possesses a high degree of accuracy but is a complex process involving machine vision, which is slower than mechanical pruning. Hence for the case of shrubs grown on the highways, mechanical pruning given the specified conditions will be effective and efficient.

Various studies have been conducted on the automation of pruning of trees and plants. Automation of pruning has been introduced primarily in the early 1960s as an effort to mechanically trim lemon trees [5]. Much research and developments have been carried out on larger tree pruning robots [6], fruit tree pruning robots [7,8] and harvesting [9]. In selective pruning as depicted in pruning of apple trees, integration of machine vision and neural networks is performed to train models to analyze and select the branches to be cut and pruned [7,8]. A study on economic feasibility of an autonomous pruning system against the conventional hand pruning using a hedge trimmer [10] has revealed that that the pruning robot is more viable than labor use owing to the intensive nature of operation.

This paper proposes an Automatic Pruning System for the purpose of maintaining the shrubs grown in the median strip of highways. However, this can even be utilized in parks and open areas to prune the shrubs and bushes with modifications to suit the application. Section II indicates the studies that have been developed and the research that is thus carried out. Section III and IV showcase the proposed system overview and design for the specific application of pruning. Finally, Section V, VI and VII portray the results of the MATLAB simulation, the discussions drawn from them and the conclusion.

II. System Overview

The model of the system is as given in Fig (a). The proximity sensors attached to the base of the device identify the distance between the device and the shrub. The device can locate itself at a specific location at a predefined distance to carry out the pruning process. After locating itself, the imaging sensors in the pruning system capture high resolution images to find the shrub boundary for the pruning process. The captured images are sent to the centralized control system for image recognition.

Utilizing the User interface, the user is able to set the boundary up to which the shrub needs to be pruned. The shrub boundary will serve as the path planned for the robotic arm. Pruning instructions including the path planned are fed into the robotic arm. The robot arm with a suitable cutter as the end-effector travels along the path fed and carries out the pruning process.

The Pruning Log Database serves as a repository of information, storing details about completed pruning tasks, including the date, time, location, and specific branches pruned. These data allow the Centralized Control System to analyze past performance and identify areas for improvement.

In the Monitoring Model, the system continuously analyzes feedback from Centralized Control System to monitor the pruning process and ensure safety. Based on this real-time data, it can adjust instructions as needed, ensuring the smooth and safe operation of the system. Additionally, this data is constantly analyzed to improve future pruning plans and optimize the system's performance over time.

The system consists of two major mechanisms considered in this project:

A. Image Recognition

As stated above, image recognition is used to detect the shrub boundary of the image captured by the imaging sensor. Side profile of the shrub is observed which is fed into the Centralized control system for processing. The MATLAB code utilized for this purpose is shown in Fig 1 and 2.

Two sample figures given below (Fig 1 and 2) are fed as input to the system to test the code.

After executing the code above, the shrub boundary is detected. Colour sensing is the technique being used here. Shades of green are employed to detect the boundary hence, the captured image is transformed to the LAB colour space to emphasize on the colour representation. The two channels present, a and b extracts the information of the shades of green-to-magenta and that of blue-to-yellow. A green mask is being formed by utilizing the channels created to selectively extract the region of the bush.

After the detection of the bush region is performed, the edge detection is carried out to identify the boundary of the bush region. A distance transform is carried out to assess the pixel wise distance measurement from a line in the right side (which can be predefined by the user) to the boundary extracted before.

B. Robotic Arm

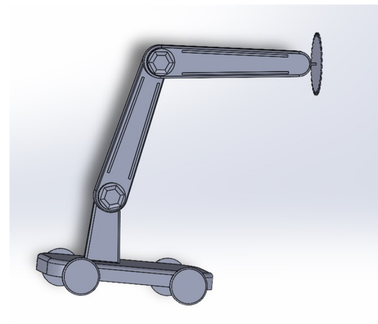


Fig. 8. Pruning Robotic Arm - Solidworks Model

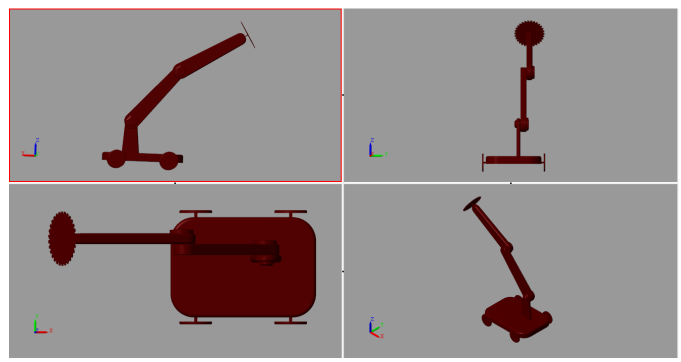


Fig. 9. Simulation

Here shown is the sample model of the integrated robotic arm. This model has three parts, which are the Base, Arm 1(Middle Arm) and the Arm 2(Top Arm)

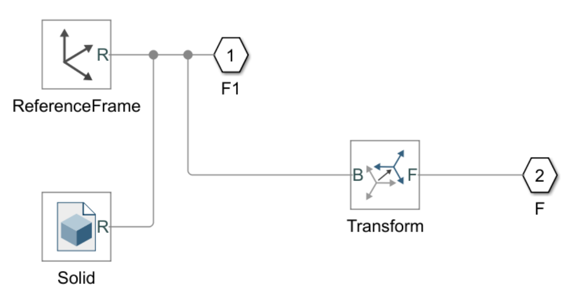


Fig. 10. Base - Simulink Model

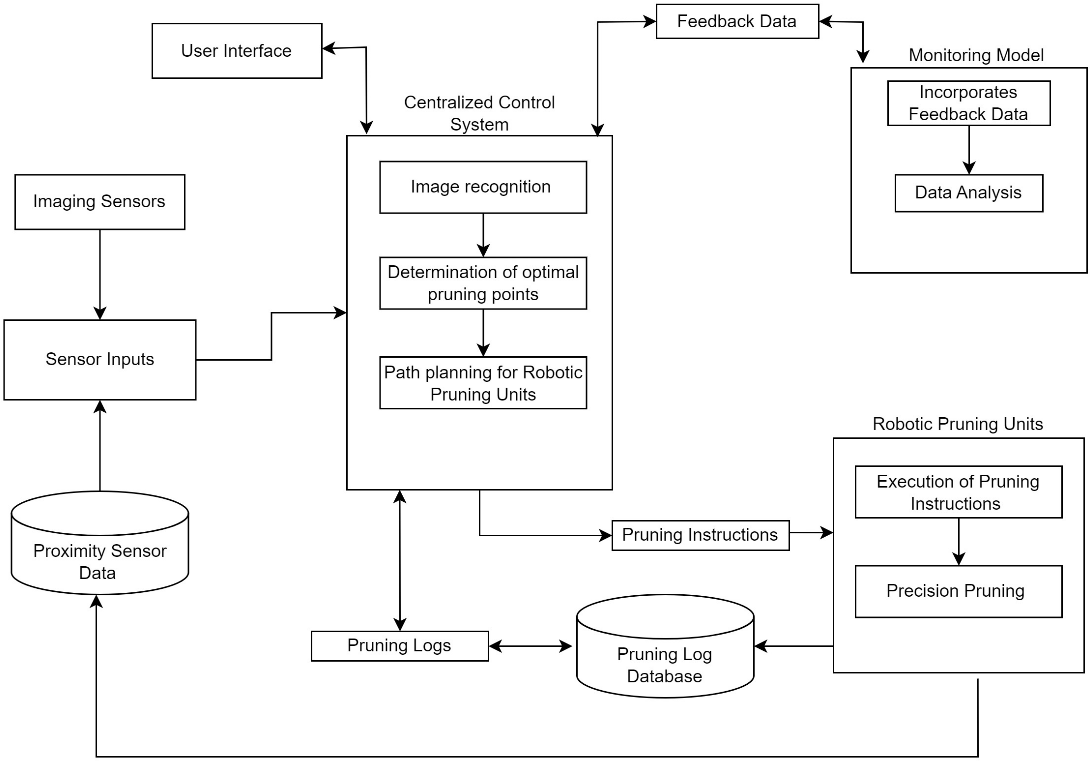


Fig. 1. System Overview

Fig. 2. Image of Shrub 1

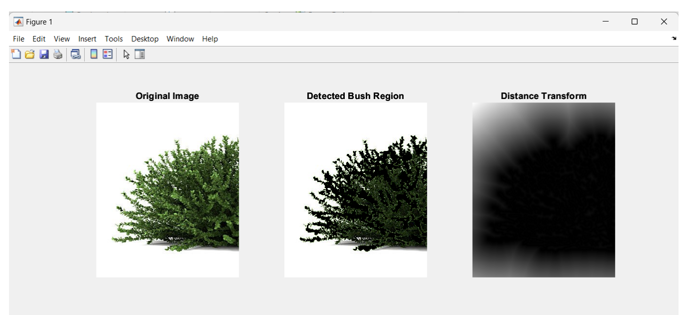


Fig. 5. Boundary identification for Shrub 2

Fig. 3. Image of Shrub 2

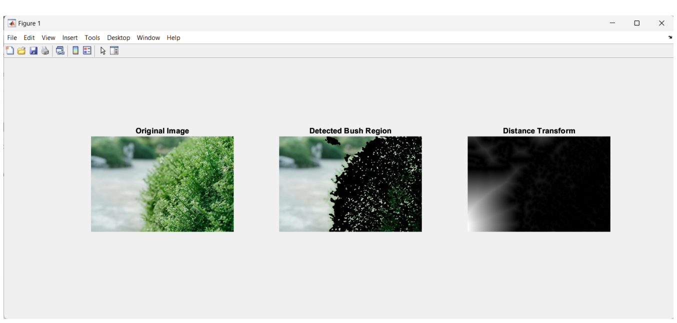


Fig. 4. Boundary identification for Shrub 1

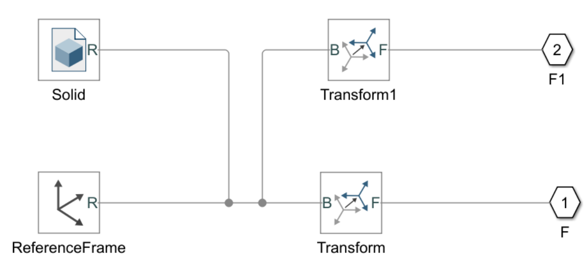


Fig. 11. Arm 1 - Simulink Model

```
% Read the image
originalImage = imread('bush_img.jpg'); % Replace 'bush_image.jpg' with the actual snapshot taken

% Convert the image to LAB color space for better color representation
labImage = rgb2lab(originalImage);

% Extract the 'a' and 'b' channels, which represent color information
aChannel = labImage(:, :, 2);
bChannel = labImage(:, :, 3);

% Threshold the 'a' and 'b' channels to segment the green part (bush)
greenThreshold = 20; % Adjust this threshold based on your image
greenMask = (aChannel < greenThreshold) & (bChannel < greenThreshold);

% Use the green mask to extract the bush region
bushRegion = originalImage;
for c = 1:3
    bushRegion(:, :, c) = originalImage(:, :, c) .* uint8(greenMask);
end

% Find the boundary of the detected bush region
edgeBushRegion = edge(rgb2gray(bushRegion), 'Canny');

% Optional: Fill enclosed regions in the edge-detected bush region
filledBushRegion = imfill(edgeBushRegion, 'holes');

% Calculate the distance transform from the right side of the image
distanceTransform = bwdist(filledBushRegion);
[maxDistance, maxDistanceIndex] = max(distanceTransform, [], 2);

% Spatial resolution (pixels per meter) - replace with actual value of lens
pixelsPerMeter = 1000;
```

Fig. 6. MATLAB Code for Image recognition

```
% Convert distances from pixels to meters
maxDistanceInMeters = maxDistance / pixelsPerMeter;

% Display the original image and the identified bush region
figure;
subplot(1, 3, 1);
imshow(originalImage);
title('Original Image');

subplot(1, 3, 2);
imshow(bushRegion);
title('Detected Bush Region');

subplot(1, 3, 3);
imshow(distanceTransform, []);
title('Distance Transform');

% Display the distance to the edge from a line at the right side in meters
figure;
plot(maxDistanceInMeters, 1:size(originalImage, 1), 'LineWidth', 2);
title('Distance to Edge from Right Line (in meters)');
xlabel('Distance (meters)');
ylabel('Vertical Position');
```

Fig. 7. MATLAB Code for Image recognition (contd.)

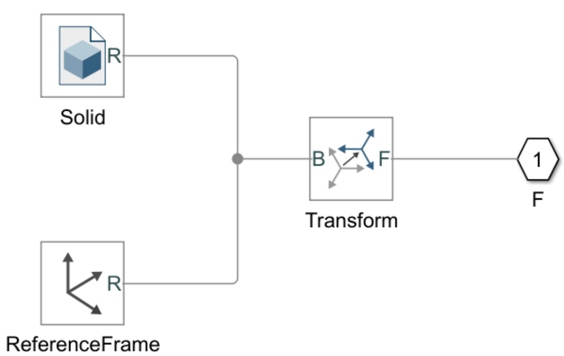


Fig. 12. Arm 2- Simulink Model

III. System Design

A. Sensor Array

The most important sensor that is implanted in this system is the Imaging Sensor. This captures high – resolution images for visual recognition, allowing the system to identify specific branches and determine optimum level of pruning points. These sensors are implanted on the edge line of the Median Strip of the highways, so that it could capture the images of the twigs that has crossed the boundary line of the median strip. Also this examines the branch thickness of the twigs, growth patterns that helps the pruning tools to determine the rotational speed of its blades. Another sensor is also integrated to the system which is known to be the Proximity Sensors. These sensors detect abnormal activities during the pruning process, that enhance safety of the system

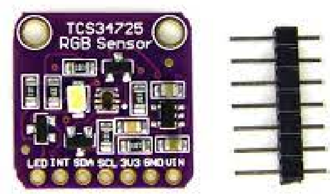


Fig. 14. RGB sensors

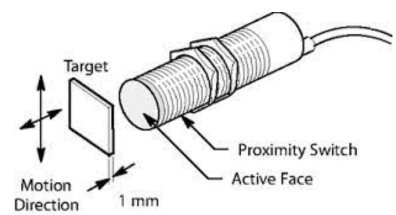


Fig. 15. Proximity sensors

B. Central Control System

This acts like the brain of the whole system that analyses and assigns the specific task for the pruning tools. The centralized control system takes over

i. Data Processing

ii. Path Planning

iii. Monitoring and Feedback

After receiving the images from the sensors, the system analyzes all the information that has been received and then comes to a conclusion. This is called as the Data Processing. Then according to the analyzed information, the path of the pruner is being planned where the optimal usage of the blades is also taken into consideration. Monitoring and Feedback is done using the data that is collected by the Proximity sensors.

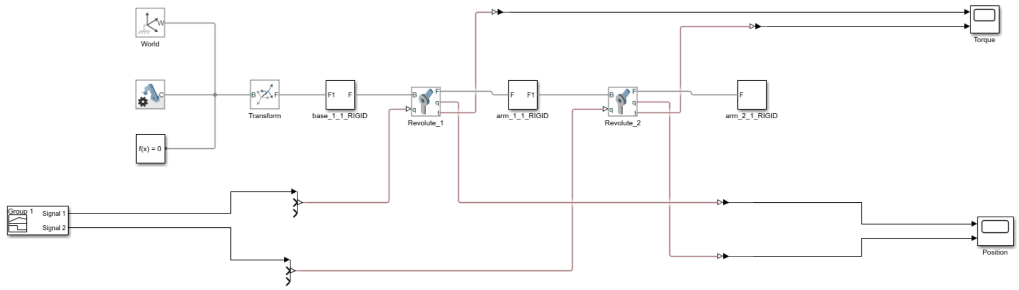


Fig. 13. Final System - Simulink Model

Fig. 16. ADC chip

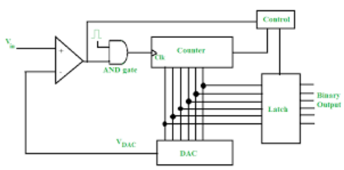


Fig. 17. Analog to Digital Converter

Fig. 18. DAC chip

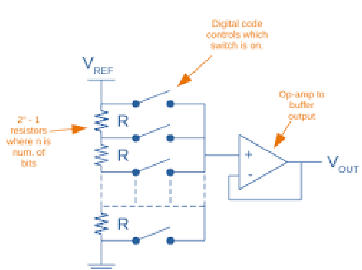


Fig. 19. Digital to Analog Converter

C. Robotic Pruning Units

This is the core of the system where we have implemented some advanced pruning tools, including precision blades and some impact sensors. These pruning tools crop the unwanted parts of the shrubs according to the data that has been provided by the equipped sensors. The precision blades that are integrated to the system shows high accuracy, whereas it could trim the particular twigs which were calculated by the sensors.

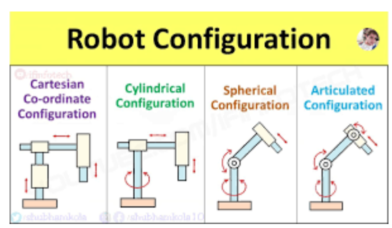


Fig. 20. Types of Arms Used

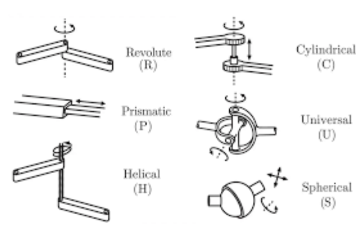


Fig. 21. Most Common Arms in use

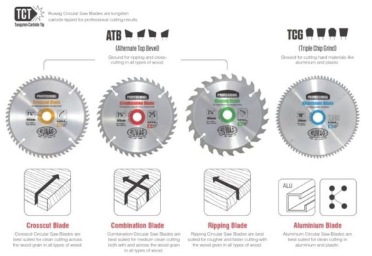


Fig. 22. Blades in usage

Fig. 23. Best recommended cutter

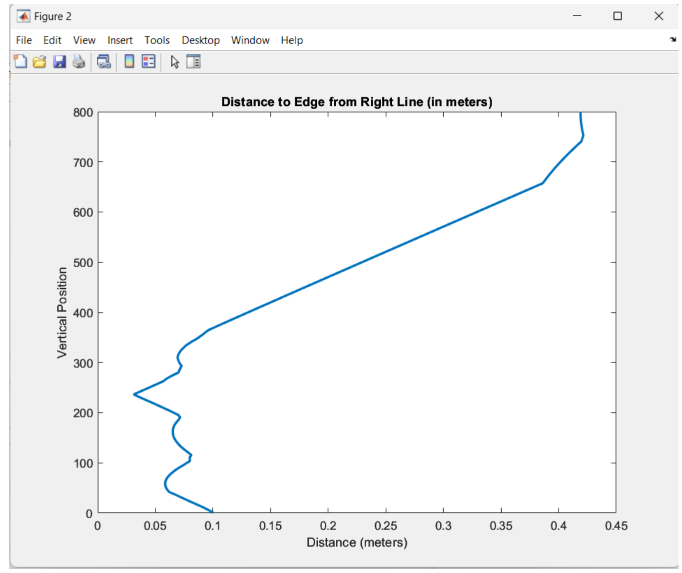
IV. Results

The results with respect to the image processing being carried out is instrumental in carrying out the pruning process. This is fed into the robot arm as the path for the trimming to be carried out.

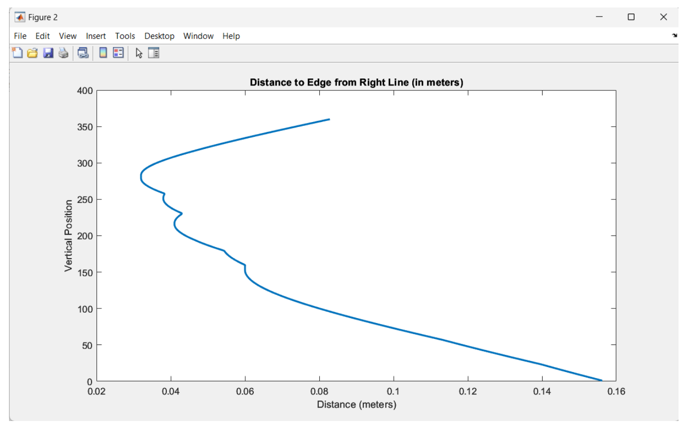
A. Image Recognition

The distance transform applied to the boundary detected in the bush region is present as a pixel measurement. In order to feed this data in to the robotic arm, a spatial parameter called pixels per meter is being employed. This can be customized according to the image sensor being used to capture the real time image before the pruning process. Proximity sensors can assist in providing input to validate the parameter being used.

The following graphs obtained (a and b) portray the distance transform of the aforementioned shrub figures.



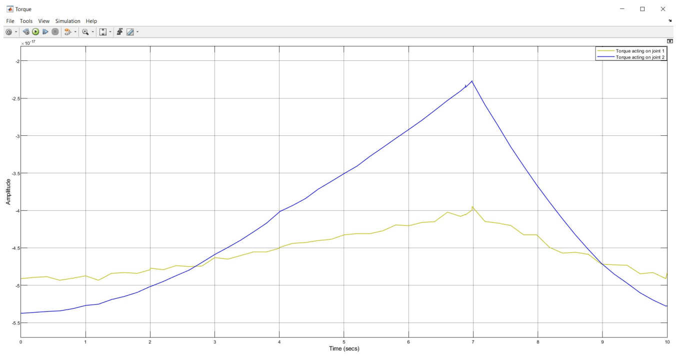
(a) Distance Transform on Shrub 1



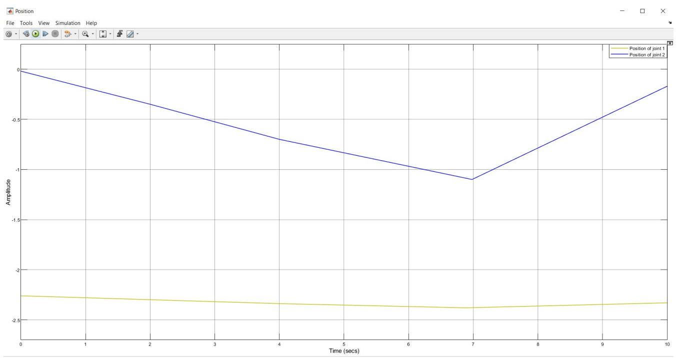
(b) Distance Transform on Shrub 2

B. Robotic Arm

1) Torque with respect to time: The graph representing torque about revolute joints provides a direct insight into the forces at play within the mechanical system. This visually illustrates the variations in torque experienced by the joint throughout the duration of the pruning process. Spikes or fluctuations in the torque graph signify instances of notable force application, indicating scenarios such as sudden shifts in motion, instances where the joint encounters resistance, or external disturbances impacting the system. By observing this graph, it's easy to discern the intensity and timing of forces acting on the joint. Peaks in torque suggest high loads or moments exerted on the joint. This visual representation simplifies the understanding of the joint's load conditions and dynamic behavior, aiding in optimization strategies and troubleshooting efforts within the mechanical setup.



(c) Torque acting on joints w.r.t. time



(d) Position of joints w.r.t time

2) Position with respect to time: The graph representing the position of re volute joints unveils a clear representation of the joint's rotational behavior throughout the pruning process. This visually illustrates how the joint's angle changes over time, offering an immediate view of its movement dynamics. Quick spikes or gradual slopes in the graph unveil moments of rapid rotation, while flat sections indicate periods of stationary or slow movement. Examining this graph reveals variations in the joint's speed, changes in its movement direction, and even hints at potential areas where the system could be optimized or its performance improved.

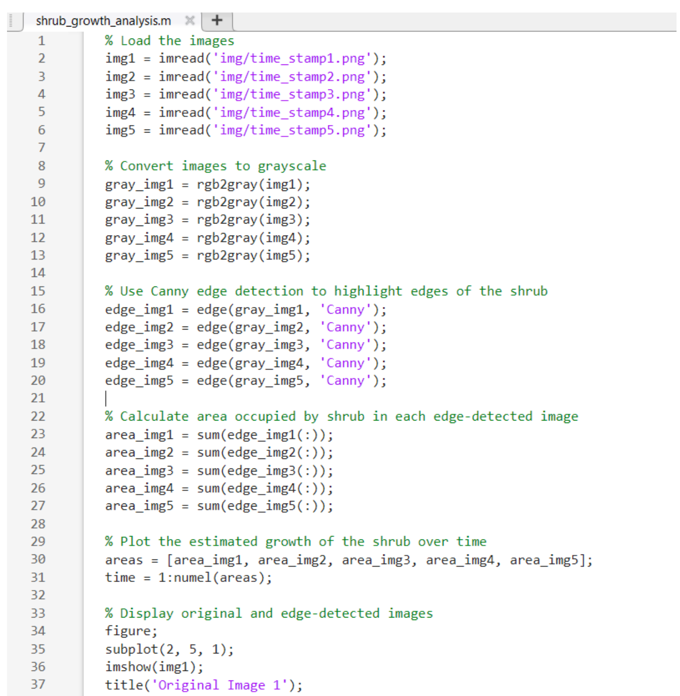
V. Discussion

A. Tracking the growth of bushes

MATLAB script can be used to analyze the shrub growth over time by processing a series of images captured at distinct timestamps. The code utilized standard image processing techniques, converting the loaded images to grayscale and applying the Canny edge detection algorithm to accentuate shrub edges. Subsequently, the code estimated the area occupied by the shrub in each image through edge detection. The visual representations, including edge-detected images and a plotted graph showcasing estimated shrub areas across different timestamps, offered valuable insights into the observed growth patterns and variations in the shrubs throughout the captured image series. This analysis aids an automated shrub pruning system by informing optimal pruning timings, enhancing efficiency, promoting shrub health, and enabling adaptive pruning strategies.

B. Pruning different shapes

The improvements of the algorithm and path planning should be implemented for trimming the shrubs into different shapes. 3D coverage trajectories for shrub pruning should be considered and the smoothness in the path taken plays a pivotal role here. Path planning needs to be further researched using 3D coordinate system before implementation.


shrub_growth_analysis.m

```
% Load the images
img1 = imread('img/time_stamp1.png');
img2 = imread('img/time_stamp2.png');
img3 = imread('img/time_stamp3.png');
img4 = imread('img/time_stamp4.png');
img5 = imread('img/time_stamp5.png');

% Convert images to grayscale
gray_img1 = rgb2gray(img1);
gray_img2 = rgb2gray(img2);
gray_img3 = rgb2gray(img3);
gray_img4 = rgb2gray(img4);
gray_img5 = rgb2gray(img5);

% Use Canny edge detection to highlight edges of the shrub
edge_img1 = edge(gray_img1, 'Canny');
edge_img2 = edge(gray_img2, 'Canny');
edge_img3 = edge(gray_img3, 'Canny');
edge_img4 = edge(gray_img4, 'Canny');
edge_img5 = edge(gray_img5, 'Canny');

% Calculate area occupied by shrub in each edge-detected image
area_img1 = sum(edge_img1(:));
area_img2 = sum(edge_img2(:));
area_img3 = sum(edge_img3(:));
area_img4 = sum(edge_img4(:));
area_img5 = sum(edge_img5(:));

% Plot the estimated growth of the shrub over time
areas = [area_img1, area_img2, area_img3, area_img4, area_img5];
time = 1:numel(areas);

% Display original and edge-detected images
figure;
subplot(2, 5, 1);
imshow(img1);
title('Original Image 1');
```

Fig. 24. MATLAB code for shrub growth analysis

```
subplot(2, 5, 6);
imshow(edge_img1);
title('Edge-Detected Image 1');

subplot(2, 5, 2);
imshow(img2);
title('Original Image 2');

subplot(2, 5, 7);
imshow(edge_img2);
title('Edge-Detected Image 2');

subplot(2, 5, 3);
imshow(img3);
title('Original Image 3');

subplot(2, 5, 8);
imshow(edge_img3);
title('Edge-Detected Image 3');

subplot(2, 5, 4);
imshow(img4);
title('Original Image 4');

subplot(2, 5, 9);
imshow(edge_img4);
title('Edge-Detected Image 4');

subplot(2, 5, 5);
imshow(img5);
title('Original Image 5');

subplot(2, 5, 10);
imshow(edge_img5);
title('Edge-Detected Image 5');
```

Fig. 25. MATLAB code for shrub growth analysis (contd.)

```
% Display the edge-detected images
figure;
subplot(2, 5, 1);
imshow(edge_img1);
title('Edge-Detected Image 1');

subplot(2, 5, 2);
imshow(edge_img2);
title('Edge-Detected Image 2');

subplot(2, 5, 3);
imshow(edge_img3);
title('Edge-Detected Image 3');

subplot(2, 5, 4);
imshow(edge_img4);
title('Edge-Detected Image 4');

subplot(2, 5, 5);
imshow(edge_img5);
title('Edge-Detected Image 5');

% Plot the estimated area of the shrub
subplot(2, 1, 2);
plot(time, areas, 'bo-', 'LineWidth', 2);
xlabel('Time');
ylabel('Shrub Area');
title('Shrub Growth Over Time');
grid on;
```

Fig. 26. MATLAB code for shrub growth analysis (contd.)

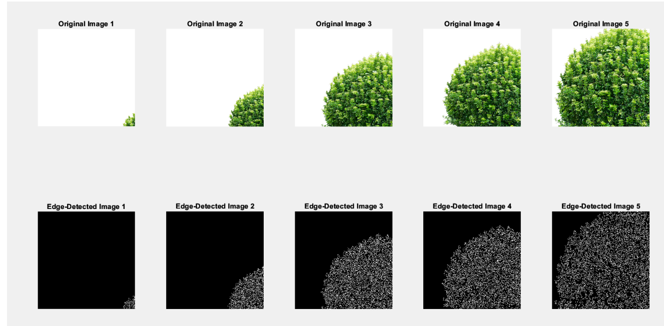


Fig. 27. Original and Edge detected images of a shrub at distinct timestamps

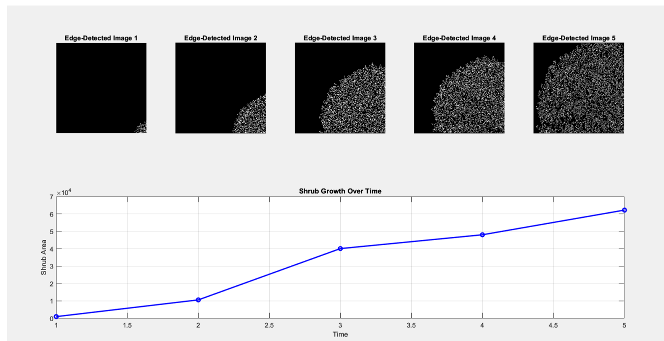


Fig. 28. Growth Analysis of a shrub

VI. Conclusion

In conclusion, the automatic pruning system unveils promising aspects in the industry. The proposed system can be further improved using the applications of machine vision and data model training to prune different shapes by regression of the time spent for trimming at each coordinate point. The system can even be utilized in horticultural work by developing the required areas to ease the laborious process.

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Given below are the individual contributions of the members of Group 18:

Niyumi Nethmanthi (210422H): Image recognition, Report writing.

V. Nilesh (210426A): Overall system Design, Report writing.

Saranga Pathirana (210452A): Conceptual model of the Robotic arm, MATLAB simulations, Overall system overview, Report writing

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