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CS445 Final Project: Turf Density Estimation

Motivation and Impact (5pts)

Turf grasses occupy 2% of the land in the United States and Americans, making it the biggest irrigated crop in the United States. That is about $30 billion of lawn care on 40 million acres of land that uses large amounts of water, fertilizers, and pesticides. I chose the topic of turf grass density measurement because of its significant implications for sustainable land management.

By focusing on digital imaging for turf density measurement, this project aims to provide a rapid and accurate method to assess the health of turf areas. Our goal is to offer a streamlined approach to identifying specific regions that require additional care. This not only enhances the overall efficiency of turf management but also has broader environmental implications. The ability to pinpoint areas in need allows for targeted interventions, potentially reducing water consumption, minimizing fertilizer and pesticide usage, and promoting overall sustainability in the management of highly maintained turf.

By leveraging digital imaging tools, the project contributes to the broader discourse on resource conservation, precision agriculture, and environmentally friendly land management practices. In essence, the research holds the promise of not only improving the health and appearance of turf but also fostering a more sustainable and responsible approach to land use on a larger scale.

Approach (15pts)

Two algorithms were developed and compared, and one additional method from a paper was implemented.

1. Color-based Approach
    a. Convert the input image to the HSV color space.
    b. Create a mask by selecting pixels within a specified green color range, representative of grass color.
    c. Apply LineSegmentDetector (LSD) to detect the number of lines in the grass mask.
    d. Adjust the number of lines by a constant.*
    e. Calculate the area in square centimeters per pixel using a reference image with a ruler.
    f. Compute the total grass area in square centimeters.
    g. Divide the number of detected lines by two (considering both sides of grass blades) and then divide by the calculated area to get the density of grass blades per square centimeter.

2. Connected Components Approach:
    a. Use the ConnectedComponentsWithStats function to create a mask and obtain statistics for connected components.
    b. Extract the mask for the first connected component.
    c. Apply LineSegmentDetector (LSD) to find the number of lines in this connected component mask.
    d. Adjust the number of lines by a constant.*
    e. Calculate the area in square centimeters per pixel using the same reference image with a ruler.
    f. Compute the total area of the connected component in square centimeters.
    g. Divide the number of detected lines by the calculated area to get the density of grass blades per square centimeter.

* the constant was found by laying exactly 6 blades of grass on a solid light green colored paper. The number detected from LSD is divided by 6, since the curvy nature of grass blades would be made up of many small segments. It is not an ideal method, but provides a benchmark / guestimate. (see image in results section)

An additional method using run-length encoding (RLE) from the paper *A Machine Approach to Objective Turfgrass Texture Evaluation* (Narra, Fermanian, Voigt 2009) published in International Turfgrass Society Research Journal Volume 11, was implemented. However, the results obtained were difficult to interpret.

Step 1: read image and remove artifacts and extraneous material that do not meet the minimum threshold pixel prequirement
Step 2: Set minimum and maximum thresholds for the contiguous pixel widths
Step 3: Create a zero matrix of the image size with a one pixel buffer
Step 4: Assign original matrix to the zero matrix
Step 5: Create a vector matrix from the transpose of the original matrix
Step 6: Find positions where one element is different from the next
Step 7: Find run lengths and values after determining the end position of each run
Step 8: Assign zeros for all widths above and below the specified threshold range
Step 9: Perform run-length decoding
Step 10: Repeat Steaps 5 through 8 for each image angle from 0 to 90 degrees at 5 degrees interval
Step 11: Calculate image statistics

The example in the paper was performed on twist ties, which might explain why the algorithm did not work on actual patches of grass.

Results (5pts)
Explain your results and their significance
Results from the two approaches were compared to 3 human guesses.

Grass Image	Grass Description	Human Guess	Method 1 (#, #/cm²)	Method 2 (#, #/cm²)
	Benchmark used for the constant to adjust number of lines detected. The brightness and contrast was adjusted to minimize influence from lighting.	6 (not a guess)	6, 0.03	7, 0.02
	Green bermuda grass from the internet (cited in references)	6, 7.4, 11	308, 3.05	398, 8.92
	Indoor bermuda grass wilted	4, 8.7, 7	731, 1.05	1591, 4.71
	Outdoor bermuda grass dormant	4, 6.5, 5	191, 0.27	1303, 3.70

Implementation Details (5pts)

- Provide details, such as programming language, packages
- Include a list of any external resources used, such as open-source code and data

Programming language: python
Packages: opencv, numpy, matplotlib
External resources
Turf references: web articles, agronomy papers (see references)
Human guesses: Hope (soil scientist), Emily (soil scientist), Adam (architect)

Challenge/innovation (20pts)

- Describe what you think was challenging or innovative about your project. Explain the effort required to interpret unclear steps to a paper's implementation or a proposed new idea to work.
- Write and justify how many points you expect to receive for the challenge/innovation component of grading.

This project was challenging because there is very little pattern to how grass might decide to grow. There are also many variables to consider such as the lighting of the environment and condition of the grass. It would be a much easier problem if grass grow perfectly straight. Even for humans, it is hard to guess exactly how many grass is in a given area. If the area is too small, it seems like there are more grasses passing through then just exisiting in that area. It is similar to guessing the number of cheerios in the jar, except all the cheerios have different colors, sizes, and shapes. An exisiting software TurfAnalyzer has a couple features including estimating the number of plants per unit area via a complex shadow analysis of the turf canopy, but the accuracy is not mentioned or confirmed. The actual ground truth might be sitting next to a patch and pluck out the grass blades one by one and counting how many pieces of grass there are.

Without using additional open source code, the proposed methods were simple but novel. There was an attempt to implement the steps listed in a paper, but it seems to only apply to much simpler structures. There are plenty of room for improvements for the current approach and it has many limitations such as identifying little lines as many segments and overestimating the number of segments due to the grass blades overlaying and crossing over. I had three more ideas that I wanted to try outlined in the "come back to this later" sections towards the end of the jupyter notebook. 1) Compare to known density patcheds directly and find result in a range of numbers rather than a specific number. 2) Use projection from a video like project 5 of our course. 3) Instead of LSD, try tri-points based line segment detector (TP-LSD) proposed in this 2020 paper using deep convolutional model to detect line segments with more accuracy at real-time speed.

I am hoping to recieve between 18 to 20 points for the challenge/innovation component of grading.

Note: a different project was submitted for the project proposal; however, after reciving the feedback, I pivoted to a more challenging project without much prior research or existing product. There are weed detection research using deep learning; however, not much about counting the shoots / blades of grass.

References

Business Insider: Grass takes up 2% of the land in the continental US
https://www.businessinsider.com/americas-biggest-crop-is-grass-2016-2?op=1
Narra, Siddhartha & Fermanian, Thomas & Voigt, Thomas. (2009). A MACHINE VISION APPROACH TO OBJECTIVE TURFGRASS TEXTURE EVALUATION. International Turfgrass Society Research Journal. 11. 437-448.
https://www.researchgate.net/publication/301232211_A_MACHINE_VISION_APPROACH_TO_OBJECTIVE_TURFGRASS_TEXTURE_EVALUATION
TurfAnalyzer
https://turfanalyzer.com/
Green bermuda grass image
https://www.gardeningknowhow.com/lawn-care/specific/bermuda-grass/growing-bermuda-grass.htm
Stackoverflow: using connectedComponents
https://stackoverflow.com/questions/51523765/how-to-use-opencv-connectedcomponents-to-get-the-images
Opencv doc: thresholds
https://docs.opencv.org/3.4/d7/d4d/tutorial_py_thresholding.html
Deep Neural Networks to Detect Weeds from Crops in Agricultural Environments in Real-Time: A Review
https://www.mdpi.com/2072-4292/13/21/4486
Deep Learning-Based Weed Detection in Turf: A Review
https://www.mdpi.com/2073-4395/12/12/3051/htm
TP-LSD
https://arxiv.org/abs/2009.05505
Understanding run-length encoding
https://www.geeksforgeeks.org/run-length-encoding/