Progress Review 9

Individual Lab Report 8

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Team E:

Wholesome Robotics

Teammates:

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Individual Progress

Capstone Project

Team E is creating an organic monitoring robot which has to autonomously navigate through crop rows. For this phase of the project, I had two main tasks which can listed as follows:

1) Understanding and experimenting with foliage area estimation in order to provide a height-invariant heuristic for the Mask R-CNN based inference pipeline.

2) Facilitate integration of additional features with the complete software architecture for the plant health visualizer pipeline.

Foliage area estimation

Understanding the problem

Problem: The problem of foliage estimation can be defined as finding the pixel area of the foliage present in a given image.

Definition of foliage: The term foliage can itself be considered as the leaf area which is in direct sight of the camera.

Assumptions: This problem assumed that the exposure of the images is not an issue. The height of the custom stereo camera is assumed to be fixed.

Problem description: For the inference problem of finding the amount of fungus and holes in an image, the current solution proposed by the team is a Mask R-CNN based segmentation pipeline. The current approach is to find the segment the holes and disease in a given image. Depending on the area of holes and disease, the plant is classified as healthy or unhealthy.

One of the issues associated with this pipeline comes up when the height of the plant changes over time. The same fungus and disease area with the same camera height, appears zoomed in if the plant grows over time, due to the scale issue in camera-based perception. Hence, same fungus/hole area in and could be classified as unhealthy. Hence, the aim of this exploration was to find the pixel area of the foliage in the scene. This would allow us to find the hole/fungus level as a ratio of the foliage area. This could potentially make the metric invariant to changes in height.

Methodology and key steps

The requirements for satisfying this work package can be summarized as follows:

1) Taking the initial development on foliage estimation as input, the goal of this work was to work on parameter tuning and conclude whether one set of parameters can be found successfully estimate foliage area. The results from this will be discussed in the **Results** section.

2) Provide potential solutions for the challenges faced during the process. This will elude to the limitations of the current classical vision based pipeline and how this problem could be solved. These strategies will be discussed in detail in the **Proposed Solutions** section.

General Concepts

The initial efforts put into the foliage area estimation was done using the Semi-Global Block Matching algorithm [1] in OpenCV. Some initial time was spent understanding this algorithm to get a good general idea of the tunable parameters. The general concepts of stereo geometry state that in case of stereo images, for every pixel on say the left image, the corresponding pixel on the right image can be found along a line called the epipolar line. If the image is rectified, the search for the corresponding pixel can be performed across the horizontal scan line. For each pixel, we evaluate possible disparity results by moving along the line. The cost of each pixel and the potential path to reach that pixel can be added into a matrix. We can also add smoothness constraints in order to prevent sudden changes. The minimum path and the potential disparity is found by modelling this as a linear programming based solution. Using this general understanding, different parameters for the SGBM algorithm were tuned and the results can be seen as follows.

SGBM-based leaf area estimation results

The following images showcase the results from the SGBM algorithm being applied to pair of images with the maximum disparity being 160 pixels and the block size being 5. The image on the extreme left is the left image, the image on the extreme right is the right image, and the image in the middle is the predicted disparity image. Figure 1(a) shows the results from a random image taken from a ROS Bag of row1.

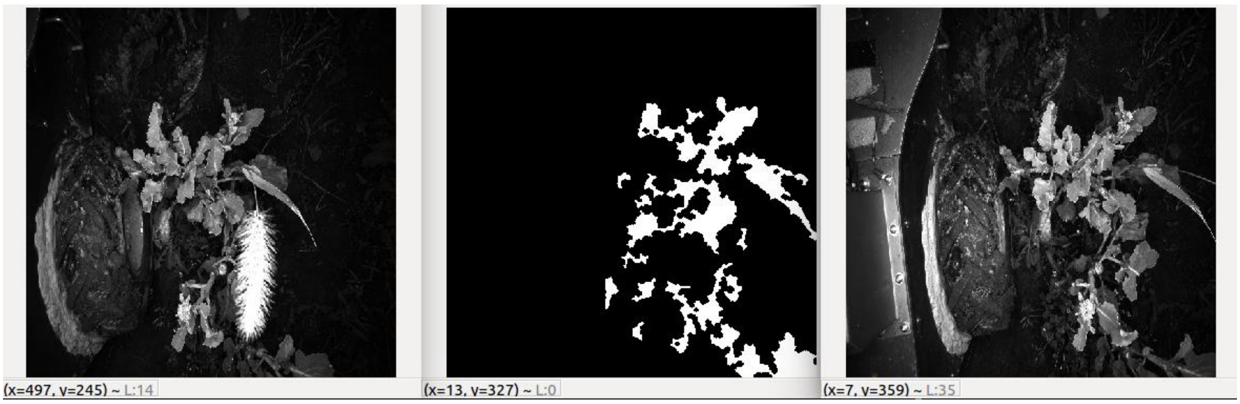

Figure 1 (a): Raw images and disparity results for an image from row 1

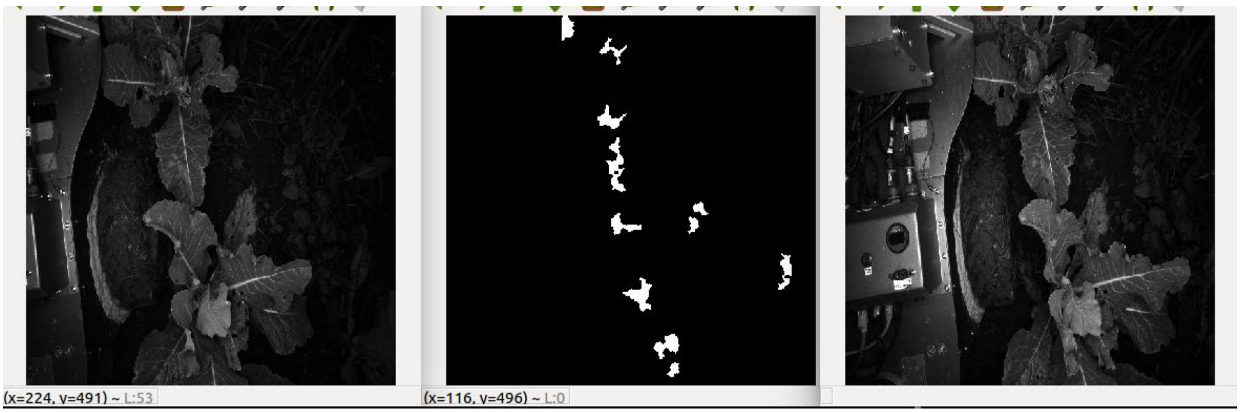

Figure 1 (b): Raw images and disparity results for an image from row 8

Figure 1(b) shows the results from a random image taken from a ROS Bag of row8. It can be seen that there is a drastic difference in results even though, the images don't have any major changes in exposure between them. There were other conflicting observations, where the tuned parameters work for a single row, however, the same set of tuned parameters do not work for a different row.

Potential solutions

As seen from the results of the investigation, there are considerable issues with parameter tuning which prevent this method to be robust for use over different set of rows. During the analysis phase of this problem, it also came to light that, depth-based estimation may not be the correct approach to go. Potential solutions could include semantic segmentation based networks (such as Mask R-CNN) for estimating leaf area. The other potential solutions could be using deep network based solutions which estimate depth from stereo images. These solutions are however intensely time consuming and challenging. The problem of leaf segmentation is somewhat an open problem, hence, the current MRSD project schedule doesn't allow further work into this area.

Integration of the plant health visualizer tool

For this progress review, one of the features to be added was the capability of parsing multiple ROS Bags and allowing the inference pipeline as well as the visualizer GUI to work with multiple rows. I played a direct role in expanding this capability for the parser as well the inference pipeline side. I actively collaborated with Dung-Han Lee to solve the ROS-Python3 conflicts which were faced during the previous Progress review.

Challenges

The key challenges faced during this progress review lie in the plant health visualizer side.

One of the key issues I faced was a software architecture change throughout the plant health visualizer pipeline. Initially, to store different data fields, a dictionary based data-structure was utilized. However, we recognized that, it will be hard to track the dictionary indices to extract the information as the data-fields grew over time. To solve this problem, I proposed a solution of packaging all the data as class objects (which should have been the logical choice from the start). The effort put in changing the pipeline made me realized how initial software architecture decisions need more thought, keeping the expansion of the project in mind.

Secondly, during the process of integration of visualizer side features such as clustering, the problem of defining interfaces was not enforced on my colleagues. This lead to an issue, where an interface was changed, leaving me incapable to replicate the results of the work done by my colleague. Defining key interfaces between components in the pipeline is an important problem and effective team-work requires that these interfaces are maintained and not changed over time.

Teamwork

John Macdonald

John worked on fixing the problem of drift in yaw estimate by using geometric constraints from the IMU to prevent the GPS estimate to taking geometrically inconsistent values. He also worked on investigating into the newly collected data and testing the row detector tested in the previous semester on the new data.

Aman Agarwal

Aman worked on the map builder which aims to create a unique map representation across the navigation stack. He also integrated the map builder with the currently existing navigation stack and tested it during the field visit.

Hillel Hochsztein

Hillel worked on adding additional features to the plant health visualizer, which includes clustering of different data-points, adding arrows to the GUI to navigate and view different images in the cluster. He also created version 1 of the plant guards for the robot model using acrylic sheets.

Dung-Han Lee

Dung-Han Lee worked on testing a UNet based architecture for end-to-end classification of hole and fungus area. He also worked on fixing the package conflicts between Python3 and ROS for the plant health visualizer pipeline.

Future Plans

Team

The future team goals for the upcoming weeks can be summarized as follows:

1) Testing the navigation pipeline with RTK GPS and the first version of the Map builder directly at the field.

2) Creating an MVP of the plant health visualizer pipeline which works on multiple ROS Bags (multiple crop rows).

3) Further exploration on utilizing the UNet based architecture for improving the inference results.

4) Working on IMU, RTK GPS and Visual odometry based sensor fusion to correct for the drift in the yaw estimate.

Individual

The future individual tasks which are planned for the coming weeks can be summarized as follows:

1) Collaborate with Aman on using the robot_localization package for fusing IMU, RTK GPS and Visual odometry data in order to improve the yaw estimate.

2) Play a leading role in developing the key features necessary to demonstrate MVP version 1 of the plant health visualizer pipeline. This includes clustering for multiple rows, having common file/IO protocols throughout the pipeline, adding labels for row names in the GUI.

References

[1] H. Hirschmuller, "Stereo Processing by Semiglobal Matching and Mutual Information," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 30, no. 2, pp. 328-341, Feb. 2008.
doi: 10.1109/TPAMI.2007.1166