Northeastern University

Determination of Plant Health using NoIR Camera & Implementing vSLAM

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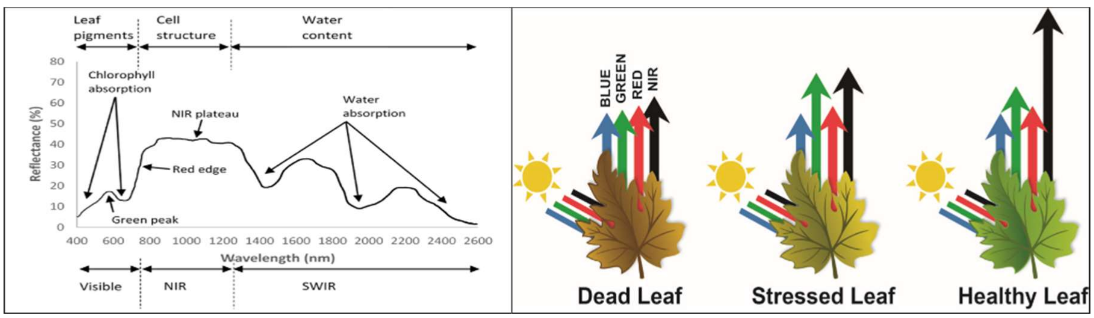
ABSTRACT: This project primarily focuses on determination of plant health by calculating a parameter called *'Normalized Difference Vegetation Index'* using the captured IR images from a sensing & navigation unit. The project is implemented using a NoIR (No-Infrared) camera for determining plant health and a Stereo Camera to perform ORB-SLAM (Oriented Fast and Brief), all connected to a Raspberry Pi. The aim of the project is to create a system for tracking health conditions of plants in indoor environments such as a greenhouse, lab, etc. The initial trial was performed in Northeastern University's campus where both live and dead plants were scanned to test our NDVI results.

Keywords: NDVI, Plant health, vSLAM, NoIR camera, Stereo camera, Raspberry Pi.

1. INTRODUCTION

1.1. NDVI:

Normalized Difference Vegetation Index (NDVI) is used as a popular remote sensing index to assess the vegetation by analyzing the spectral signature of leaves [1].

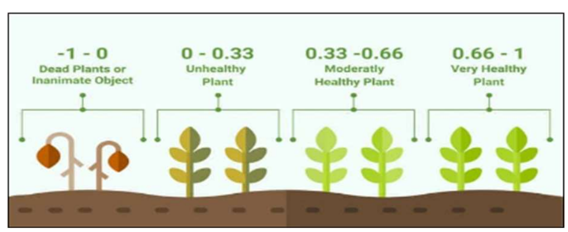


(a) (b)

fig. 1: (a) Spectral property of vegetation (b) Effect of health condition on spectral signature

As seen in *fig. 1*, during photosynthesis, blue and red regions are absorbed and only green region is reflected. Moreover, vegetation reflects excessive amount of Near-Infrared light [1]. This phenomenon is used to capture the Near-Infrared and Red wavelengths for calculating NDVI to determine the green vegetation. This system is currently being used on large-scale by means of satellites to scan vegetation and determining its health. Our system implements the same on a small-scale with cost-effective solutions for indoor environments.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$



(a) (b)

fig.2: (a) NDVI standard formulae (values range from -1 to 1) (b) NDVI representing the plant health

For healthy plants, the difference between the NIR and Red will be high and thus NDVI will be close to 1 and for stressed and dead plants, the leaf reflects less amount of NIR and NDVI will be less. This index gives a quantitative analysis of plant health.

1.2. vSLAM (RTAB vs ORB):

Real-Time Appearance-Based Mapping (RTAB) is a graph-based SLAM approach. It makes use of vision sensor data for localization and mapping. RTAB is divided into two parts, front end, and back end [4]. The front end focuses on the data collected from sensors and uses this data to get environment constraints which is then used for feature optimization. Visual odometry is made possible using Speeded Up Roust Features or SURF. RTAB map relies solely on appearance and there is no metric distance information. To incorporate metric distance information RTAB map requires a stereo camera or an RGBD camera for computation of geometric constraints between different images, for loop closure purposes. The back end of RTAB map consists of graph optimization and an assembly of an occupancy grid from the graph's data. RTAB map uses global loop closure along with some techniques to ensure that the loop closure process happens in real-time. Loop closure in RTAB mapping is done using what is called a *bag of words approach*.

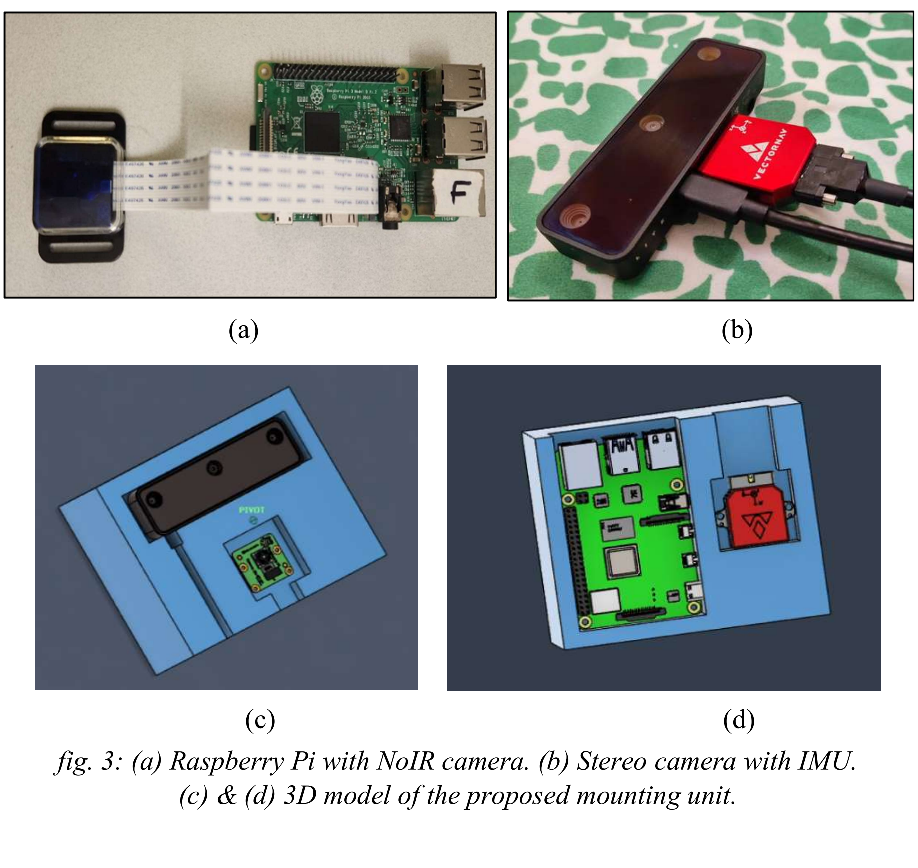
ORB (Oriented Fast and Brief) SLAM is an accurate real-time SLAM solution for Monocular, Stereo and RGB-D cameras. It can perform real time computation of the camera trajectory and a sparse 3D reconstruction of the scene in a wide variety of environments [5]. ORB SLAM works on three tasks simultaneously which consists of tracking, local mapping, and loop closure [6]. For tracking it performs a frame-by-frame feature map and compares it with the local map to find exact camera position in the environment. For local mapping, it makes local maps and then performs optimization using algorithms like iterative closest point (ICP). Finally, it uses pose-graph optimization to correct the accumulated drift and perform a loop closure. This algorithm relies more on feature extraction from an image than the whole image. It makes use of stereo points and monocular points for estimation of translation and rotation. The last part of the algorithm is localization. ORB SLAM shuts down local mapping and loop closing threads and the camera is free to move and localize itself in each map or surrounding. During this mode, the tracking makes use of visual odometry matches to map points.

2. SETUP

By standard definition, the NIR and Red bands are used to calculate NDVI, but obtaining NIR and Red bands separately requires expensive equipment. An alternate approach is to use $NDVI_{blue}$ in which NIR and blue light is used for calculation as chlorophyll also absorbs the blue band. This will allow the use of a low-cost Raspberry Pi NoIR camera (no InfraRed filter) with a blue filter which transmits only blue and NIR wavelengths. Red pixels will correspond to NIR band and blue pixels will correspond to blue band.

$$NDVI_{blue} = (Red - Blue)/(Red + Blue)$$

To capture the infrared images, our system uses the Raspberry Pi NoIR camera v2 integrated with Raspberry Pi 3 Model, but a Raspberry Pi 4 could be used with at least 4GB RAM for better processing speeds.



(a) (b) (c) (d)

fig. 3: (a) Raspberry Pi with NoIR camera. (b) Stereo camera with IMU. (c) & (d) 3D model of the proposed mounting unit.

For vSLAM, the Luxonis OakD-Lite stereo camera and the VN-100 IMU are used. This model has three cameras: One Stereo Camera Pair with 480p resolution and 4K fixed focus depth camera at the center. A stereo camera closely copies how our eyes work to give us accurate, real-time depth perception. It achieves this by using both stereo cameras at a set distance apart to triangulate similar pixels from both 2D planes. For SLAM in Stereo Cameras, feature detection is sequenced in each frame separately, and then the features are mapped between left and right images. This avoids feature drift in long time operation. *fig. 3(a)* & *3(b)* shows the setup used to capture our test images and to perform vSLAM. However, the final unit will look like the 3D model depicted in *fig. 3(c)* and *fig. 3(d).* This unit will enable simultaneous operation of both sensing and navigation systems.

3. PROPOSED ALGORITHM AND DATA COLLECTION

3.1. Image Acquisition and NDVI calculation

For plant health determination, the captured images are first resized and saved. To get the NDVI images, the raw images are read and images are parsed to obtain the R and B bands of image. NDVI image is generated using the $NDVI_{blue}$ calculation method. The obtained grayscale NDVI Image is then enhanced using Contrast stretching method to improve visibility. To get a better visual information, color map is applied on the grayscale image of NDVI. Several datasets were collected in different lighting conditions on multiple plants ranging from healthy to dead conditions.

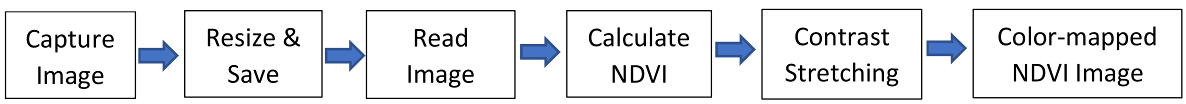


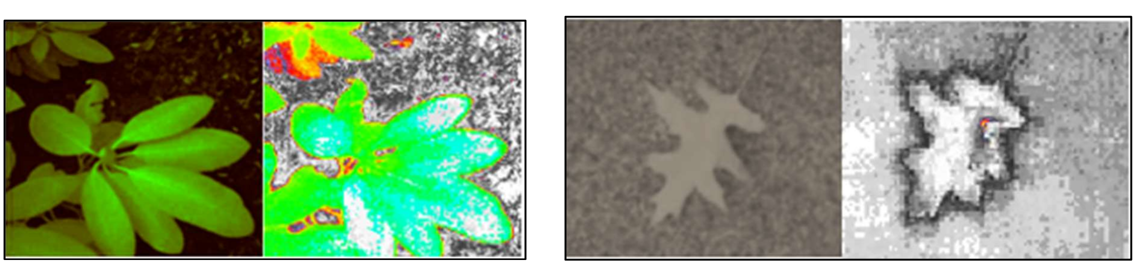
fig. 4: Flowchart for plant health determination.

3.2. SLAM:

After a comparative analysis of *RTAB Map* and *ORB-SLAM3*, we observed that ORB-SLAM is a better contender for the project's purpose since it works very accurately and efficiently with stereo cameras specifically in indoor environments. Unlike ORB SLAM, RTAB map SLAM creates a dense 3D map of the environment. The trajectory estimation of RTAB map is good but the distance measurement is better estimated in ORB-SLAM. The orientation correction is then performed by fusing it with the IMU data to get a more accurate trajectory map.

4. ANALYSIS AND RESULTS

We have implemented the algorithm for plant health detection and SLAM independently and analysed the data under test conditions. *fig. 5(a)* shows the NDVI result of healthy plant and *fig. 5(b)* shows NDVI result of dead leaf. The colormap used to generate the color NDVI images is shown in *fig. 6*.



(a) (b)

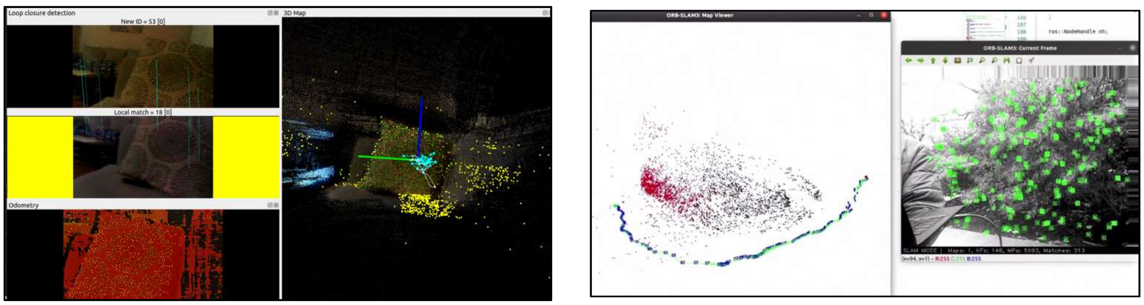
fig. 5: (a) Healthy plant actual and NDVI image (b) Dead leaf actual and NDVI image

-1 0 1

fig. 6: Colormap used to map NDVI images (-1 for dead and 1 for healthy)

The NDVI image shows the healthy part as bluish-green and dead part as greyish-black which is confirmed from the result shown in *fig. 5*.

For vSLAM, we tested both the SLAM algorithms: RTAB and ORBSLAM. RTAB provided us with 3D Reconstruction but it didn't react properly with new data, whenever new data occurred it changed its trajectory significantly. This issue was not there with ORBSLAM. In ORBSLAM, it handled new data efficiently using previous key feature points. The distance estimated by the RTAB is not better than that of ORB SLAM.



(a) (b)

fig. 7: (a) RTAB SLAM Mapping (b) ORB-SLAM Mapping

During tests it was observed that the localization error in RTAB was more than compared to ORB-SLAM and in our application of plants where there are repeated features of leaves, accurate localization becomes a vital factor in mapping the trajectory. The ORB-SLAM provided a good trajectory of the system and was also able to accurately map the area as can be seen in *fig. 7(b)*.

5. CONCLUSION AND FUTURE WORK

With the analysis of data, we can conclude that the NDVI and ORB-SLAM were successfully implemented to determine the plant health and mapping of the area respectively. The way forward is to combine the results from all the sensors simultaneously to map a greenhouse and provide plant health data by mounting the whole on a drone. The drone can fly over the greenhouse to capture images. The SLAM will help to figure out specific locations where the health conditions of plant need to be observed. The fused system will output us results as shown in *fig. 8*. Based on the data the researchers could figure out the environment conditions required to maintain the optimum health of the plant.

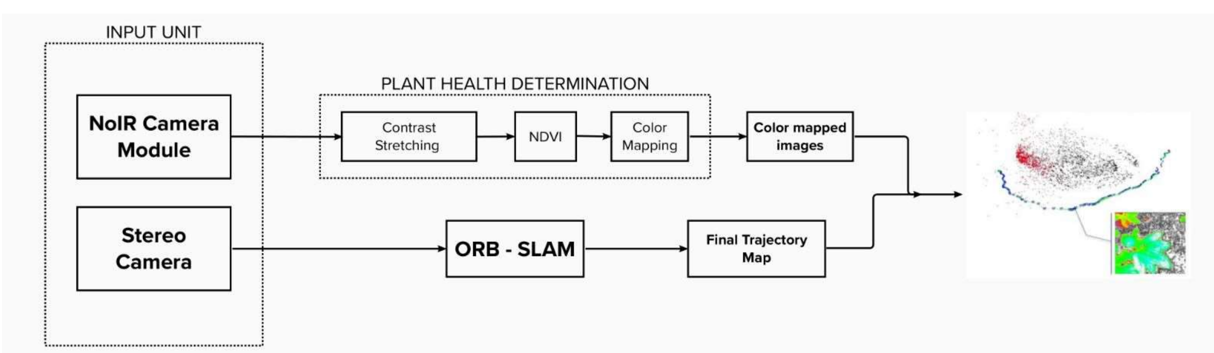


fig. 8: Working methodology of the overall sensing and navigation system.

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