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Senior Design: Design Document

Project Objectives

A robust method of terrain traversal in autonomous robots is crucial to applications such as disaster response, navigation in alien landscapes (ex. surface of the moon, Mars, etc.), and creating humanoid robots. Current research towards creating autonomous robots focuses on physically robust algorithms governing the kinematics of the robot to address the variety of possible terrains. This approach towards robot movement uses brute force, requiring motion algorithms to be able to accommodate an incredibly broad range of worst case scenarios. Not only is this illogical for pathway traversal in new landscapes such as those in space and those in disaster zones, but it is also unlikely that the humanoid robots we hope to interact with would move in such a fashion.

Using computer vision algorithms and new depth imaging technology, my project will identify different terrain sections, classify terrain types, and rank terrain sections based on the ease of mobility in the terrain for a multi-legged robot. By mounting a tablet with depth imaging capabilities to be front-facing on a multi-legged robot, I will use images from the forward path to calculate the best traversal path for the robot based on an understanding of the different terrains that paths would cross to choose a final path that is easier to navigate. My project aims to show that, given an environment with a variety of terrains and a starting and end point, elucidating best paths for traversal based on terrain type will increase the ease of robotic traversal by avoiding the kinematic problems faced by rough terrains.

Main Components

The proposed project will utilize a Structure sensor connected to an iPad Air 2, both mounted on a multi-legged robot. The Structure sensor uses a near-infrared (near-IR) emitter and receiver to measure depth, information which is calibrated to correspond with the RGB images captured by the iPad camera. This data capture system will feed images and depth data to the algorithm, which will in turn direct the multi-legged robot's movements.

The benefit of adding the dimension of depth to imaging is that depth images are lighting invariant, unlike RGB images, which are subject to changes in lighting. Changes in lighting are responsible for issues with traditional imaging such as shadows and illumination, classical challenges in computer vision that, despite decades of research, remain tough to address. Adding depth imaging will allow for the computer vision algorithms implemented in this project to bypass these challenges and for my project to focus on terrain traversal rather solving problems associated with traditional imaging.

The multi-legged robot used will take output from the algorithm, which classifies terrains in front of the robot and ranks terrains based on the robot's mobility on various terrains. This output will influence the robot's future path decisions. Since current robotics focuses less on being able to avoid obstacles and more on being able to be physically robust in different terrains, this project's unique contribution will be to impart the robot with some understanding of the terrain in front of it, allowing for choices to be made so that the path chosen is the most easily traversable.

Pathway Scenarios

Terrain traversal can be likened to scene understanding, a fundamental problem in computer vision that has yet to be solved. However, unlike scene understanding, there is yet to exist any clearly defined classes of terrains for understanding. For my project, I propose that terrains be measured by two categories: the smoothness of the surface and the incline or decline detected, if any. Within these two categories, there should be a sliding scale metric of robot mobility. For example, a non-smooth surface could simply have one or two bumps with radius smaller than a centimeter each, which would be an easier surface for a robot to traverse than an extremely mottled surface. With cliffs, as the angle of the incline or decline increases, a robot is much less likely to be able to traverse that terrain.

Parts of the terrain that share similar attributes will become segmented together. For example, a patch of terrain that is of similar smoothness with the same angle incline will be classified as a single terrain segment. After the entire scene has been segmented into terrain groups, they will be ranked based on how easy it is for multi-legged robots to navigate on the terrain.

Users

This project will be accessible to users through an iPad application that will visualize what the algorithm is producing. Since the sensors will be forward facing, the application will display the real-time images the sensor is capturing in a greyscale depth map, with terrains found labeled in colors indicating how easily traversable each terrain is in relation to one another. For example, terrains that are difficult to traverse will be labeled with colors towards the red side of the color spectrum and terrains that are difficult to traverse will be labeled with colors toward the blue side of the color spectrum. An ideal path will be mapped out over the depth image in white and will be recalculated every few seconds as the robot moves to a new section of the terrain.

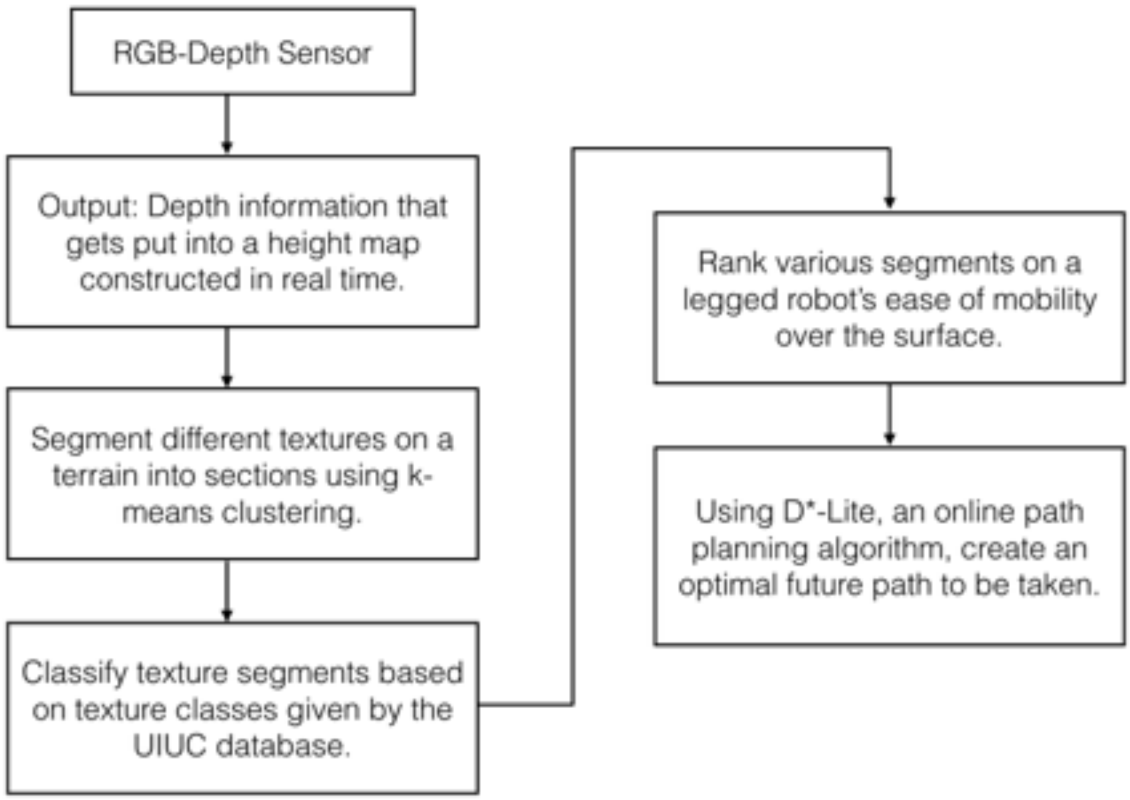
The user-facing side of my project will primarily be used by those engaging in this research to provide them with a qualitative understanding of how the algorithm is working from a visualization of the ranking algorithm. This should equip them with further intuition about how the algorithm is working, scenarios in which the algorithm is not performing robustly, and common failure cases. Accessing information from the application will require the user to open the application on the iPad and attach it to the robot before beginning a test terrain traversal. My application will have additional functionalities to provide more information about the scene such as height information on various points in the scene, outputting classifications of terrain types, and mapping the other pathways considered.

Functional Requirements

The application should be able to read accelerometer and gyroscope data from the iPad to calculate the distance and direction in which the robot has moved. This data will be combined with the depth information output by the depth sensor to create a real-time height map of the scene that allows for users to keep track of salient points in the scene and keep the height map egocentric.

The three main components of this project will also display their outputs to the user. As different terrain textures are segmented using k-means clustering into different segments, segments will be overlaid with different colors indicating different clusters. The classification of these textures against preexisting texture templates from the University of Illinois Urbana-Champaign will output a number corresponding to the class on the texture segment. Ranking the textures will be based on a pre-determined set of texture rankings from the pre-classified texture types, and path planning will occur using the D* online path planning algorithm.

Visual Representation



Non-Functional Requirements

This application will work in real-time by discarding a certain percentage of frames and only creating the height map from a fraction of the frames given by the real-time video feed. The user interface will be simple, only displaying the height map, the color segmentation, the segment texture classification, and the ultimate path generated by the D* algorithm. This will allow for simpler interactions with the outputs from the application and allow for the user to gain further intuition from the output. Given sufficient time and ability to implement components of the Structure SDK, I also hope to be able to stream the contents of the iPad display to a corresponding Mac application, allowing for users to view outputs from a stable display.