Outdoor Terrain Traversability Analysis for Robot Navigation using a Time-Of-Flight Camera

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Autonomous robotic systems operating in unstructured outdoor environments need to estimate the traversability of the terrain in order to navigate safely. Traversability estimation is a challenging problem, as the traversability is a complex function of both the terrain characteristics, such as slopes, vegetation, rocks, etc and the robot mobility characteristics, i.e. locomotion method, wheels, etc. It is thus required to analyze in real-time the 3D characteristics of the terrain and pair this data to the robot capabilities.

Stereo cameras or 3D laser range finders are generally used as input devices for traversability analysis and two main approaches can be distinguished. There are the methods as the ones advocated by Labayrade (1) and Mufti (2) who assume a (piecewise) planar ground plane. They estimate the ground plane, set a threshold and consider objects with distances to the ground plane further than this threshold as obstacles. Other methods, as the ones proposed by Birk (3) and Helmick (4) search for specific types of objects (rocks, canyons) and classify the image based on this data.

To our knowledge, time-of-flight cameras have until now not been used for these kind of applications, simply because there were no sensors capable of coping with outdoor conditions, especially due to the interference of solar irradiation. This situation is changing now, with the advent of outdoor-capable sensors. Therefore, we present in this paper an approach for outdoor terrain traversability which mixes 2D and 3D information for terrain classification.

The methodology towards time-of-flight-based terrain traversability analysis extends our previous work on stereo-based terrain classification approaches (5). Following this strategy, the *RGB* data stream is segmented to group pixels belonging to the same physical objects. From the *Depth* data stream, the $v-disparity$ (1) is calculated to estimate the ground plane, which leads to a first estimation of the terrain traversability. From this estimation, a number of pixels are selected which have a high probability of belonging to the ground plane (low distance to the estimated ground plane). The mean a and b color values in the *Lab* color space of these pixels are recorded as $\mathbf{c}$. The result of both data streams is then combined to optimize the classification result. For each pixel i in the image, the color difference $\|\mathbf{c}_i - \mathbf{c}\|$ and the obstacle density in the region where the pixel belongs to are calculated. The obstacle density δ_i is here defined as: $\delta_i = \frac{\langle o \in A_i \rangle}{\langle A_i \rangle}$, where o denotes the pixels marked as obstacles (high distance to the estimated ground plane) and A_i denotes the segment where pixel i belongs to. This allows us to define a traversability score as $\tau_i = \delta_i \|\mathbf{c}_i - \mathbf{c}\|$, which is used for classification. This is done by setting up a dynamic threshold, as a function of the distance measured. Indeed, as the error on the depth measurement increases with the distance, it is required to increase the tolerance on the terrain classification as a function of the distance. An important issue when dealing with data from a time-of-flight sensor is the correct assessment of erroneous input data and noise. Therefore, the algorithms combines information from the 2D intensity image (indicating the intensity of the measured irradiation) with 3D distance data. Regions with low intensities and a large variance in distance measurements are therefore automatically detected and marked as "suspicious".

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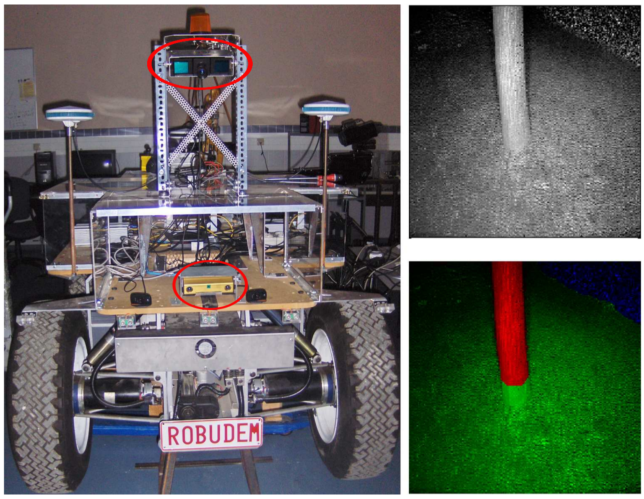

Figure 1: Left: System setup - Outdoor robot with a Time-Of-Flight Camera (on top) and a Stereo Camera (in the middle); Top Right: Amplitude Image; Bottom Right: Traversability Estimation (green: traversable; red: obstacle; blue: suspicious / not enough data)

Figure 1 shows the Robudem platform which was used as a testbed for the presented algorithms. It is a heavy outdoor robot equipped with a PMDTec CamCube time-of-flight sensor (on top) and a Point Grey Bumblebee stereo camera (in the middle). The time-of-flight camera is mounted in a tilted angle to avoid typical signal modulation problems. The top right image shows the amplitude input image, whereas the bottom left image shows the terrain classification result. Obstacles are red, well traversable terrain is green and "suspicious" areas (not enough data) are blue. It can be noticed that the classification is correct, as the obstacle (the tree) is well-detected. In the upper left corner, there are some problems with foliage giving erroneous reflections (blue area), which is due to the sensor.

A video demonstration of the presented algorithm is available on http://www.youtube.com/watch?v=CNFc5qPvnB0

References

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