Vision based Obstacle Detection in Rough Terrain

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Application
Motivation & Goal

- GNSS based agricultural guidance systems like AutoTrac™
  - are not able to detect static or dynamic obstacles on the pre-calculated path (e.g. parallels, curved tracks)
  - can cause driver fatigue which may lead to accidents
- Thus, obstacles like trees, transmission poles, other machinery can cause severe accidents or personal injury
Stereo System

- Specifications
  - Resolution 1024 x 768 pixel
  - Frame rate 20fps
  - Baseline 12cm
  - Cameras already aligned in one housing
  - Connection (FireWire and GPIO)
  - Focal length 2.5mm
    - 97° HFOV
    - Very distorted output
1. Acquisition

- Camera delivers a synchronized image pair
- Point cloud acquisition steps
  - Undistortion
  - Rectification
  - Scaling
  - Stereo matching (Block Matching)
- Devices now becoming available where these computationally expensive tasks are calculated on the camera’s electronics
2. Grid Generation

- The following steps are executed to pre-filter the point cloud (3D distance data)
  - Engine hood and wheels are removed from the data
  - Desired volume is extracted (errors become to large after a certain distance)
  - Point cloud is subdivided using a 2D grid to speed up following steps
3. Pre-Processing

- Estimation of a ground guess
  - Extracting the lowest z-coordinate from the cells
  - Calculating a dominant ground plane using least-squares fitting
  - Extracting an initial ground guess from the plane if the cell is empty or the lowest z-coordinate is too far from the plane
  - Applying a Gaussian blur to the matrix of z-values to reduce the influence of cells which do not provide ground points
4. Parallelized Cell Evaluation (1)

- Cells are analyzed individually and parallelized

Steps

- 3D points density test
  - number of points
  - volume of bounding box

- Cell is classified as an obstacle if extreme values are present
  \[ p_{1z} > z_{\text{max}} \lor p_{n_z} > -z_{\text{max}}, \] where \( z_{\text{max}} \) is based on max. drivable slope
4. Parallelized Cell Evaluation (2)

- If the z-range $p_{nz} - p_{1z} > \text{vehicle height}$, the point cloud is clustered into two segments or the ground guess is used to separate drivable overhangs.
- After overhanging points are separated (or if no overhang was present):
  - application of a smoothing and a statistical outlier filter
  - again a density test is performed
4. Parallelized Cell Evaluation (3)

- Cell is classified as an obstacle if
  - the range is too big: $p_{mz} - p_{l_z} > t$, where $t$ is based on the ground clearance
  - the highest point is above the reachable position: $p_{mz} > z_{max}$
- As a last step,
  - a plane is fitted to the points using least-squares fitting.
  - special fitting if all points form a line
  - cell is classified as an obstacle if the slope exceeds a threshold.
Neighborhood Evaluation

- After cells are individually classified, the neighborhood is taken into account:
  - Cells which are surrounded by more than 2 opposite obstacles will be classified as obstacles.
  - Cells will be classified as obstacles if the slope (calculated using the mean cell height) to neighboring cells exceeds a threshold.
  - Scattered drivable cells which are surrounded by obstacles are eliminated in a final flood fill step.
Derived Values

- Terrain estimation
  - Using the ground estimation (step 3) and the medium height of non-obstacle cells
  - Output: Triangle mesh

- Clustered point cloud
  - Ground point cloud
  - Connected cells are clustered and outputted as individual, colored point clouds
  - E.g. for further obstacle classification
6. Mapping, Trajectory Evaluation, Velocity Ctrl

- Obstacles are stored in a local map around the vehicle to
  - increase detection robustness
  - eliminate false positives
  - test for intersections with the planned trajectory

- If the calculated track is blocked by an obstacle, the speed is reduced and the vehicle is brought to halt
Field Results
Forest Results
Quantitative Results

- 100 randomly selected stereo pairs (from 100k recorded)
- Ground-truth was manually set for each grid cell
- Average precision: 81.76%, recall: 93.16% and an accuracy of 99.41%
- False positive detections
  - were caused by weeds sticking out of the ground
  - cells connected to real obstacles which appear larger in the stereo cloud
  - wrong slope estimations at the border of the camera’s FOV
Thank you for your attention!