Computational Geometry in Robotics: Digital Terrain Modeling

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Modern robotics systems rely on artificial intelligence. A part of that intelligence relies on using cameras to understand its surroundings, recognize objects, and avoid hazards. Computer Vision algorithms help robotics systems process images and videos in real time in order to translate visual information in digital models. Using 2D images, a 2.5D or 3D model can be maintained on the device. Once a robot has a model of the terrain, it can then determine traversable parts of the terrain, plan paths to reach a goal and avoid hazards in real time.

In order to determine depth from stereo 2D images, the position of an object in both images is compared. This disparity is used to calculate the depth of the object in the image. The challenge of this process is determining the objects and features in images to use for stereo matching. Reducing the points that need to be compared improves speed but reduces accuracy. Delaunay Triangulation has been used in stereo matching algorithms to allow real time processing.

Historically significant methods for stereo matching were researched. The Jet Propulsion Laboratory developed the first stereo matching algorithms used in early planetary rovers. These rovers used stereo matching algorithms to create digital terrain models used for autonomous operation. Modern methods were researched that improved these algorithms for use in real time systems that extend the capability of autonomous rovers.

Stereo Matching for computer vision has been common practice in NASA robotics systems since the early 80s. NASAs most recent Mars rovers are equipped with Computer Vision systems for Hazard avoidance, path planning, entry decent and landing, and digital terrain modeling. The Hazcam system uses multiple pairs of stereo cameras to map surrounding terrain, building an internal map that details areas for safe traversal. The Carnegie Mellon Algorithm involves comparing 7x7 pixel windows of a left image with all pixels in a right image in order to find correlating pixels. This process was not capable or designed to operate in real time. This limits autonomous rover operation to around 200 meters per day, building small terrain maps on a daily basis that enable path planning.

Modern computational geometry algorithms help robotics systems move to more efficient hazard detection systems. These algorithms allow for depth perception using stereo cameras in real time. These algorithms can be easily parallelized. The improvement comes from the reduction of the search space of pixels in an image by using triangulation of features to add context to the image. This greatly improves the efficiency and accuracy of matching pixels in stereo images.

This can be further improved by reducing the search space to an even smaller amount, using sparse feature detection. It has been shown that this reduces accuracy, but when done iteratively, performs effectively in real time.