3D Reconstruction with Bundle Adjustment (SSJ1-15)

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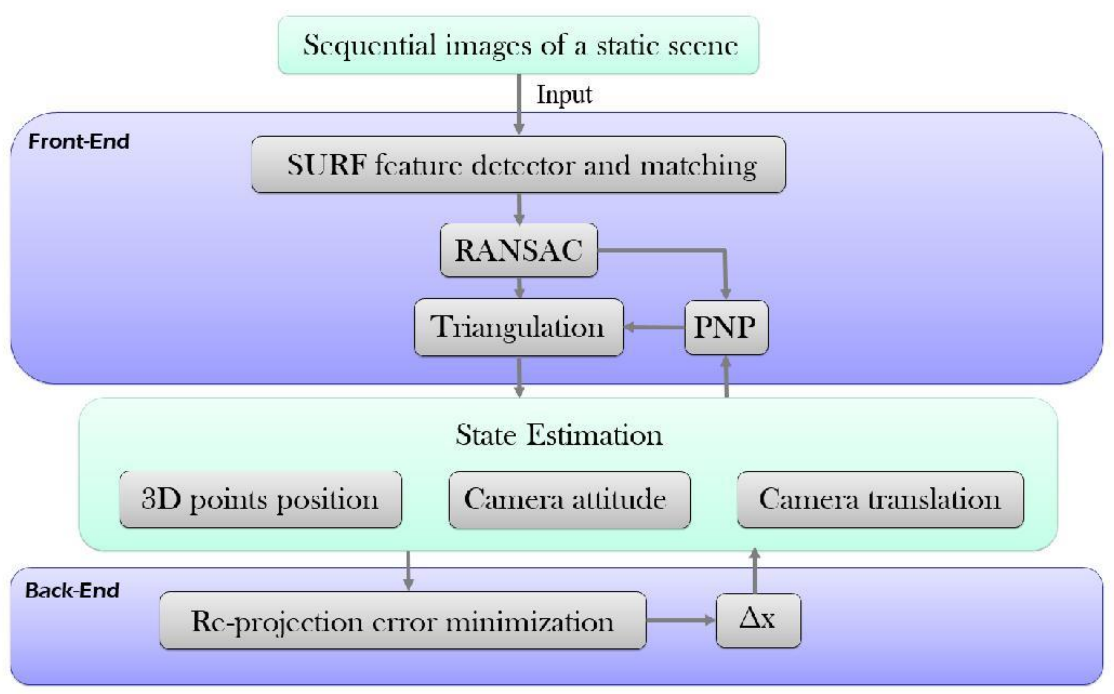
Overview

Robots are playing an increasingly important role in our lives, and they are often applied to unknown and intricate environments to carry out tasks such as search and rescue. In order for robots to navigate around and interact with their surroundings, an accurate perception or modeling of the environment is essential. A precise and detailed 3D map of the working area can not only give robots the necessary information to operate, but also efficiently assist humans by providing a global visual description of the region so that they can make better decisions.

There are numerous ways to obtain a 3D model of the environment. Simultaneous Localization and Mapping (SLAM) as an effective method to generate such a model has been the center of attention in robotics vision research in the past few decades. Graph-Based SLAM is one of the most recent and efficient methods in solving robot poses and environment modeling at the same time. Our project is to explore the application of Graph-Based SLAM on images, and analyze the employment of Bundle Adjustment method. This project will serve as an example of the applications of Graph-Based SLAM algorithm and investigate the effective ways to integrate theory and practice.

System Flow

This project is designed to reconstruct a 3D model of the environment and optimize the result using Bundle Adjustment.

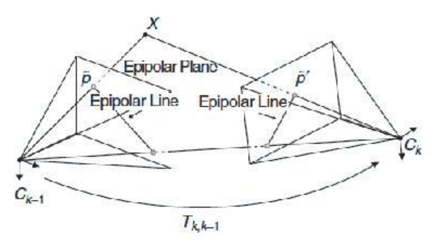


The front-end takes images as input and construct a state estimation which includes 3D point positions and camera poses. The back-end optimizes the state estimation by minimizing the reprojection error of all measurements.

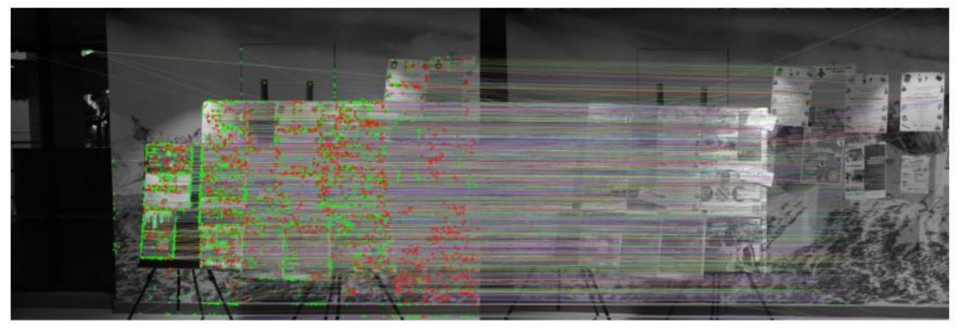
Methodology

Front-end

The program first takes a sequence of images from a scene as input, and finds matching feature points by *SURF detector*. The points on image are related to the points in space by *camera model*. With the matches between the first two images, the relative pose and position of the two cameras using can be recovered and the 3D points can be triangulated using *epipolar constraints*.



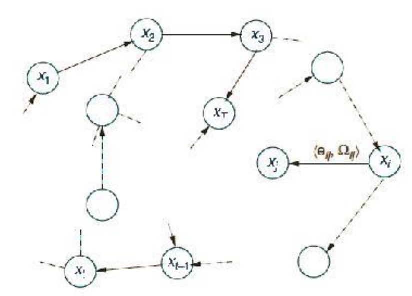
For multiple images, in order to preserve scale, *Perspective N-Points (PnP)* algorithm is implemented. With correspondence between constructed 3D points and 2D features in the new image, the pose of the new camera can be calculated without losing scale. New 3D points can then be reconstructed and successfully merged to the old points.



The above image shows the matching result of two adjacent images. Green points indicate all matches returned by SURF detector and red points indicate features that do not exist in past images.

Back-end

The back-end uses a method called Bundle Adjustment. Our goal is to find a state, namely 3D points and camera poses that minimizes the total error of all measurements.

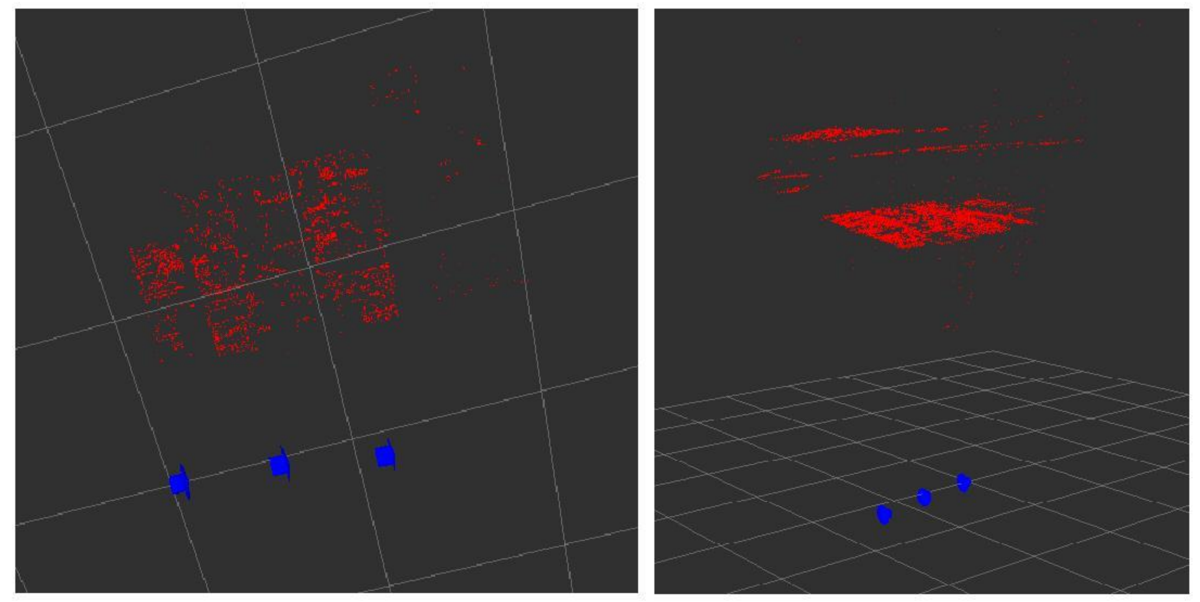


For each measurement of each point the error is taken as the difference of its observation and reprojection on the camera image plane. It can be proved that this minimal error sum corresponds to the maximum log likelihood in the probability distribution of the state. In Graph-Based SLAM it is the optimal node configuration of the graph.

Solving the least square problem involves linearizing the error term to obtain a Jacobian for every iteration until a converged result is found. For every iteration a linear system is constructed from the current state and error, also the Jacobian. Solving the linear system gives a state increment, and the updated state can be used in a new iteration. When the error is small enough, the optimal state is obtained.

Result

This is the scene that we are testing our algorithm on. A board and a few papers hanging in front of the wall with plenty of features to detect.



Here is our reconstruction result shown on RViz software. The three blue arrows are cameras and the red points are 3D points. The direction of the arrows show the direction of the x-axis of the camera frame. The points shows the wall at the back, the pictures hanging before the wall, and the board on the left.

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