Vision Aided Navigation
Project Report

Over the semester we implemented a system that estimates the trajectory of the vehicle from a video captured with an onboard stereo camera.

The system uses a suite of algorithms in several stages to achieve this goal. In the final project report we present the different parts of the system, explore their properties and the quality of the estimation.

Present in your own words the different stages of the system. Summarize the ideas and algorithms as you comprehend them. The discussion should include:

1. Introduction and overview: provide a brief background and explain why the problem is important.

2. Code: For each stage of the process what is the relevant code that implements this stage. State what functions are used in the process, what each one does and where in the code it can be found (function name, file name, line number)
The code should be readable and well documented.

3. Performance Analysis (חקר ביצועים): A detailed quantitative and qualitative analysis of the different stages of the system.

4. Discussion and Conclusions: Summarize the report and provide some criticism: identify weak points, unrealistic assumptions or aspects that could be improved. Suggest how you would improve the system and what are good directions for future research.

Performance Analysis

Present any graph, figure or statistic that demonstrates the performance of the different stages of the system as well as the system as a whole.
For each graph, provide an analysis of the information presented in the graph, highlight what the graph shows and explain what aspect (positive or negative) it demonstrates.
Where appropriate combine different data in the same graph. Zoom in such that the data is presented in a meaningful manner.

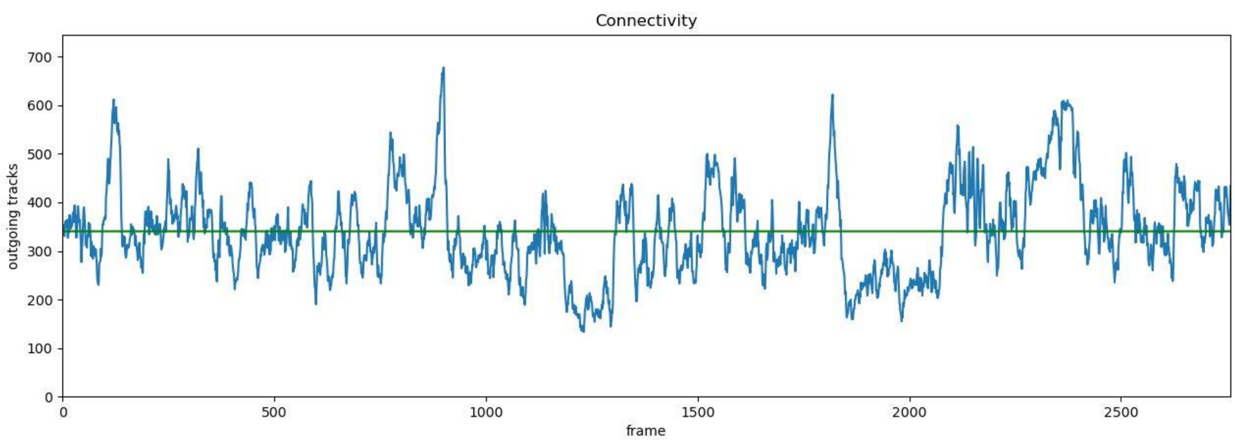
Present the following tracking statistics:

- Total number of tracks
- Number of frames
- Mean track length
- Mean number of frame links
- A graph of the number of matches per frame
- A graph of the percentage of inliers per frame

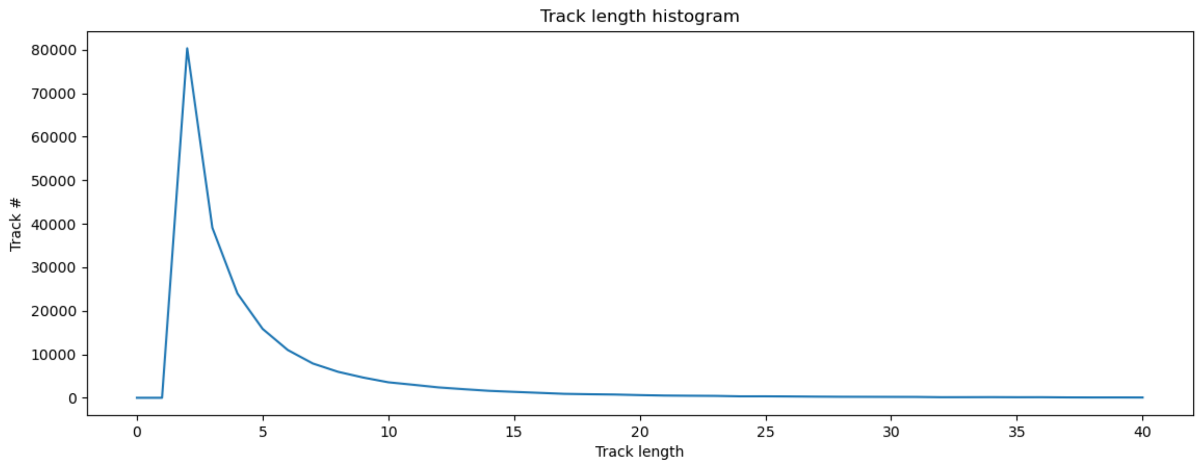
Add any graph / figure that you think presents of the information and demonstrates the ideas you want to convey. A list of suggested graphs includes:

Note: While including all the suggested graphs is not mandatory for a perfect grade, it should include at least a substantial subset of them, and enough to convey the main points.

- Connectivity: For each frame, the number of tracks **outgoing** to the next frame (the number of tracks on the frame with links also in the next frame)

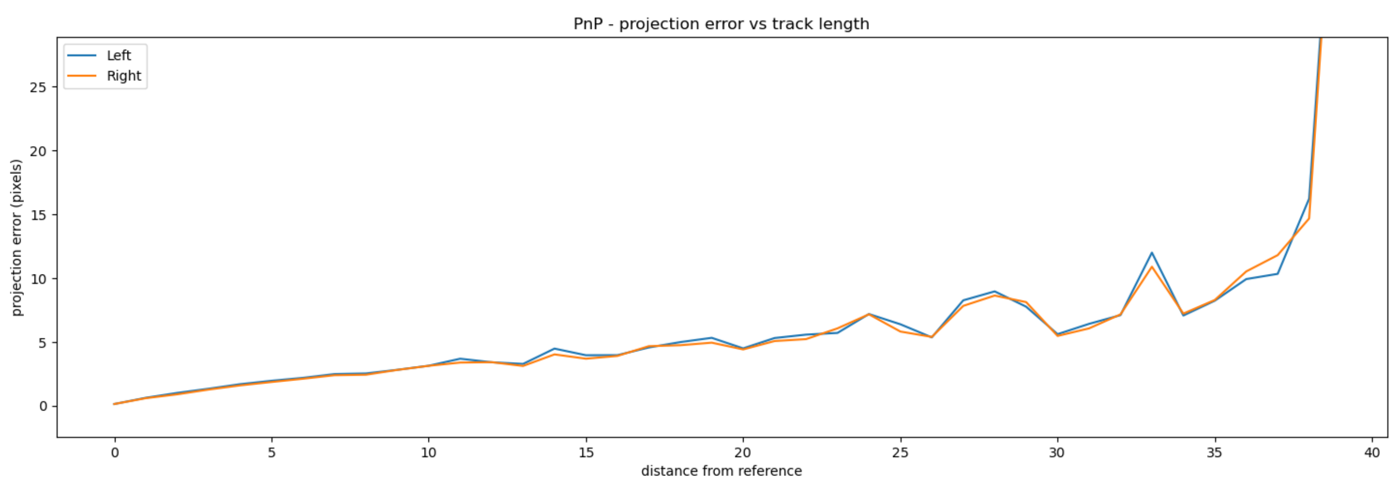


- Track length histogram



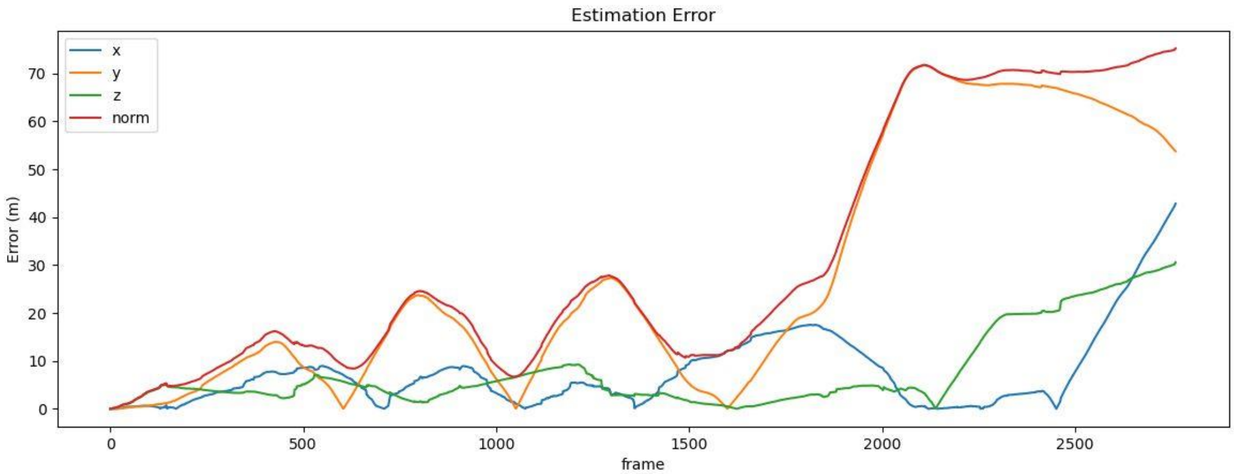
- Median (or any other meaningful statistic) projection error of the different track links as a function of distance from 1st frame the track appeared on
  - for PnP estimation
  - for Bundle estimation

  Note that for this and other similar graphs the required information can take a while to collect for all the tracks. A graph of a representative subset of the tracks can be a good approximation - Explain how you chose this subset.



- Median (or any other meaningful statistic) factor error of the different track links as a function of distance from 1st frame the track appeared on
  - for PnP estimation (initial solution)
  - for Bundle estimation (optimization result)

- Absolute PnP estimation error:
  - X axis error, Y axis error, Z axis error, Total error norm
  - Angle error



- Absolute Pose Graph (**without** loop closure) estimation error:
  - X axis error, Y axis error, Z axis error, Total error norm
  - Angle error

- Absolute Pose Graph (**with** loop closure) estimation error:
  - X axis error, Y axis error, Z axis error, Total error norm
  - Angle error

- Relative PnP estimation error:
  The error of the relative pose estimation compared to the round truth relative pose. This can be between every two consecutive frames or between every two consecutive keyframes
  - X axis error, Y axis error, Z axis error, Total error norm
  - Angle error

- Relative Bundle estimation error:
  - X axis error, Y axis error, Z axis error, Total error norm
  - Angle error

- Number of matches per successful loop closure frame
- Inlier percentage per successful loop closure frame

- Uncertainty size vs keyframe – pose graph **without** loop closure:
    - Location Uncertainty
    - Angle Uncertainty

- Uncertainty size vs keyframe – pose graph **with** loop closure:
    - Location Uncertainty
    - Angle Uncertainty

  How did you measure uncertainty size? How did you isolate the different parts of the uncertainty?

Relative error:

Some stages in our process estimate the relative pose between two poses. A suitable measure of the accuracy should also be relative. To check the error of a relative pose estimate we compare the ground truth relative pose between two poses c_a, c_b to the estimated relative pose. Comparing the rotation difference is not straight-forward, we addressed this in two posts in the course forum, here is a summary:

Rodrigues formula represents a rotation as a 3D vector. The direction of the vector is the axis of rotation, and the size of the vector is the magnitude of the rotation in Radians.

For the size of a rotation represented by rotation matrix R (for example the relative rotation between c_a and c_b, $R = R_a^T R_b$) in degrees:

```
rvec, _ = cv2.Rodrigues(R)
np.linalg.norm(rvec) * 180 / np.pi
```

To get the Euler angles (in Radians) of the rotation matrix R:

```
# rotation matrix --> Euler angles
def rotation_matrix_2_euler_angles(R):
  sy = np.sqrt(R[0, 0]*R[0, 0] + R[1, 0]*R[1, 0])
  singular = sy < 1e-6
  if not singular:
    x = np.arctan2(R[2, 1], R[2, 2])
    y = np.arctan2(-R[2, 0], sy)
    z = np.arctan2(R[1, 0], R[0, 0])
  else:
    x = np.arctan2(-R[1, 2], R[1, 1])
    y = np.arctan2(-R[2, 0], sy)
    z = 0
  return np.array([x, y, z])
```