HW3 Visual Odometry

Due: 2023/11/14 (二) 11:59 AM

3DCV 2023

Email: 3dcv@csie.ntu.edu.tw

GitHub Classroom: https://classroom.github.com/a/uTe6xq4r

GitHub Registration: https://forms.gle/R9JBiAAehcYyvoUu9

Goal: Visual Odometry

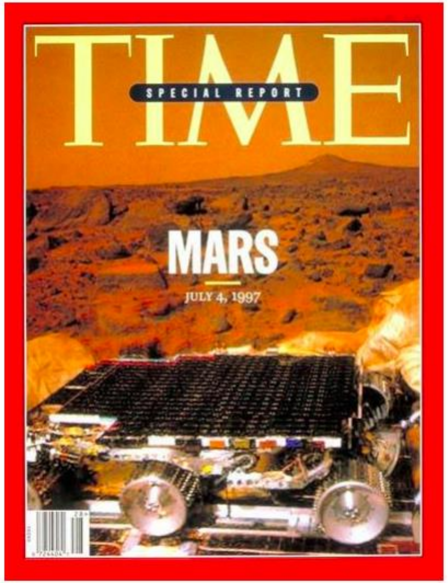
- Odometry

  Estimating change in position overtime

- Visual Odometry

  Estimating the motion of a camera in real time using sequential images (i.e., ego-motion)

- Difference from SLAM
  - VO mainly focuses on local consistency and aims to incrementally estimate the path of the camera pose after pose
  - SLAM aims to obtain a globally consistent estimate of the camera/robot trajectory and map



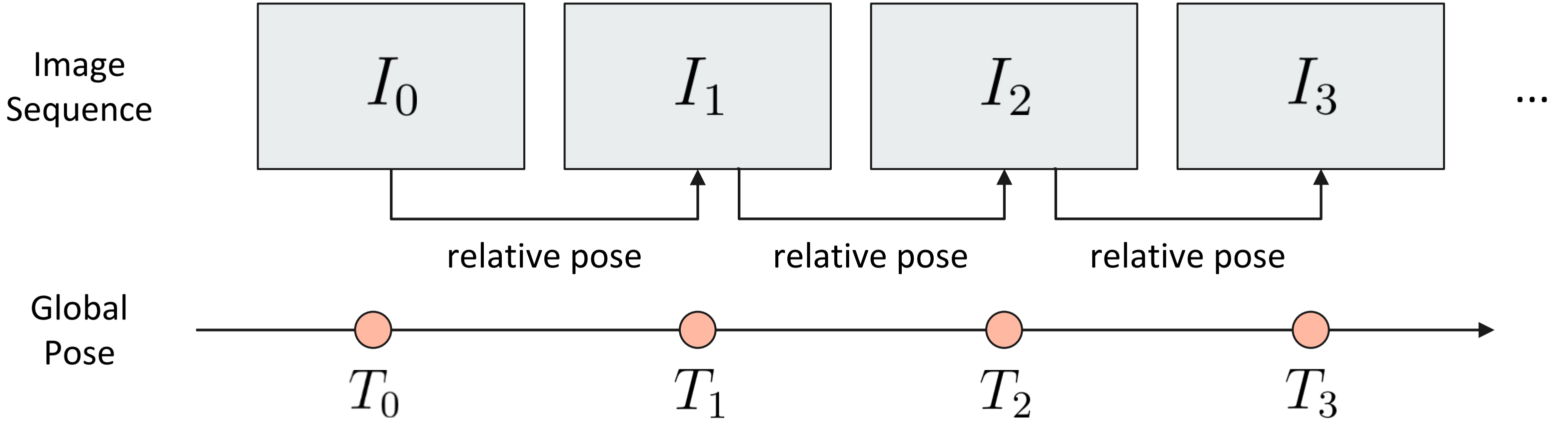
Pathfinder landing, 1997

ref: http://www.cs.toronto.edu/~urtasun/courses/CSC2541/03_odometry.pdf

Goal: Visual Odometry

Implement a VO based on two-view epipolar geometry

- Input: a provided image sequence and the camera intrinsic
- Output: a sequential global camera pose (w.r.t. the coordinate system of the 1st frame)
- You are **allowed to use any OpenCV API**



Step 1: Camera calibration

We have introduced camera calibration (slide)

Just calibrate the camera with the provided program to obtain camera intrinsic matrix and distortion coefficients

[How to use]

- $ python3 camera_calibration.py [CALIBRATE_VIDEO]

  Use "python3 camera_calibration.py --help" to check more argument information

  Enter SPACE key to add new frame to calibrate
- The program will save "camera_parameters.npy" by default

  Checkout "vo.py" template to know how to read the npy file

https://youtu.be/H1OzJPKYOFQ

Step 2: Feature Matching

We recommend to use ORB [Rublee 2011] as feature extractor

- faster than SIFT over 10x
- binary descriptor
- orientation and scale invariance
- Compute **Hamming distance** for binary feature matching
- Sample code:
  https://docs.opencv.org/4.5.1/dc/dc3/tutorial_py_matcher.html

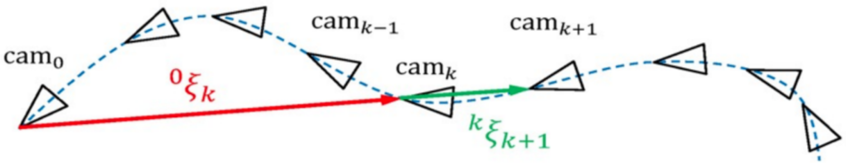
```
# create BFMatcher object
bf = cv.BFMatcher(cv.NORM_HAMMING, crossCheck=True)

# Match descriptors.
matches = bf.match(des1,des2)
```

Rublee, et al. ORB: An efficient alternative to SIFT or SURF. ICCV, 2011.

Step 3: Pose from Epipolar Geometry

- Recap: page 13 in [Slide 21]



Visual odometry from 2D-correspondences

1. Capture new frame img_{k+1}
2. Extract and match features between img_{k+1} and img_k
3. Estimate the essential matrix $E_{k,k+1}$
4. Decompose the $E_{k,k+1}$ into ${}^kR_{k+1}$ and ${}^k\boldsymbol{t}_{k+1}$ to get the relative pose
$$ {}^k\xi_{k+1} = [{}^kR_{k+1} \quad {}^k\boldsymbol{t}_{k+1}] $$
5. Calculate the pose of camera $k+1$ relative to the first camera
$$ {}^0\xi_{k+1} = {}^0\xi_k \, {}^k\xi_{k+1} $$

Step 3: cv2.findEssentialMat

Step 4: cv2.recoverPose

Step 3: Pose from Epipolar Geometry

- Recap: Scale consistency in page 17 in Slide 20

  By default, the translation t from cv2.recoverPose is normalized to unit norm

  You have to rescale t according to previous triangulated points

A better visual odometry algorithm can look like this

- How to compute $\|{}^{k+1}\boldsymbol{t}_k\|$ from $\|{}^{k}\boldsymbol{t}_{k-1}\|$?
- Determine two scene points ${}^{k}\boldsymbol{X}_{k-1,k}$ and ${}^{k}\boldsymbol{X'}_{k-1,k}$ by triangulation of two 2D-correspondences ${}^{k-1}\boldsymbol{x} \leftrightarrow {}^{k}\boldsymbol{x}$ and ${}^{k-1}\boldsymbol{x'} \leftrightarrow {}^{k}\boldsymbol{x'}$
- Determine the same two scene points ${}^{k}\boldsymbol{X}_{k,k+1}$ and ${}^{k}\boldsymbol{X'}_{k,k+1}$ by triangulation of two 2D-correspondences ${}^{k}\boldsymbol{x} \leftrightarrow {}^{k+1}\boldsymbol{x}$ and ${}^{k}\boldsymbol{x'} \leftrightarrow {}^{k+1}\boldsymbol{x'}$
- Then

$$\frac{\left\|{}^{k-1}\boldsymbol{t}_k\right\|}{\left\|{}^{k}\boldsymbol{t}_{k+1}\right\|} = \frac{\left\|{}^{k}\boldsymbol{X}_{k-1,k} - {}^{k}\boldsymbol{X}'_{k-1,k}\right\|}{\left\|{}^{k}\boldsymbol{X}_{k,k+1} - {}^{k}\boldsymbol{X}'_{k,k+1}\right\|}$$

You can directly get triangulated points by cv2.recoverPose or further use cv2.triangulatePoints

Step 4: Results Visualization

- We provide template code (vo.py) of jointly showing current image and visualize camera trajectory in Open3D
- Draw the matched (tracked) point on current image
- Update the new camera pose in Open3D window
- Feel free to use any other 3D visualizer (e.g. pangolin) if you implement in C++

Template vo.py

We provide a template vo.py (tested in python3.6, 3.7, 3.8)

dependency: numpy, opencv-python==4.5.1.48, open3d==0.12.0

[How to run] python3 vo.py /path/to/frames/dir

```python
if __name__ == '__main__':
    parser = argparse.ArgumentParser()
    parser.add_argument('input', help='directory of sequential frames')
    parser.add_argument('--camera_parameters', default='camera_parameters.npy', help='npy file of camera parameters')
    args = parser.parse_args()

    vo = SimpleVO(args)
    vo.run()
```

```python
class SimpleVO:
    def __init__(self, args):
        camera_params = np.load(args.camera_parameters, allow_pickle=True)[()]
        self.K = camera_params['K']
        self.dist = camera_params['dist']

        self.frame_paths = sorted(list(glob.glob(os.path.join(args.input, '*.png'))))
```

We have already helped you read the camera parameters

Template vo.py

```
def run(self):
    vis = o3d.visualization.Visualizer()
    vis.create_window()

    queue = mp.Queue()
    p = mp.Process(target=self.process_frames, args=(queue, ))
    p.start()

    keep_running = True
    while keep_running:
        try:
            R, t = queue.get(block=False)
            if R is not None:
                #TODO:
                # insert new camera pose here using vis.add_geometry()
                pass
        except: pass

        keep_running = keep_running and vis.poll_events()
    vis.destroy_window()
    p.join()
```

```
def process_frames(self, queue):
    R, t = np.eye(3, dtype=np.float64), np.zeros((3, 1), dtype=np.float64)
    for frame_path in self.frame_paths[1:]:
        img = cv.imread(frame_path)
        #TODO: compute camera pose here

        queue.put((R, t))

        cv.imshow('frame', img)
        if cv.waitKey(30) == 27: break
```

Run two window (cv2.imshow and Open3D) in the same time

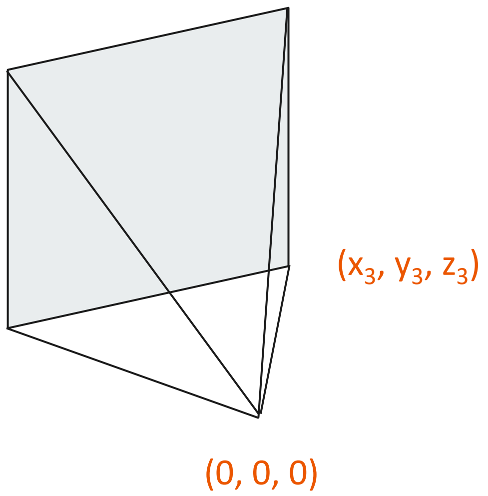
You can press ESC to kill each window

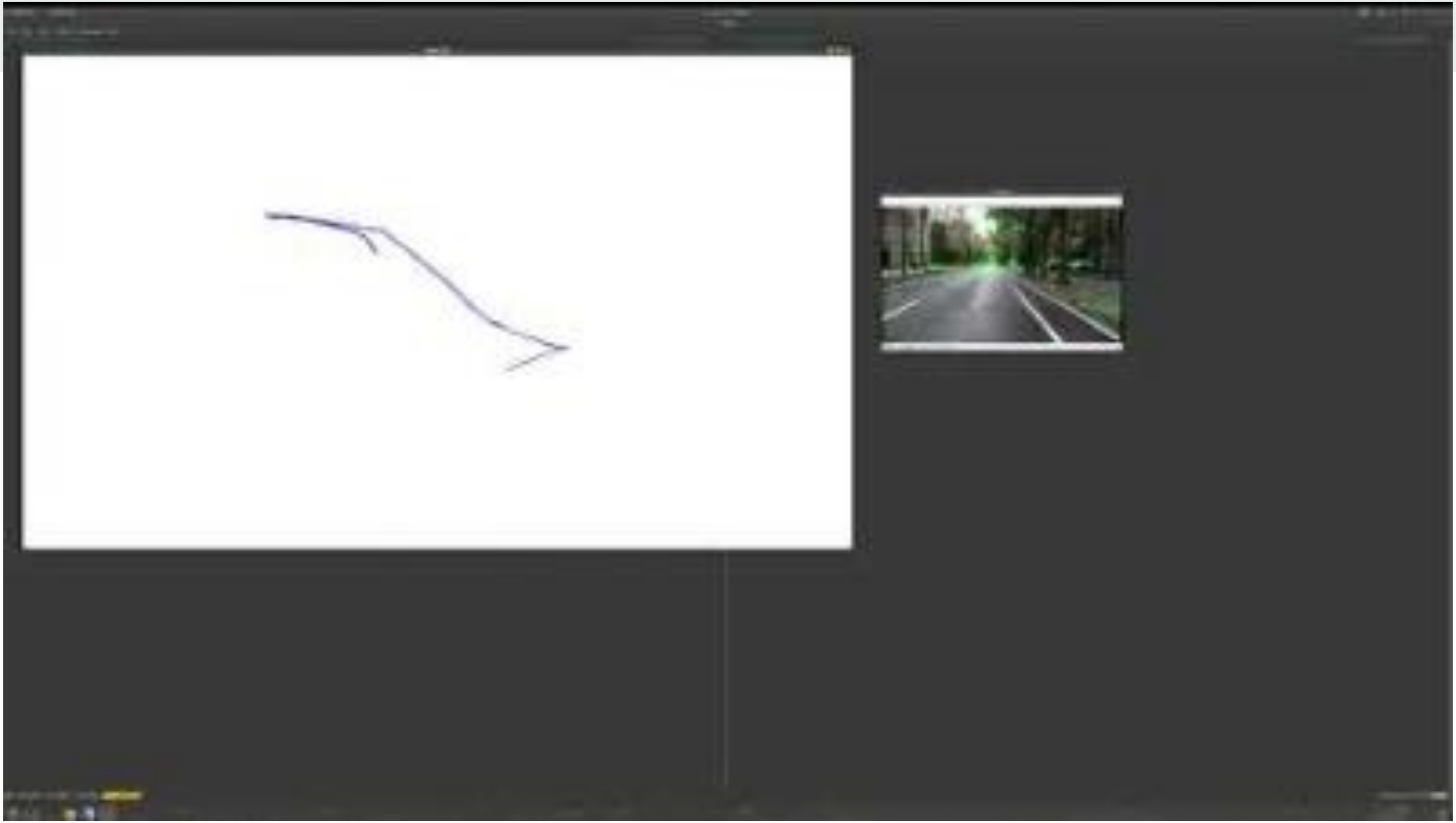
Add LinSet in Open3D

- Open3D LineSet tutorial
- The points of camera frame w.r.t. camera coord. sys., e.g.

$$\begin{bmatrix} x_3 \\ y_3 \\ z_3 \end{bmatrix} \sim K^{-1} \begin{bmatrix} w-1 \\ h-1 \\ 1 \end{bmatrix}$$

  z_3= 1 since the point is on the image plane (z=1)
- Finally, use R, t to transform (x_3, y_3, z_3) into global coord. sys.





https://youtu.be/nL9xXurote0

Report

- Briefly explain your method in each step
    - Camera calibration
    - Feature Matching
    - Pose from Epipolar Geometry (pseudo codes and comments)
    - Results Visualization
- Youtube link

① Your video should be like the video shown in **page 13**

② You should record your demonstration, including the start time and the GitHub clone action

- Example : https://youtu.be/-VnjVda7c8o?si=77nV7V1ngjZqoY5G

- Please tell us how to execute your codes, including the package used and the environment.

Bonus List

- Loop detection
    - only detect, please describe your loop detection method
    - provide a demo video of loop detection with showing message when loop detected
- Point cloud and bundle adjustment (i.e. SLAM)
    - local bundle adjustment for local map
    - global bundle adjustment (loop closing) after loop detection
- Any performance improvement in the VO
    - runtime speedup (from the original speed to the improved speed on your device)
    - qualitative comparison of the original trajectory and the improved trajectory
- Implement both cv2.findEssentialMat and cv2.recoverPose by your self

Bonus List

Notice

- OpenCV from pip does not contain sfm module. You can still find another way to use it, e.g. implement in C++
- The time performance is important since VO is an online application
- Please also explain how to run your bonus code

Grading

- We will evaluate both **the functionality of the code** and **the quality of the report**.
- **Functionality**: Can it run? How's the performance?
- **Quality**: theoretical/experimental analysis, observation, discussion, …
- Note that it **might be curved** based on overall performance of students.
- Grade
  - Meet the basic requirement (programming & report) → A
  - Basic requirement + advanced studies (programming & report) → A+

Grading Policy

- Push your code and report to the GitHub classroom.
- Programming Languages: Python (Python>=3.8), (C++)
- Report Format: PDF or Markdown

  (Warning for Markdown users: Latex equations cannot be rendered properly in GitHub)
- Late Submission: **-10% from your score** / day
- **Plagiarism: You have to write your own codes.**
- Discussion: We encourage you to discuss with your classmates, but remember to **mention their names and contributions in the report**.

Thanks

If you have any question, please email 3dcv@csie.ntu.edu.tw