Progress Report

Bardia Mojra

September 11, 2021

Robotic Vision Lab

The University of Texas at Arlington

1 Specific Research Goals

- Grant Proposal: Controls-Deep Learning Hybrid Systems for Industrial Cable Harnessing Applications. Focus on this for September (hard deadline).
- VPQEKF (IROS - Mar. 1st): Work on the paper, focus on this in October.
- NBV-Grasping (IROS - Mar. 1st): Work on tasks assigned by Chris, one day a week. Focus on this from November till March.

2 To Do

- Grant Proposal: I will work on this every day for the next 2-3 weeks, then I will move back on VPQEKF project.
- PVQEKF:
  - Write equations in LateX with description. — Done.
  - I will go over the paper once every morning and expand sections for 30 minutes to an hour.
  - Double-check my data prep implementation. Use KITTI Python module.
  - Test with Hilti dataset.
  - Add L2-norm and L2 loss features.
  - I need to separate the state observation and control input vectors from the
  - Develop object tracking and robust-to-truncation feature.
  - Get ROS environment up and running. I need to install Armadillo (C++) with a certain dependency configuration.
- Real-time pose estimation demo.
- NBV-Grasping:
  - Update URDF and Xacro files for UR5e to include a sensor, sensor mount (with offset), and the gripper. – Next
  - Add movement constraints for tables and scenes.

- Write two IK functions for gripper and sensor, one for each. It should plug-in with MoveIt configurator.
- Research and implement point-cloud data to training TensorFlow models.
- Learn and implement GraspIt package.

3 Reading List

- Leveraging feature uncertainty in the pnp problem [1].
- Normalized objects [2].
- NASA papers [3].

4 Progress

The following items are listed in the order of priority:

- Fellowship: I have already prepared an execution plan with steps and instructions. I prioritize this task moving forward until the end of the month. I am working on dissecting [4], [5], and [6]. [5] and [6]provide a relatively simple framework for modeling and estimating system behavior for *discrete elastic rods*. [4] introduces a straightforward and effective approach for manipulating cables and wires for harnessing applications. It is my understanding that the source code for these papers is available.
- VPQEKF: I continued working on the paper. It is still in the early stages; I will continue to review it and provide updates regularly. I wrote a section on Quaternion Algebra based on a book with the same name. It is added to this report in the next section. I also started working on the Hilti dataset.
- NBV Grasping Project: No updates. We are going to work on this project every Friday afternoon.
- PyTorch Tutorials: Transfer learning.
- Pose Estimation: On pause.

- SD Team: No update.
- EE Autonobots: No update.

5 QUATERNION ALGEBRA

Quaternion space is a non-minimal representation belonging to *SO(3)* Lie group.

5.1 Unit Quaternion

Moreover, the quaternion term from the dataset has *four terms* with $xyzw$ format. Hamilton's quaternion defined by 3 perpendicular imaginary axes i, j, k with real scalars x, y, z and a real term w which constraints other 3 dimension to a *unit magnitude.* Thus, the fourth term normalizes the vector's magnitude conveniently and preserves the 3D rotation (3 DOF). We define **Unit Hamiltonian** or **Unit Quaternion** as,

$$\begin{aligned} \mathbb{H}^1 \quad := \quad & \{q_{wxyz} = w + xi + yj + zk \ \in \mathbb{H} \mid \\ & w^2 + x^2 + y^2 + z^2 = 1\} \end{aligned} \tag{1}$$

Where superscript 1 in $\mathbb{H}^1$ denotes a unit quaternion space with 4 terms. There are two equal representations for $\mathbb{H}^1$ subgroup; thus, we provide a concise definition and notation for both to avoid confusion. The first representation is shown in **??** where the four terms of the quaternion are arranged in $wxyz$ order and it is represented by q_{wxyz}. The second quaternion is arranged in $xyzw$ format and is represented by q_{xyzw}. It is important to note the difference as both are used in our derivation and implementation.

$$q_{wxyz} = q_{xyzw} \ ; \quad q_{wxyz},\ q_{xyzw} \in \mathbb{H}^1 \tag{2}$$

5.2 Pure Quaternion

As previously mentioned, the three imaginary terms of the quaternion represent the 3D angles of interest in radians and the fourth dimension constraints the vector magnitude. Thus to avoid computational errors, in the prediction step, we use the unit quaternion where it only has its three imaginary terms,

xyz. This quaternion space representation is defined by $\mathbb{H}^0$ and denoted by $q_x yz$ variables.

$$\begin{aligned} \mathbb{H}^0 \quad := \quad & \{q_{xyz} = xi + yj + zk \ \in \mathbb{H} \mid \\ & x, y, z \in \mathbb{R}\} \backsimeq \mathbb{R}^3 \end{aligned} \tag{3}$$

5.3 Exponential Map

For calculating incremental rotation in

Incremental rotation estimation using the skew-symmetric matrix obtained form the rotational rate vector and matrix exponential mapping function, [QEKF01]. Gamma, Γ, represents incremental

$$\Gamma_0 := \sum_{i=0}^{\infty} \frac{\left(\Delta t^{i+n}\right)}{(i+n)} \omega^{\times i}, \tag{4}$$

Where $(.)^{\times}$ represents skew-symmetry matrix of a vector

5.4 Updating Quaternion State

$$q_{i+1} = \delta q_i \otimes \widehat{q}_i \tag{5}$$

5.5 Capturing Quaternion Error

We use the mapping function $\zeta(.)$ to calculate the quaternion state error from the error rotation vector, [QEKF01].

$$\delta q = \zeta(\delta \phi), \tag{6}$$

$$\zeta : v \rightarrow \zeta(v) = \begin{bmatrix} \sin(\frac{1}{2}\|v\|)\frac{v}{\|v\|} \\ \cos(\frac{1}{2}\|v\|) \end{bmatrix} \tag{7}$$

6 Intermediate Goals - Fall 2021:

- QEKF: Finish paper.

- Active Learning.
- ARIAC: Once I am up to speed, I will do the ARIAC workshops/tutorials and will talk to Jerry about possible contributions.

References

[1] L. Ferraz Colomina, X. Binefa, and F. Moreno-Noguer, "Leveraging feature uncertainty in the pnp problem," in *Proceedings of the BMVC 2014 British Machine Vision Conference*, pp. 1–13, 2014.

[2] H. Wang, S. Sridhar, J. Huang, J. Valentin, S. Song, and L. J. Guibas, "Normalized object coordinate space for category-level 6d object pose and size estimation," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2019.

[3] NASA, "Nasa technical reports server (ntrs)." `https://ntrs.nasa.gov/`, 2020. (Accessed on 05/07/2021).

[4] A. Sintov, S. Macenski, A. Borum, and T. Bretl, "Motion planning for dual-arm manipulation of elastic rods," *IEEE Robotics and Automation Letters*, vol. 5, no. 4, pp. 6065–6072, 2020.

[5] T. Bretl and Z. McCarthy, "Quasi-static manipulation of a kirchhoff elastic rod based on a geometric analysis of equilibrium configurations," *The International Journal of Robotics Research*, vol. 33, no. 1, pp. 48–68, 2014.

[6] M. Bergou, M. Wardetzky, S. Robinson, B. Audoly, and E. Grinspun, "Discrete elastic rods," in *ACM SIGGRAPH 2008 papers*, pp. 1–12, 2008.