



Case Studies in Nonlinear Optimization (Summer 2018)

Motion Interpolation and Sensor Fusion

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1 Content

Measuring the 6 degrees of freedom for a general rigid motion in space at a certain time is an important task for many Computer Vision as well as Robotic applications. Knowing where an object is located in space is important to interact with it e.g. to manipulate or grasp it. There are many current systems that estimate the location and orientation of an object of interest by using a variety of sensors such as cameras (optical tracking systems: OTS), inertial measurement units (IMU) or tactile systems. All of them have advantages and drawbacks which is why oftentimes a suitable approach is to use them hybridly together.

In order to calculate a pose (rotation & translation) given the different modalities a fusion of the data is needed. This project aims to fuse input streams of IMU and vision which work at very different frequencies and with different accuracy levels - and ultimately find the smooth trajectory describing the underlying motion via nonlinear optimization in pose space. For this, a pose stream can be viewed as a sequence of data points on the (dual) quaternion manifold, which is a parametric representation of the space of rotations (3D motions). With the help of interpolation techniques on pose space (e.g. LERP, SLERP), the different pose sequences are combined and a continuous trajectory is approximated by efficient robust interpolation on the manifold.

Possible Applications are:

- 3D Animation / Rendering
- Video Stabilization in mobile phone
- Robotic Applications such as grasping / cooperative robotics
- Automatic sensor synchronization

The goal of this project is to develop an optimization pipeline that takes the input from the two modalities and calculates a pose trajectory where the weighted error towards these measurements is minimal.

2 Tasks

After getting familiar with pose parametrization (description of position and orientation in space) with (dual) quaternions, the group deals with optimization on the Riemannian manifold of (dual) quaternions. An optimization problem is modeled in case of single sensor input (OTS) which optimizes for a smooth trajectory in pose space. This is tested for $SO(3) \times \mathbb{R}^3$ with quaternions and on $SE(3)$ directly with dual quaternions. A first milestone is the successful calculation of an optimized pose path which minimizes the error towards the OTS measurements as well as a spline interpolation of the data. This is tested and compared in a real experiment.

Consecutively, the optimization problem is extended to involve also IMU data (for rotation); and pose weighting that reflects the measurement uncertainty is included. Different robustifier methods (L1-norm usage, iterative reweighting, etc.) are discussed and tested.

Finally, the focus is on real-time applications of the approach. A method based on the previous optimization is developed to estimate a future pose. Experiments for extrapolation based on the data at time t are conducted and compared to the data available at $t + 1$.

3 Literature

In the following some of the relevant literature is proposed, which serves as an initial guidance and shall be extended during the literature research:

- Pose Parametrization and Quaternions
 - Overview on the use of quaternions, interpolation and animation [DKL98].
 - Dual Quaternions, Riemannian geometry and application example [BBN17].
- Pose Interpolation
 - Interpolation and extrapolation with dual and non-dual quaternions [BEFN16].
 - Rotation averaging, mean, median etc. on pose graphs [HTDL13]
 - Weighted pose averaging and splines [BF01]
 - Fast and accurate splines with quaternions [RB97]
 - Dual quaternion toolbox in MATLAB [Kla10]
 - Construction scheme for unit quaternions curves [KKS95b]
 - C2-continuous b-splines for quaternions [KKS95a]
- Multi Modal Data
 - Dataset for visio-inertial odometry [PSDC17]

4 Starting Point and Project Steps

The team starts to get familiar with pose parametrization and basic motion interpolations. For the initial meeting, it should be understood that there is a difference between (non-dual) quaternions and rotation matrices as well as dual quaternions and homogeneous transformation matrices. The concepts of interpolation (LERP, SLERP, trajectory optimization) should be clear and the principle (dis-)advantages of optical tracking and IMU-based pose estimation should be understood. Moreover, the individual project parts are discussed in the first meeting.

Some possible project steps are:

- Literature research on pose parametrization and optimization on quaternion space
- Understand the benefits of sensor fusion with regard to OTS and IMU
- Formulate the problems mathematically
- Define project plan
- Model the optimization problems
- Develop robust optimization scheme
- Implementation
- Error evaluation and testing
- Visualize the results
- Extend different aspects of your project

5 Cooperation with Framos GmbH

This project is a cooperation with the Framos GmbH. Details of the approach, optimization aim, project steps, etc. are closely discussed with our cooperation partner.

There will be an initial meeting with the industry partner early in the semester on April 12th at 6.30 pm. The meeting is going to take place at Framos, Taufkirchen (Mehlbeerenstraße 2, 82024 Taufkirchen). The office can be reached with public transportation (S3, hop off at Taufkirchen). Just come to the 5th floor and ring the bell (or call +49 (0) 89 710 667 243 when you are there).

You should have some questions prepared for this meeting, especially about the concrete project steps since you have to prepare a project plan in the first days. Our contact person at Framos is Benjamin Busam (b.busam@framos.com).

References

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