Paper ID: 97800
student

IAF SPACE SYSTEMS SYMPOSIUM (D1)
D1 - Extra session (8)

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DEEP POSE UNCERTAINTY LEARNING BASED ON A LOG LIKELIHOOD LOSS FOR LOW-QUALITY SATELLITE IMAGES

Abstract

Space images exhibit high contrast and low signal-to-noise ratios, and contain some targets of symmetry or truncated. As a result, vision-based pose estimation of noncooperative spacecraft suffers from high uncertainties. Incorporating uncertainty information along with the predicted pose becomes crucial for providing confidence in pose measurements to the filter and achieving accurate pose tracking of noncooperative spacecraft. Deep probabilistic network has been widely applied among object orientation estimation tasks with uncertainty quantification since it can learn implicit mapping relationship between RGB images and probability distribution parameters without any prior information, such as 3D models and artificial marks of the target. Existing studies either only model the probability distribution of attitude, or only split the pose uncertainty into two independent probability distributions, i.e., the matrix Fisher distribution and the multivariate Gaussian distribution. The former cannot model $SE(3)$ (pose) uncertainty, and the latter does not consider correlation information between $SO(3)$ (rotation matrix) and $\mathbb{R}^3$ (position vector), inconsistent with the fact that mutual coupling of attitude and position leads to the uncertainty of image features.

To accommodate these issues, we present a deep probabilistic dual quaternion network that performs the relative pose estimation and model pose uncertainties. The advantage of the proposed network is that it directly models the uncertainty on $SE(3)$ while avoiding the complex closed form solution for maximum likelihood estimation (MLE) of joint distribution. Specifically, the proposed network not only learns parameters of the marginal distribution on S^3 (unit quaternion) and $\mathbb{R}^3$ (position vector) but also quantifies correlation relationship between S^3 and $\mathbb{R}^3$ by optimizing negative log-likelihood of the dual quaternion distribution. This distribution is an antipodally symmetric one defined on the unit dual quaternion. Moreover, a non-linear interpolation and lookup tables as part of the computation graph is utilized to efficiently compute the non-trivial normalization constant of the dual quaternion distribution.

Extensive experiments are carried out on challenging SPEED+ and dragon-hard datasets, to validate uncertainty quantification capability of the proposed network for symmetry, truncated, and blur images. Furthermore, data-driven pose uncertainty learning combined with the nonlinear filter and informed motion models, accurately estimated the satellite pose, with degree-level attitude errors and centimeter-level translation accuracy at steady-state.

Keywords: dual quaternion distribution; Uncertainty quantification; log-likelihood