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MODEL-BASED VISUAL 3D POSE TRACKING OF NON-COOPERATIVE SPACECRAFT IN CLOSE RANGE

Abstract

Purpose:

This work proposes a new monocular algorithm to track the 3D pose of non-cooperative spacecraft for proximity operations in real time with the 3D boundaries and 3D contour of the spacecraft as features.

Methodology:

The 3D pose consists of a translation vector $\mathbf{t}$ and a rotation vector ω in so(3). The 3D boundary segments of the spacecraft are automatically extracted from the 3D spacecraft model offline. At the time instant k=0, the tracking system is initialized by a pose retrieval method. At the time instant k>0, with the initial pose $\mathbf{p}_k^0$ and its covariance $\mathbf{S}_k^0$ provided by the extended Kalman filter (EKF), the 3D contour segments are rapidly extracted from the 3D model. The boundary segments and contour segments are taken as 3D features. In the input image, we search the image data of the 3D features within the range decided by $\mathbf{p}_k^0$ and $\mathbf{S}_k^0$. Then, the spacecraft pose is determined in real time by minimizing the geometric distances of the 3D features to the back-projection lines of their corresponding image data. The covariance of the pose is estimated via the first-order optimal condition of the minimization. Eventually, the EKF is derived from the second-order autoregression to generate the final pose estimate $\mathbf{p}_k$, and the initial pose $\mathbf{p}_{k+1}^0$ and its covariance $\mathbf{S}_{k+1}^0$ for next time instant.

Results:

The synthetic trials test the performance of our algorithm at dark space, cluster background, different distances, and different image noises. In the test of dark space and cluster background, the average relative position error (ARPE) and average angle error (AAE) of our method are about 0.6% and 0.4 degree respectively. In the distance test, the pose errors grow slight as the camera-spacecraft distance rises, with the largest ARPE and AAE of around 1% and 0.6 degree. In the noise test, the pose errors rise gently with the noise level growing. The largest APRE and AAE are approximately 0.8% and 0.5 degree respectively. The real trials qualitatively evaluate our method with the physical models of spacecrafts under the simulated space environment in laboratory. The CPU run time of our method is about 0.03s.

Conclusions:

The synthetic trials quantitatively indicate that our method can track the 3D pose of spacecraft with high accuracy and has outstanding robustness to the dark occlusion, cluster background, large image distance, and image noise. The real trial qualitatively validates the effectiveness of our tracking method.