

Kelvins Satellite Pose Estimation Challenge

ESA Advanced Concepts Team

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Spacecraft Pose Estimation



- Predicting relative position + orientation from images
- Rendezvous with uncooperative spacecraft
- Enabling:
 - debris removal
 - on-orbit servicing



(ESA - David Ducros)



(Netflix)

Kelvins Satellite Pose Estimation Challenge



- Releasing SPEED dataset
- Common benchmark
- Raising awareness in CV/ML community
- Pushing state-of-the-art
- 1st February 1st July, 2019

Kelvins - ESA's Advanced Concepts Competition Website

Reach the absolute zero error.



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SPEED Dataset - in a nutshell



- Satellite PosE Estimation Dataset, created by SLAB
- 15000 synthetic images
- 300 real images
- Ground truth pose labels
- 300 real images





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Dataset Properties - position distributions





Dataset Properties - orientation distributions





Competition design - Metric



• Position and orientation error

$$e_{r} = \frac{\left| \boldsymbol{r}_{gt} - \boldsymbol{r}_{est} \right|_{2}}{\left| \boldsymbol{r}_{gt} \right|_{2}} \qquad e_{q} = 2 \cdot \arccos\left(\left| \left\langle \boldsymbol{q}_{est}, \boldsymbol{q}_{gt} \right\rangle \right| \right)$$

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• Pose error and average pose error

$$e_{pose} = e_q + e_r$$
 $E = \frac{1}{N} \sum_{i=1}^{N} e_{pose}^{(i)}$

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- Calculated on synthetic and real test sets separately
- Sensitivity: 10 cm ~ 0.7094 degrees
- Also considered: average distance error, reprojection error



Competition Results

Participants

esa

- 48 teams participated in total
- 20 submitted a post competition questionnaire

Have you/your team been involved in pose estimation related research before the competition?

20 responses



Have you/your team been involved with space related research before the competition?

20 responses



Yes

No

Final results





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Team	E_{syn}	E_{real}	$\mu(e_q) \pm \sigma(e_q) \ [\circ]$	$\mu(e_r') \pm \sigma(e_r')$ [m]	PnP
1. UniAdelaide	0.0094	0.3752	$0.41^\circ\pm1.50^\circ$	0.032 ± 0.095	Yes
2. EPFL_cvlab	0.0215	0.1139	$0.91^{\circ} \pm 1.29^{\circ}$	$0.073~\pm~0.587$	Yes
3. pedro_fairspace	0.0571	0.15548	$2.49^{\circ} \pm 3.02^{\circ}$	0.145 ± 0.239	No
SPN [24]	-	-	8.43°	0.783	No

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Accuracy - Example 1





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Where is Waldo Tango?

Accuracy - Example 2







Analysis

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Which samples are difficult?



- 'Super Pose Estimator' best prediction for each sample
- Performance ~ difficulty
- Ranking test samples



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Influence of the background





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Distance dependence





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Keypoint matching vs. Direct pose estimation



- Keypoint matching: benefits from geometrical optimization, but requires 3D model
- Direct estimation: can be trained on the dataset



Separate vs combined localization



- Separating position estimation from orientation estimation
- Most cases using bounding box detection or segmentation
- Requires additional annotation
- Allows zooming in on the relevant parts



Thank you for your attention!

• Upcoming publication:



SATELLITE POSE ESTIMATION CHALLENGE: DATASET, COMPETITION DESIGN AND RESULTS

A PREPRINT

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