Astrobee ISS Free-Flyer Datasets for Space Intra-Vehicular Robot Navigation Research (Supplementary Material)

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Abstract— **In this supplementary material, we provide detailed explanations of the characteristics of sensor measurements such as IMU, cameras obtained in the zero-g environment, the International Space Station (ISS). We present a detailed qualitative and quantitative analysis of our pre-built ISS maps used in the pseudo ground truth generation with the ISS 3D CAD model. We also provide additional experimental results for all sequences and scenarios released on the dataset homepage.**

I. IMU Measurements on the ISS

To the best of our knowledge, this is the first dataset paper obtained in the zero-g environment (ISS) to facilitate space intra-vehicular robot (IVR) navigation research in the field of space robotics. Fig. 1 shows raw (blue) and filtered (magenta) IMU acceleration measurements from Astrobee on the ISS. Unlike on Earth, we cannot find any gravitational acceleration (typically, 9.8 m/s^2) in the IMU acceleration measurements, showing values very close to 0. We will release both raw (biased) and filtered (unbiased) IMU measurements soon.

We will release some interesting and challenging sequences that include various rotational movements (e.g., roll and pitch angle of 90°), which can only be maneuvered in the zero-g environment as illustrated in Fig. 2.

II. Accuracy of Pseudo Ground Truth

We have performed additional experiments to quantitatively evaluate the previously built ISS maps used in Sec. III-E, the pseudo ground truth generation. We obtain quantitative metrics such as mean reprojection error and track length statistics of the ISS maps produced through our offline mapping pipeline shown in Fig. 9 of the paper, and analyze them through comparison with the ISS 3D CAD model. Furthermore, we reconstruct dense 3D point clouds with COLMAP [1] given pseudo ground truth 6-DoF camera poses to evaluate them qualitatively and quantitatively against the ISS 3D CAD model.

We first visualize SURF feature points of the ISS maps used for ground truth generation with the ISS 3D CAD model (vertices) as shown in Fig. 3. They overlap significantly, showing that the scale of our pre-built ISS maps for ground truth generation is almost similar to the ISS

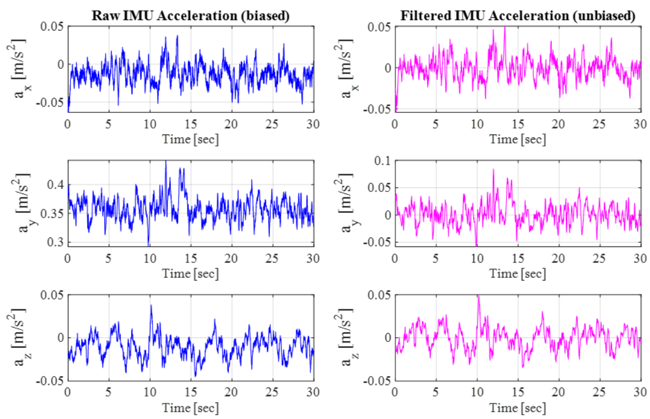

Fig. 1. Raw (blue/biased) and filtered (magenta/unbiased) IMU acceleration measurements obtained in the zero-g environment, i.e., on the ISS. We cannot find gravitational acceleration in the IMU acceleration measurements.

Fig. 2. Gray images taken in various NavCam orientations (e.g., roll and pitch angle of 90°) only possible in the zero-g environment.

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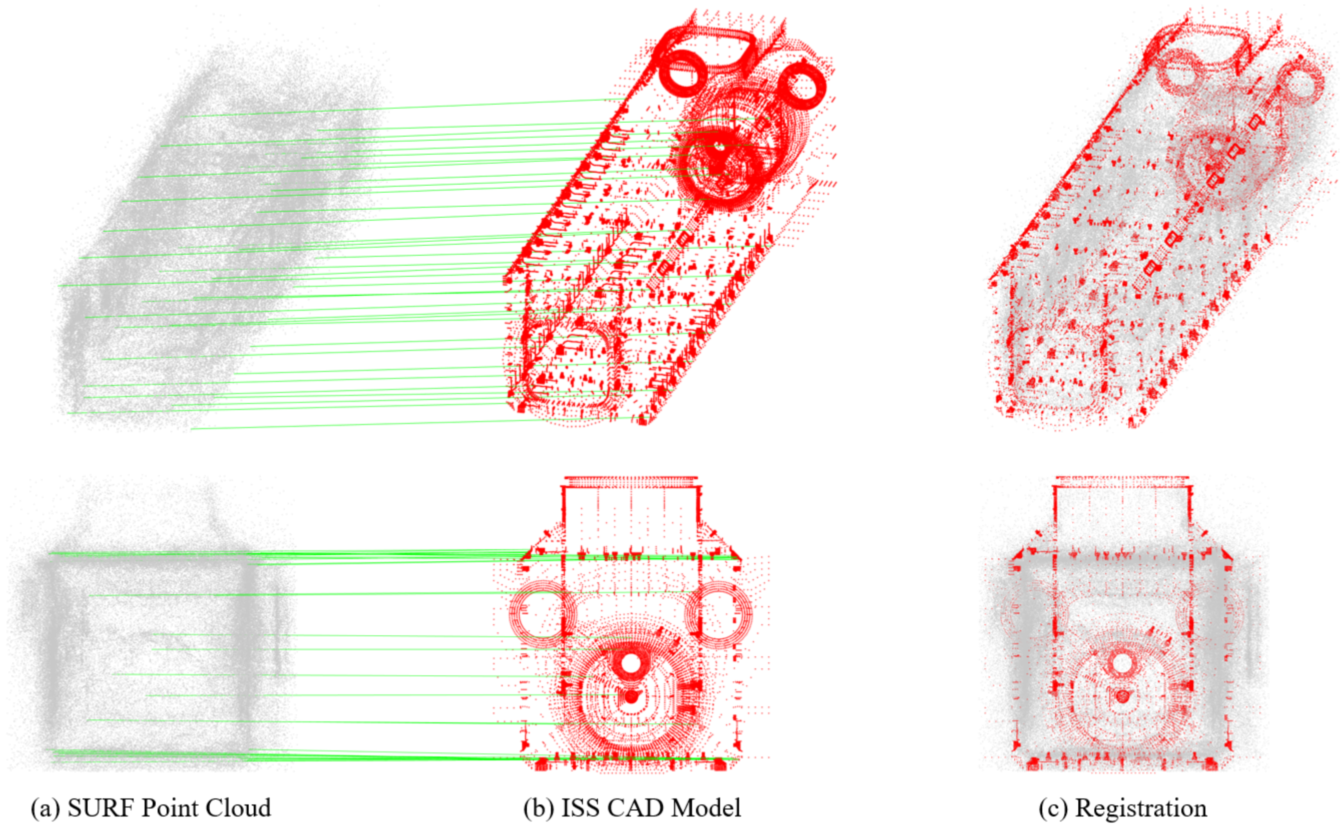

Fig. 3. ISS maps for ground truth generation with the ISS CAD model. (a) Our pre-built ISS maps consisting of SURF features (gray) used to generate the pseudo ground truth. (b) Vertices (red) of the Japanese Experiment Module (JEM) 3D CAD model in ply format. We plot landmark pairs (green) between manually selected landmark points, showing consistent matching results. (c) The scale of our pre-built maps (gray) is almost similar to the ISS CAD model (red).

TABLE I
QUANTITATIVE METRICS ON GROUND TRUTH GENERATION

ISS Map File Name	Avg. Reproj. Error [px]	Avg. Track Length	Accuracy [m]
ff_return_journey_forward.map	0.230	2.88	0.102
ff_return_journey_up.map	0.252	2.78	0.054
ff_return_journey_left.map	0.256	2.84	0.098
iva_kibo_trans.map	0.282	3.31	0.143
iva_kibo_rot.map	0.282	3.12	0.077
iva_ARtag.map	0.314	2.70	0.054
td_roll.map	0.322	2.90	0.108
td_yaw.map	0.263	2.88	0.094

CAD model. It should be noted that some parts of the ISS CAD model are not super accurate though. We report quantitative metrics (mean reprojection error, track length statistics, and accuracy) for the corresponding ISS maps in Table I. We employ mean reprojection error and mean track length metrics used in COLMAP [1], and compute the geometric accuracy as the root mean square error (RMSE) between manually selected landmark points on the ISS in the reconstructed ISS maps and the ISS 3D CAD model. Fig. 3 shows matched landmark points carefully selected by us to measure quantitative accuracy, which is about 0.09 m on average.

We additionally perform dense 3D reconstruction with COLMAP [1] given the 6-DoF camera poses (pseudo ground truth) obtained through our ground truth generation as shown in Fig. 4. It shows a high-accuracy and consistent dense point cloud with our pseudo ground truth, and overlaps significantly with the ISS CAD model as well. As quantitative metrics of COLMAP results, mean reprojection error, mean track length, and accuracy are 0.71 pixel, 8.74, and 0.13 m, respectively. The reason the mean track length is a bit different from our ISS maps is that we downsample input images to avoid adding a small baseline between images to the mapping pipeline.

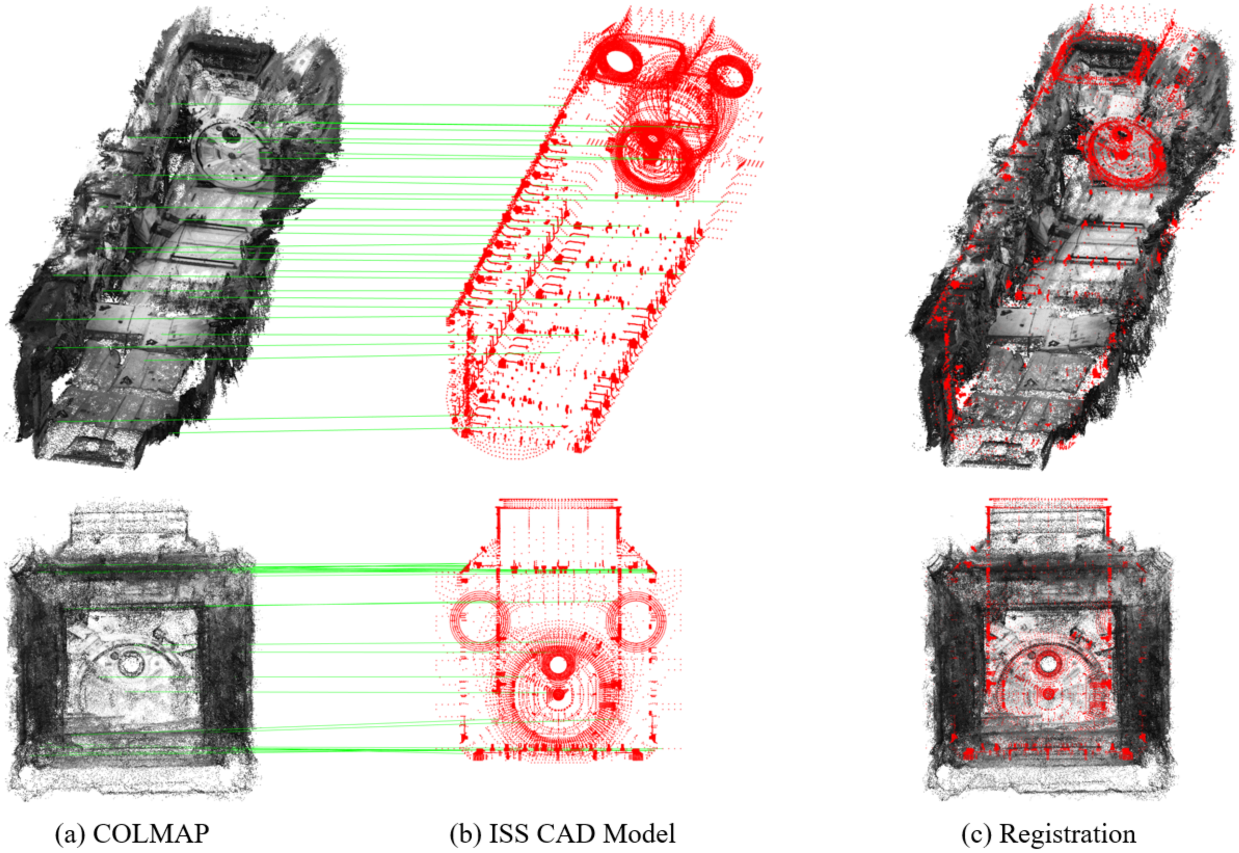

Fig. 4. Multi-view stereo (MVS) with the ISS CAD model. (a) Dense 3D reconstruction with COLMAP [1] given our pseudo ground truth 6-DoF camera poses. (b) Vertices (red) of the JEM 3D CAD model in ply format. We plot landmark pairs (green) between manually selected landmark points, showing consistent matching results. (c) The scale of the dense 3D point cloud from COLMAP is almost similar to the ISS CAD model (red), and they overlap consistently.

III. Additional Experimental Results

References

[1] J. L. Schonberger and J.-M. Frahm, "Structure-from-motion revisited," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 4104–4113.