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The Canadian planetary emulation terrain 3D mapping dataset

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Abstract

This paper describes a collection of 272 three-dimensional laser scans gathered at two unique planetary analogue rover test facilities in Canada, which offer emulated planetary terrain at manageable scales for algorithmic development. This dataset is subdivided into four individual subsets, each gathered using panning laser rangefinders on different mobile rover platforms. This data should be of interest to field robotics researchers developing rover navigation algorithms suitable for use in three-dimensional, unstructured, natural terrain. All of the data are presented in human-readable text files, and are accompanied by Matlab parsing scripts to facilitate use thereof. This paper provides an overview of the available data.

Keywords

mobile and distributed robotics SLAM, space robotics, field and service robotics

1. Introduction

The Canadian planetary emulation terrain 3D mapping dataset is a collection of three-dimensional (3D) laser scans gathered at two unique planetary analogue rover test facilities in Canada. As can be seen in Figure 1, these test facilities offer realistic conditions for rover deployment, without the complexity and cost of mounting a full-scale field campaign. This dataset is subdivided into four individual subsets, each gathered using panning laser rangefinders on a mobile rover platform.

Half of the data was obtained at the University of Toronto Institute for Aerospace Studies (UTIAS) indoor rover test facility, depicted in Figure 2(a). This facility consists of a large dome structure which covers a circular workspace area 40 m in diameter. In this workspace, gravel and sand was distributed to emulate scaled planetary hills and ridges. The other half of the data was obtained at the Canadian Space Agency’s (CSA) newly renovated Mars Emulation Terrain (MET), depicted in Figure 2(b). This outdoor test facility has workspace dimensions of 120 m × 60 m, and contains ridges, craters, and outcrops.

At these sites, three different rovers were employed for dataset collection. These rovers are depicted in Figure 3. The common characteristic shared between the hardware configurations was that the 3D laser scans were obtained using a laser rangefinder mounted on a panning unit. Due to the slow nature of the sensor, a stop–scan–go approach was taken where the 360° × 180° scans were obtained with the rover stationary. As a result, the rover poses and their associated measurements were easily segmented, providing no significant time synchronization issues to overcome in this dataset. Furthermore, all of the data were post-processed into a common format, abstracting the data products from the hardware specifics.

This data should be of interest to field robotics researchers developing laser-based rover navigation algorithms suitable for natural, unstructured 3D terrain in GPS-denied environments. Possible applications include terrain reconstruction, path planning, and simultaneous localization and mapping (SLAM). In addition, with data from two different test sites, the robustness of an algorithm to changing environmental conditions can be tested. By considering the data from the two sites separately, the pitfall of over-tuning for environmental specifics can be avoided. For example, the UTIAS data can be considered to be training data for development and tuning, while the data from the significantly larger CSA site can be used for validation.

This dataset uniquely focuses on 3D laser scans collected in natural, unstructured terrain. Commonly used laser datasets such as Radish (Howard and Roy, 2003) and the Victoria Park dataset (Guivant and Nebot, 2003) provide only 2D information, and other available 3D datasets such as RAWSEEDS (Bonarini et al., 2006), the New College dataset (Smith et al., 2009), Ford Campus dataset (Pandey

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Fig. 1. A panoramic image of the CSA Mars Emulation Terrain, with the Clearpath Husky A200 used to gather one of the datasets in the middle of the terrain. As can be seen, this terrain offers realistic field conditions for rover deployment.

(a) A panoramic image of the UTIAS indoor rover test facility, with the rover used to gather the data identified by the red arrow. The terrain consists of gravel spread in a 40 m diameter circular workspace, emulating scaled planetary hills and ridges. The reflective signs used for ground truth localization are highlighted by the green arrows in the background.

(b) An aerial view of the CSA Mars Emulation Terrain, with the P2AT used to gather one of the datasets identified by the red arrow. The terrain consists of scattered rocks on sand, along with some large ridge, crater, and outcrop features. (Photo courtesy of Équation Groupe Conseil, Inc.)

Fig. 2. The two planetary analogue test facilities utilized for the dataset.
The three rover platforms utilized to gather the dataset. The relevant payloads on each rover are identified, as well as the coordinate frame for the laser scans, where +x (red) points forward, +y (green) to the left, and +z (blue), up.

Fig. 3. The three rover platforms utilized to gather the dataset. The relevant payloads on each rover are identified, as well as the coordinate frame for the laser scans, where +x (red) points forward, +y (green) to the left, and +z (blue), up.

et al., 2011), the annotated laser dataset (Yang et al., 2011), and the Osnabrück robotic 3D scan repository (Nüchter and Lingemann, 2011) were collected in urban environments.

Though Furgale et al. (2012) also provides data collected in planetary analogue terrain, this dataset focuses on the shorter-range rover mapping scenario. Laser scans obtained in natural terrain using a mobile rover are provided along with varied experimental conditions that should be challenging for both dense data and sparse feature approaches. The simplistic appearance of this dataset resulted purely from design. The dataset was prepared with the intent of providing a simple interface with a low-entry learning curve. As a result, this dataset can be utilized by existing software without significant engineering effort, making it suitable for both research and teaching purposes.

The full dataset is available at http://asrl.utias.utoronto.ca/datasets/3dmap/. This webpage provides a more detailed description of the available data, including hardware configurations, file formats, and experimental considerations, as well as additional images of the rovers and test facilities.

The remainder of this paper is organized as follows. We begin with Section 2, which provides a brief overview of the contents of each of the four subsets, and their experimental considerations. This is followed by Section 3, which describes the data format common to all four subsets, and concludes with Section 4, where the details for accessing the data are summarized.

2. Datasets

In this section, we provide a brief overview of the contents of each of the four subsets. Primarily, these subsets consist of 3D laser scans obtained at various locations in the terrain.

2.1. UTIAS indoor rover test facility (dome)

The UTIAS indoor rover test facility, depicted in Figure 2(a), is located in Toronto, Ontario, Canada. It consists of a large dome structure which covers a gravel-filled circular workspace area 40 m in diameter. Since the terrain lies in the middle of an artificial structure, the scans were trimmed to remove the points that fell outside the workspace. Four large retroreflective sheets were also placed on the dome structure, serving as known landmarks in a SLAM formulation to determine the ground truth sensor poses at each scan stop. Previous benchmarking experiments involving the same configuration demonstrated centimeter-level accuracy in translation, and half-degree accuracy in orientation (Tong and Barfoot, 2011).

2.1.1. a100_dome

The 95 laser scans comprising this dataset were obtained using a Clearpath Husky A100, depicted in Figure 3(a). These scans were collected with short motions conducted between each scan stop. This process encouraged overlap between scans, which should be beneficial for dense matching methods. The scan distribution is depicted in Figure 4(a).

2.1.2. a100_dome_vo

The 50 scans comprising this dataset were obtained with a larger inter-scan spacing. As a result, this dataset should be more challenging for dense matching approaches. However, inter-scan visual odometry estimates were also computed using stereo imagery, which could assist in the alignment process. The covariances of the visual odometry estimates were determined by comparing the accuracy of the estimates to Vicon motion capture data obtained during calibration experiments in an indoor lab. A number of loops were traversed around the terrain, providing many loop closure opportunities. A plot of the scan distribution and odometry connections is provided in Figure 4(b).

2.2. CSA Mars Emulation Terrain

The CSA MET, depicted in Figure 2(b), is located near Montréal, Québec, Canada. It is an outdoor facility with dimensions of 120 m × 60 m with terrain consisting of scattered rocks on sand, along with some large ridge, crater, and outcrop features. For these datasets, the ground truth
positions were obtained using differential GPS (DGPS) antennas.

2.2.1. p2at_met This dataset consists of 102 laser scans obtained using a modified MobileRobots P2AT, depicted in Figure 3(b), with the goal of producing a map of the workspace. As a result, the rover was carefully driven to produce an approximately regular inter-scan spacing of 10 m. Since multiple DGPS antennas were on board the rover, accurate yaw values were also obtained for the ground truth poses. Unfortunately, due to the small baseline of the antenna array, accurate pitch and roll measurements could not be attained. These missing elements were obtained using the accelerometer measurements from an on-board inertial measurement unit (IMU) to determine the gravity vector while the rover was stationary. The scan distribution is depicted in Figure 4(c).

2.2.2. a200_met This dataset consists of 25 laser scans obtained using a Clearpath Husky A200 during an exploratory traverse of the terrain. Since we were simulating an exploration task, the motion conducted between scans was limited by the maximum effective range of the laser scanner. However, a stereo camera was used for rover navigation, which provided inter-scan visual odometry estimates for this dataset. The covariances for the visual odometry estimates were obtained in the same manner as the a100_dome_vo dataset. The ground truth positions were provided by an on-board DGPS, and the orientation values computed through manual application of the iterative closest point (ICP) (Besl and McKay, 1992) algorithm. A plot of the scan distribution and odometry connections is provided in Figure 4(d).

3. Data description

In this section, we detail the data format common to all four subsets. Each individual dataset consists of a series of folders corresponding to the number of scans obtained. These folders contain space-delimited human-readable text files with the same file name as the folder, but distinguished by their file extensions. We begin by defining the coordinate frames, and follow by describing the various file formats.
These files include the laser data, inclinometer measurements, odometry estimates, ground truth sensor poses, and sensor pose estimates.

3.1. Coordinate frame definitions

For clarity, we begin by defining the various coordinate frames that relate to the measurement data. These coordinate frames are illustrated in Figure 5. The estimate reference frame is denoted by $F_{k0}$, and the sensor frames at scan $k-1$ and scan $k$ are indicated by $F_{k-1}$ and $F_k$, respectively. The leveled inclinometer reference frame is indicated by $F_{ik}$, which is drawn with respect to the gravity vector, $g$, where the underarrow indicates that the value has an associated direction.

Transformation matrices are utilized in this dataset to express the combination of translations and rotations. For example, to transform a 3D point from $F_b$ to $F_a$, a transformation matrix, $T_{ab}$, may be used as

$$p_{a}^{l} = C_{ab} p_{b}^{l} + \rho_{a}^{b} = \begin{bmatrix} C_{ab} & \rho_{a}^{b} \\ 0_3 & 1 \end{bmatrix} \begin{bmatrix} p_{b}^{l} \\ 1 \end{bmatrix} = T_{ab} \begin{bmatrix} p_{b}^{l} \\ 1 \end{bmatrix}$$

where $p_{a}^{l}$ is the column whose coordinates represent the translation from $F_a$ to point $l$ expressed in $F_a$, $p_{b}^{l}$ is the translation from $F_b$ to point $l$ expressed in $F_b$, $C_{ab}$ is the rotation matrix from $F_b$ to $F_a$, and $\rho_{a}^{b}$ is the translation from $F_b$ to $F_a$, expressed in $F_a$.

3.2. Spherical coordinate laser data (.fcl)

A spherical coordinate laser file is composed of an 11-line header, and the laser points expressed in the sensor frame, $F_k$. The header provides details about the scan, including the timestamp, the scanning field-of-view and samples per scan line, the maximum and minimum range measurements, and the number of points in the scan. The space-delimited laser points then follow the header, with each line providing the azimuth, elevation, and range in degrees and meters, respectively.

3.3. Cartesian coordinate laser data (.xyz)

The laser scans are also provided in Cartesian coordinates, which are also expressed in the sensor frame, $F_k$, but do not contain a header. The files simply contain the space-delimited laser points, with each line providing the $x$, $y$, and $z$ laser-point coordinates in meters.

3.4. Inclinometer measurements (.inc)

To assist in processing the laser measurements, rover inclination was also measured. The rover pitch and roll is expressed as a $3 \times 3$ rotation matrix, $C_{ik}$, which provides the rotation from the sensor frame, $F_k$, to a frame, $F_{ik}$, where the $+z$ direction corresponds to the opposite direction to the gravity vector, $g$. Since heading measurements were unavailable, the heading rotation used to construct this rotation matrix was assumed to be zero. Each rotation matrix is provided as a $3 \times 3$ space-delimited text file.

3.5. Odometry estimates (.odo, .odounc)

In addition to the laser scans and inclinometer measurements, pose-to-pose (i.e. inter-scan) transformations are provided for some datasets based on stereo visual odometry. Though these estimates were obtained using an alternate sensor, they have been transformed into the laser frame at each scan stop. That is, an estimate for the transformation from the previous scan frame, $F_{k-1}$, to the current scan frame, $F_k$, is provided as a $4 \times 4$ transformation matrix,
T_{\overline{k-1,k}}, as well as its associated 6 × 6 covariance matrix, \( Q_{\overline{k-1,k}} \). We define \( T_{\overline{k-1}} \) and \( Q_{\overline{k-1}} \) as

\[
\begin{align*}
T_{\overline{k-1}} &:= \begin{bmatrix} C_{\overline{k-1}} & \rho_{\overline{k-1}} \end{bmatrix}, \\
Q_{\overline{k-1}} &:= \text{cov} \begin{bmatrix} \rho_{\overline{k-1}} \\ \phi_{\overline{k-1}} \end{bmatrix}
\end{align*}
\]

where \( \phi \) is a three-parameter rotation axis parameterization (Hughes, 1986). The transformation that maps this parameterization to a rotation matrix, \( \phi \leftrightarrow C \), is defined as

\[
\phi := \phi a, \quad \|a\|_2 = 1
\]

\[
C := \cos \phi 1 + (1 - \cos \phi) a a^T - \sin \phi a^\times
\]

with \( a^\times \), the skew-symmetric matrix operator, defined as

\[
\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}^\times := \begin{bmatrix} 0 & -v_3 & v_2 \\ v_3 & 0 & -v_1 \\ -v_2 & v_1 & 0 \end{bmatrix}
\]

For consistency, the first scan folder also contains an odometry measurement, but it is simply the identity transformation, along with an associated covariance with very large uncertainty values. These coarse pose transformation estimates can be used for the initialization of more complex alignment algorithms, and are provided as 4 × 4 and 6 × 6 space-delimited text files.

3.6. Ground truth sensor poses (.gt)

For evaluation, the ground truth sensor pose is provided as a 4 × 4 transformation matrix, \( T_{b_k,b_0} \), which expresses the transformation from the rover sensor frame, \( \mathcal{F}_{b_k} \), to the global estimate reference frame, \( \mathcal{F}_{b_0} \). Though some of these values were obtained using an alternative sensor, they have been transformed into the laser sensor frame at each scan stop. For these datasets, the global estimate reference frame was set to be the same as the first scan pose. Each ground truth transformation matrix is provided as a 4 × 4 space-delimited text file.

3.7. Estimated sensor poses (.est)

For additional development, estimated poses are also provided in the same format as the ground truth sensor poses. These estimates were produced using the sparse-feature-based batch alignment framework described in Tong et al. (2012). However, some of the scans could not be aligned using this framework. As a result, those estimates were simply set to their ground truth values, and indicated by the presence of a not_solved file in their associated scan directories.

These estimates could be used to initialize other alignment approaches, if the accuracy of the odometry measurements alone is insufficient. For example, a dense matching algorithm such as ICP (Besl and McKay, 1992) could be used for further refinement. Each estimated transformation matrix is provided as a 4 × 4 space-delimited text file.

4. Data access methods

A more detailed description of the full dataset is available at http://asrl.utias.utoronto.ca/datasets/3dmap/. Each sub-set can be downloaded individually, and is accompanied by webpages providing additional dataset-specific details including hardware configurations and experimental considerations. Furthermore, useful Matlab scripts for common operations are also available for download. These include loading the datasets into arrays, conversions between the spherical and Cartesian coordinate systems, computing dead reckoning estimates, and plotting the combined laser scans using the estimated transformation matrices. While use of the data is not limited to Matlab, these scripts serve as good examples of how to interface with and utilize the data.

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