Royal Exhibition Building: Zebedee 3D Data Collection

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1 Introduction

This document provides background information on the 3D data collection for the Royal Exhibition Building in Melbourne, Australia. The scanned site (Figure 1) consists of the interior and exterior of the World Heritage-listed building. The data in this collection were acquired by Robert Zlot, Paulo Borges, and Graham Bell in February/March 2015. All the data have been collected and registered using the *Zebedee* 3D Mapping System, a mobile handheld laser scanning system that can map an environment as the operator walks through it [3]. The data collection includes point cloud maps, the 3D trajectory the laser scanner followed during acquisition, as well as raw data log files.

This document is not intended to provide comprehensive background information on the Royal Exhibition Building. There are many other sources for detailed information about the history, architecture, and significance of the site. The purpose of this summary is to describe which areas of the building have been included in the survey, the contents, format, and organization of the data files; and some ways in which the data could be used.

2 The Royal Exhibition Building

The Royal Exhibition Building, completed in 1880, was originally built to host the Melbourne International Exhibition (1880–1881). The building also hosted the opening of the first Australian Parliament in 1901. The site was granted UNESCO World Heritage status in 2004. It is currently part of Museum Victoria, and regularly hosts commercial exhibitions and other events.

3 Acquisition Technology

Data were acquired with the *Zebedee* 3D Mapping System [3]. *Zebedee* is a handheld laser scanning system that consists of a lightweight laser scanner mounted on a spring, connected to a handle (Figure 2). The system can generate a 3D point cloud map based on measurements acquired while an operator holding the device walks through an environment. The laser on *Zebedee* is a Hokuyo UTM-30LX-F, which scans in a single plane; the spring allows the sensor head to rotate, thereby increasing the laser's 2D field of view to cover a wide area in 3D. Much of the spring's non-deterministic rotation is induced from the existing motion of the operator walking. The Hokuyo laser has a 270° field of view, and scans at 100 Hz capturing as many as 41 600 range measurements per second. The field of view perpendicular to the nominal scan plane (amplitude of the spring motion), tends to be between 150–180°. The maximum range of the Hokuyo is effectively around 15–17 m in most settings (the maximum range depends on surface reflectivity and ambient light). An industrial-grade MEMS-based inertial measurement system (IMU), a MicroStrain 3DM-GX3, is mounted beneath the laser scanner. The IMU provides three-axis rotational rate, linear acceleration, and magnetometer readings with a 100 Hz update rate. The system also includes a small netbook laptop for recording the data, and a lithium-ion battery that provides several hours of power to the sensors. The setup is illustrated in Figure 2.

To convert the raw measurements to consistent and accurate maps, data from the *Zebedee* system is processed using custom-developed software [3, 5]. The software estimates the trajectory (position and orientation at all times) of the laser scanner based on the laser and inertial measurements (and in particular does not depend on any external positioning systems such as GPS). The solution is, at a high-level, based on the concept that as the scanner is moved through the environment, static surfaces in the local view appear to move. By continually tracking this apparent 'motion', the scanner trajectory can be inferred. In general, estimating both a sensor platform's motion and a map based on the sensors' measurements of the environment is a well-studied problem in the field of Robotics called Simultaneous Localization and Mapping (SLAM). The continuous-time solution developed for processing *Zebedee* data is unique in that it is able to accurately correct for significant distortions initially present in the raw measurements that arise from the continuous, highly non-deterministic motion of the sensors during acquisition. The *Zebedee* system software can also

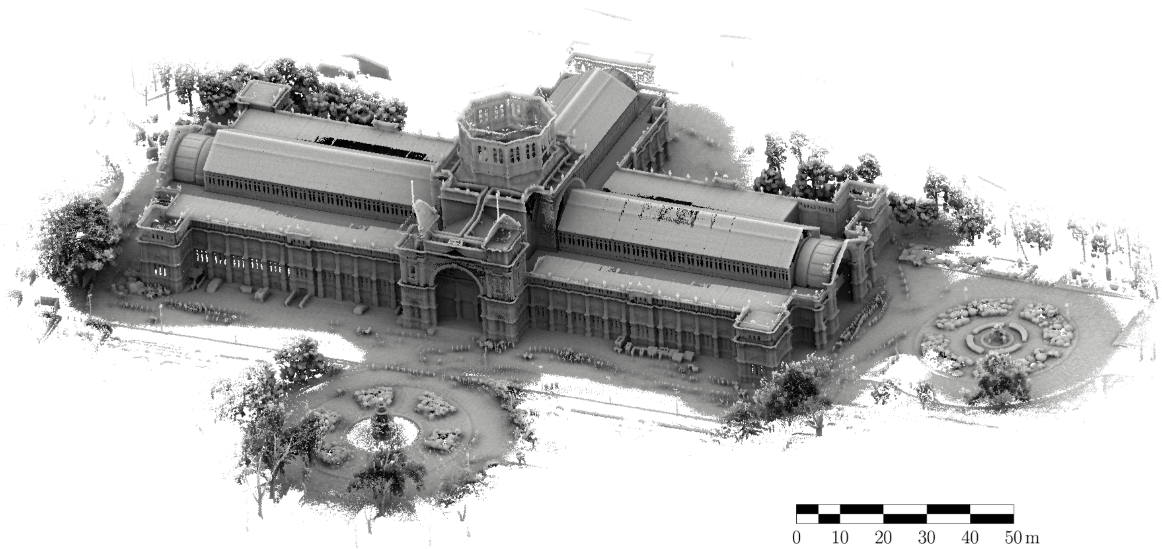


Figure 1: Oblique view of the Royal Exhibition Building *Zebedee* point cloud.

automatically merge overlapping datasets together into a common coordinate frame [2, 7]. This capability allows partial scans of a site to be acquired by multiple operators simultaneously, or by one or more operators at different times.

For more details about the *Zebedee* 3D Mapping System, please see the relevant technical papers [1, 2, 3, 5, 6, 7].

4 Data Contents

The data files included with this collection consist of raw and processed data. The raw data is included for archival and specialty processing purposes, and is likely not required for most general users. The processed data are 3D point clouds and trajectory files provided in several formats. All spatial units are in meters.

We define a *dataset* to be the data produced from an individual event in which the *Zebedee* system continuously logs measurements from the time the device is picked up until it is placed down (in between the operator moves around the environment with the device in hand). Each dataset has a unique name, and all files produced from that dataset start with that name as a prefix. This overall data collection consists of 10 datasets, which are listed in Table 1. An exterior view of the point cloud model is shown in Figure 1. Together, the datasets cover most of the building interior as well as the façade and other exterior features. Some areas, including the restrooms and basement, are not included in the data collection. At some points while mapping the exterior of the building, other people came within range of the laser scanner and as a result have been captured in the point cloud. This clutter should be minimal for the interior scans, as the building was not open to the public during data acquisition. The total duration of the data is 6.14 hours, the combined trajectory length is 7.9 km, and the number of points is 540 million.

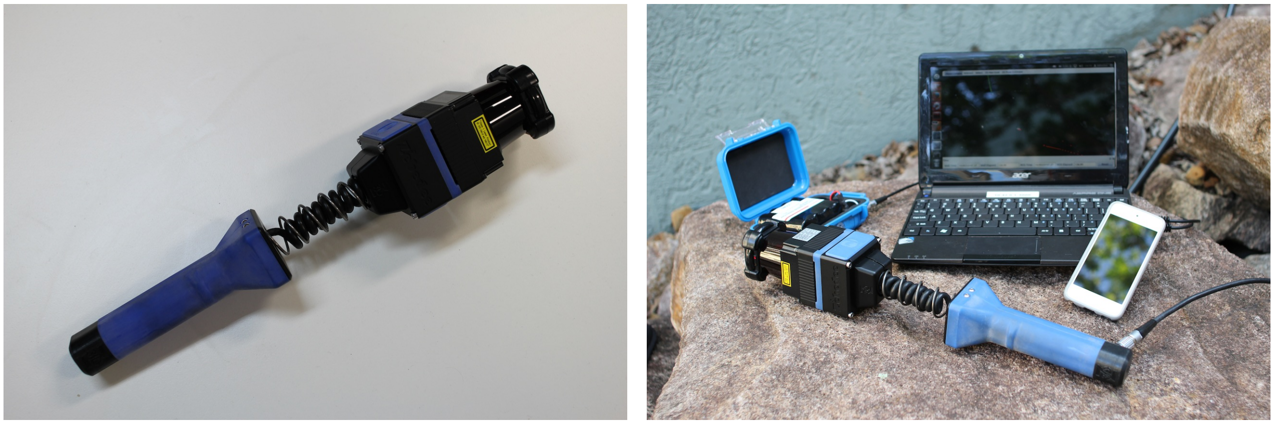
4.1 Processed Data

Processed data are provided in three file formats. Point clouds are provided in `.laz` and `.ply` format, and trajectories in `.txt` and `.ply` format. The `.laz` files implement a compressed version of the ASPRS LAS 1.2 standard. The `.ply` files use the binary version of Polygon File Format (also known as Stanford Triangle Format). Several variations of these files are included that differ in terms of data properties, downsampling, and colormap.

Point Clouds

The `.laz` files contain all of the available points, and include a timestamp for each measurement. The timestamp allows one to retrieve the corresponding trajectory information to determine from which position and orientation each measurement was made.

The `.ply` files are downsampled versions of the point cloud and do not contain any timestamp information. Filenames ending with `_3cm_shape.ply` indicate that the included data has been downsampled to 3 cm density, surface normals are included for each point, and the points are colored according to local shape (approximately planar areas appear pink, linear features appear purple, and rough/bushy features green). Files with `external_shaded` use



(a) *Zebedee* handheld device (b) *Zebedee* system

Figure 2: Components of the *Zebedee* system. (a) Handheld portion of the *Zebedee* system which contains the sensors (Hokuyo UTM-30LX-F laser scanner and MicroStrain 3DM-GX3 IMU) mounted on a spring. The length of the device is approximately 38 cm, and the mass is 650 g. (b) The other system components include a 77 Wh lithium-ion battery (back left) supplying over 6 hours of power to the sensors, and the data acquisition laptop (back right), used for recording the data to file. These components typically are carried in a backpack, and a mobile device can be used to wirelessly interface with the acquisition computer.

Table 1: Dataset names, descriptions, and sizes (duration of data acquisition and number of points rounded to the nearest million).

Dataset name	**Description**	**Duration [mins]**	**Millions of points**
`rebr01_inside`	Focus on eastern side of interior	73.4	116
`rebr02_inside`	Focus on northwest area of interior	50.7	77
`rebr03_inside_central`	Central area of interior	10.5	15
`rebp02_inside`	Focus on southern side of interior	50.0	85
`rebr11_western_door`	Western side interior and exterior	23.4	33
`rebr04_dome`	Rooftop dome and stairway	24.1	30
`rebp01_outside`	Exterior façade of building (anti-clockwise)	77.5	115
`rebg01_perimeter`	Exterior façade of building (clockwise)	32.3	46
`rebg02_fountain`	Fountains at southern and eastern doors	22.2	18
`rebg03_fountainmain`	Fountain outside southern door	4.9	4
Total		**6.14hrs**	**540**

an ambient occlusion shading algorithm that highlights features on the exterior surfaces of the building, while files with `internal_shaded` use a shading algorithm that better highlights interior features. Filenames ending with `_9pct_timecolored.ply` have been downsampled to 9% of the original points (time-based subsampling), and are colored according to measurement time (blue at the start transitioning to red at the end). Files with `_9pct_height.ply` have similarly been downsampled to 9% of the original points, and are colored according to height (scaled individually for each dataset).

Trajectories

Trajectories are provided in ASCII text format, where each line includes the time, position, and orientation of the laser scanner at a 100 Hz sampling rate. The first line of the trajectory file is a comment starting with '%' that indicates the format. Each subsequent line contains the time, followed by the x, y, z position of the scanner (in meters), and finally a quaternion to represent the 3D orientation. The text file version of the trajectory is useful for identifying the position of the scanner at a time when a measurement (in the `.laz` file) was acquired.

The trajectory is also provided as a `.ply` file (ending with `_traj2.ply`) that is colored by time (blue at the start to red at the end). The timestamp of each sample is not explicitly specified in this file.

4.1.1 Additional Files

A highly downsampled point cloud of the full data collection is also included as a file ending with `_merge_lowres.ply`. Here each dataset is downsampled to 40 cm resolution and colored such that each dataset is distinctly colored. This file is useful for visualizing the full site with a reduced memory footprint.

4.1.2 Viewing the Data

As the point clouds and trajectories are provided in standard file formats, many freely available and commercial software packages can be used to visualize, edit, and produce derivative results. As the datasets are all registered into a common frame, it is possible to open files from multiple datasets simultaneously in a viewer. Some freely-available options for visualizing and editing the data are CloudCompare[1] and Meshlab[2].

4.2 Raw Data

Raw data is provided as `.bag` files (v2.0), which are the native log file format for the Robot Operating System (ROS) [4]. The `.bag` files contain timestamped laser and inertial measurements in standard ROS message formats (`sensor_msgs/LaserScan` and `sensor_msgs/Imu` for the main sensors), and have had no processing (registration, etc) applied. Magnetometer data has been stored in the `orientation_covariance` field of the `Imu` messages. All distance measurements are in meters, and angular measurements in radians. Although the raw measurements may not be particularly useful for the general user, they are available for users developing specialized processing algorithms that require access to the raw values and scan pattern, or for researchers investigating their own localization and mapping algorithms.

5 Applications

This data collection may be useful for multiple purposes, including:

- Heritage applications: architecture; conservation; restoration
- Robotics / remote sensing research: development of SLAM, place recognition algorithms
- Building modeling: point cloud to CAD; segmentation; classification; semantic labeling.

6 Attribution

This dataset should be used in accordance with the terms specified on the CSIRO Data Access Portal. Please cite this dataset according to the details provided.

Acknowledgements

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[1] `http://www.danielgm.net/cc`

[2] `http://meshlab.sourceforge.net`

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