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May 2002

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Production of Models of the International Space Station Elements from 3D Laser Images

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1. Introduction

The Neptec Design Group has developed a Laser Camera System (LCS) that can operate as a 3D imaging scanner. The LCS uses an auto-synchronized triangulation scheme to measure range information while two orthogonal scanning mirrors sweep through the field-of-view. The LCS simultaneously records intensity of the reflected laser beam and range information. The intensity data can be used to produce 2D grayscale images as well as to map the intensities onto 3D surface models. The nature of triangulation geometry dictates that such measurements are best for close objects, with range error increasing with the square of object range[1].

The LCS was flown in the payload bay of the shuttle Discovery during mission STS-105. Four scans were taken of the same scene while the shuttle was docked to the International Space Station (ISS)[2]. Partially visible ISS elements included the SSRMS (Canadarm2), Multi-Purpose Logistics Module (MPLM), Destiny Lab Module, Node 1 (Unity), Joint Airlock Module (Quest), and several solar arrays.

2. 3D Imaging

The raw LCS scan data was acquired in (U,V,P) coordinates. U and V are the angles of the vertical and horizontal scanning mirror angles, respectively. They can roughly approximate the angles of a spherical coordinate system, except that there is an astigmatism because of an offset between the rotation axes of the scanning mirrors. P is the peak position of the reflected laser beam on the Linear Detector Array (LDA), and is inversely proportional to range. The (U,V,P) data were transformed into spatial Cartesian (X,Y,Z) coordinates using LCS intrinsic calibration parameters[3].

The LCS data were imported into PolyWorks, a 3D visualization software package from InnovMetric[3], as a structured point cloud in parametric image format (PIF). A surface model was created by importing the PIF data into the IMAlign module of PolyWorks. IMAlign automatically interpolates the data to a regularly spaced grid in the (X,Y) plane. In this experiment, the interpolation grid spacing was set to 4 mm, which is the approximate spatial resolution of the close-range measured data. IMAlign also requires a defined maximum angle between neighbouring polygon normals when generating surfaces. For this experiment, the maximum angle was set to 89 degrees to accept all polygons generated by PolyWorks.

Figure 1 shows the initial results of the data processing. Using the conventional Cartesian (X,Y,Z) method, the surfaces appear to be quite noisy and jagged. The jagged appearance can be reduced by lowering the maximum angle between neighbouring polygon normals. This process, however, removes polygons rather than replaces them with a smoother surface, and so the surfaces become highly fragmented.

These conventional polygonal/surface normals methods work well when data noise is uniformly and independently distributed within the (X,Y,Z) coordinates. However, using a large field-of-view laser scanner system, all of the data originate from a single view (spherical coordinates) and produce highly correlated data between the X,Y, and the Z axes. Furthermore, the range error distribution of a triangulation-based laser scanner system is proportional to the square of object range, so the noise distribution varies significantly over the field-of-view.

3. Image Filtering and Smoothing

PolyWorks offers a variety of surface smoothing techniques. Little visual improvement could be obtained using these tools because they are applied to the data in (X,Y,Z) coordinates. Limited success was achieved by creating a coarse mesh surface and fitting it to the point cloud data. The smoothness of the surface could be controlled by the level of fit to the data, which could be set locally to different segments of the data. This approach required much manual editing to create a usable coarse surface. Sharp corners also required a high level of localized fit to the data which resulted in noisy surfaces in these areas. Another drawback is that intensities cannot be directly mapped to the surfaces using this approach because there is no correspondence between points on the fit surface and the actual measured data.

A better approach to smoothing the surfaces was to filter the data in the original (U,V,P) coordinates. The LCS uses a triangulation scheme so most of the noise is in the range measurement and affects variable P. (U,V) noise comes from the galvo and controller dynamics of the scanning mirrors. When transformed to (X,Y,Z) the noise from variable P gets coupled into all three Cartesian coordinates.

First, the scene was manually segmented by importing the (U,V,P) point cloud to the PIFEdit tool of PolyWorks. Segments included the SSRMS, Destiny Lab Module, MPLM with Node 1 and Airlock, and the solar arrays. Within each segment, the (U,V) grid was set to a regular spacing to avoid the sharp surface angles created when the grid is irregular. The P data were filtered using a series of median filters to remove outliers and averaging filters to smooth the data. The size and order of the filters were applied differently to different segments of the data based on the range noise and the level of detail measured.

The filtered (U,V,P) data were then transformed to (X,Y,Z) using the same process described above, and converted to PIF format. The PIF data were imported to IMAlign to create the surface models. Segments were combined in the IMAlign module before exporting the scene as a polygon model. The polygon model was then imported to the IMEdit module of PolyWorks where lighting effects were used to highlight the surface features. Figure 2 shows the resulting surface model with lighting effects.

4. Intensity Mapping

The measured intensities were carried throughout the range filtering process, but remained unfiltered. They were directly mapped onto the surfaces. Figure 3 shows the surface models from Figure 2 with both measured intensities and lighting effects. The lighting effects can be turned off in PolyWorks, providing only intensity information, but this removes much of the 3D rendered appearance. All models shown in Figures 1 through 3 are full 3D models that can be rotated through 360 degrees in all directions.

5. Concluding Remarks

The largest difficulty with producing smooth 3D surfaces on ISS data was due to the type of range noise obtained using a large field-of-view, large depth-of-field, triangulation-based range sensor. Objects in the measured data ranged from several meters to over 40 meters.

Within the measured range is the cross-over point between precision of LCS triangulation and time-of-flight (TOF) range measurements[1], so measurement precision at these distances could be increased by including a TOF module. The TOF data could be either used independently or combined with triangulation data using a weighted co-measurement scheme.

References

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3. http://www.innovmetric.com

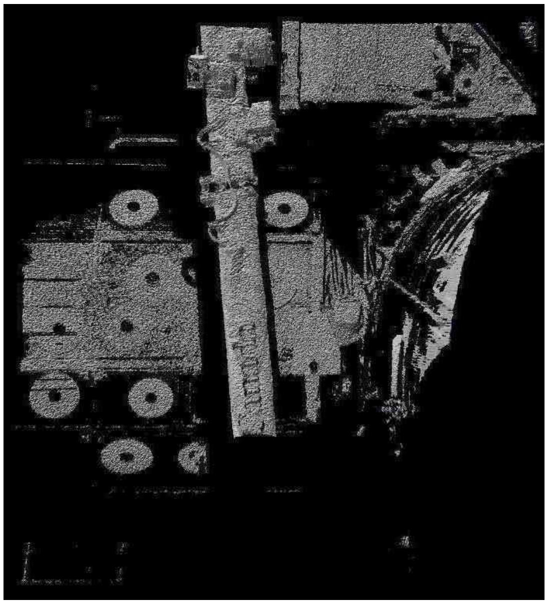

Figure 1: Initial 3D surface from unfiltered data

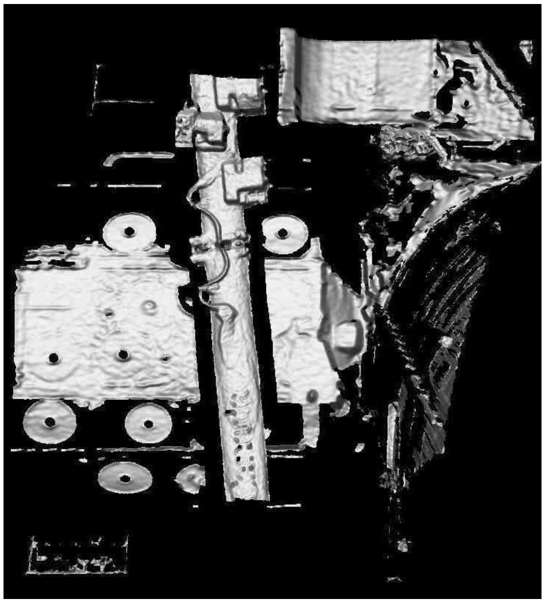

Figure 2: 3D surface produced from filtered data with lighting effects.

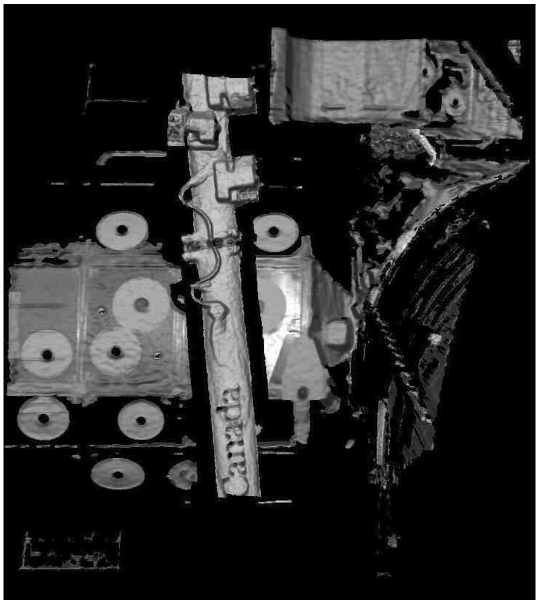

Figure 3: 3D surface with lighting and measured intensities.