Model Acquisition with a Free-hand Laser Scanner

A. Negrente, U. Castellani, A. Fusiello and V. Murino
University of Verona
alessandro.negrente@students.sci.univr.it

Introduction

We describe a three-dimensional (3-D) model acquisition system composed of a pair of calibrated cameras and a laser pointer that casts a red light stripe on the scene.

The user free-hand scans the object by moving the pointer, and an accurate 3-D model is acquired (Figure 1).

The complete system is easily calibrated, inexpensive and not difficult to use.

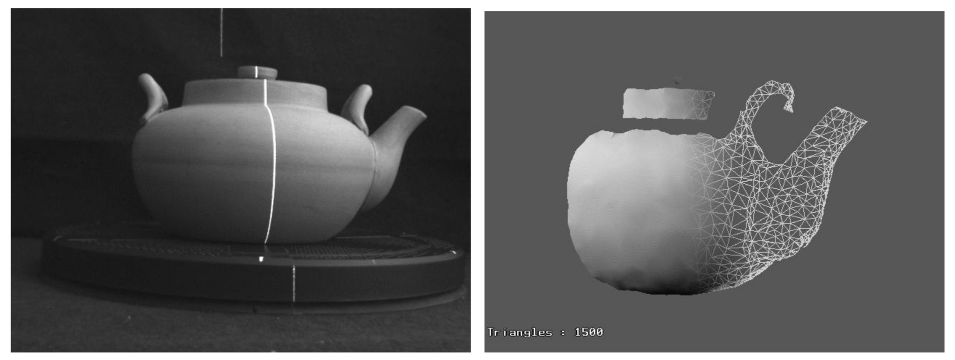

Figure 1: Left: laser stripe projected onto a teapot; Right: 3-D reconstruction of a single view of the teapot.

System Overview

We built a range scanner following the general idea behind *active stereo*, where a lighting system projects a light pattern onto the object to be scanned in order to facilitate the search for corresponding points.

The hardware we are using consists of a RGB frame grabber, two synchronized, B/W cameras, a calibration pattern, a turntable and a hand-held laser system. The latter mounts a cylindrical lens to project a thin laser sheet. In order to simultaneously acquire two B/W images, the two cameras are synchronized and the video signals are input to the R and G channels of the frame grabber respectively.

The two cameras were calibrated using the Calibration Toolbox for Matlab.

The laser is free-hand-moved, so as to scan the object's visible surface. After the acquisition of a range view is complete, the object is moved, ready for another scan. The object is placed on a turntable, whose rotation axis is computed with a calibration technique. This information will be used later to automatically initialize view alignment.

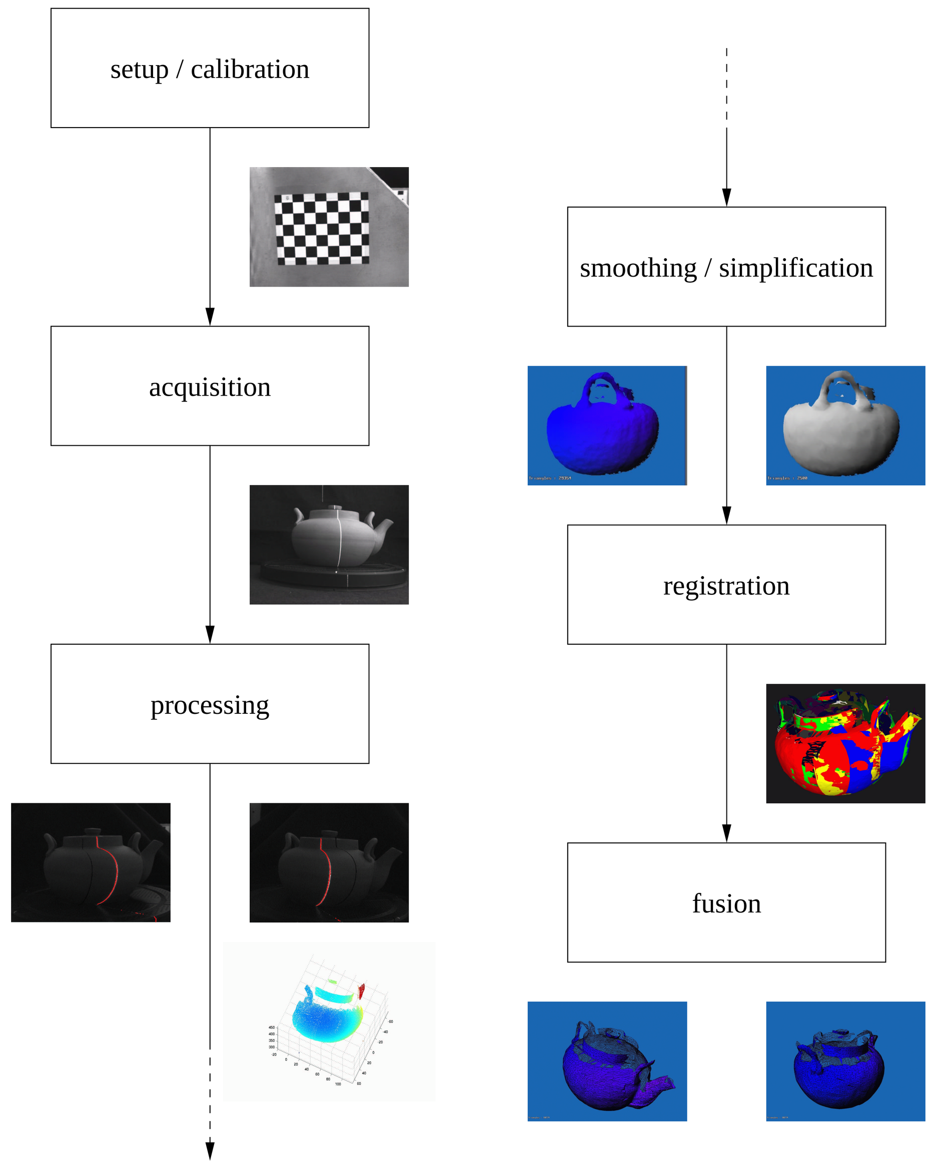

Figure 2: Model acquisition pipeline. The pipeline can be divided into two main steps: acquisition (left) and modelling (right).

Active stereo

The main data processing after the acquisition of a range view can be further divided into the following steps: laser detection, corresponding points detection, left-right consistency check and triangulation.

Laser detection The laser stripe is easily detected in the images by subtraction. Its position is then refined to sub-pixel precision by fitting a parabola to the intensity profile. Since the laser stripe has a given width, usually larger than pixel width, we use a 2^{nd} order curve fitting to find the subpixel position of the stripe's maximum intensity. We use the gray intensity level of three pixels centered on the local maximum as function values (Figure 3).

Corresponding points detection Given a point m_L belonging to the stripe in image A, the intersection of the stripe in image B with the epipolar line r of m_L is the corresponding point of m_L (we used roughly vertical stripes with nearly horizontal epipolar lines), here denoted as m_R. Since we have already detected all laser points in both images, we should find the intersection between a line and a discrete set of points. To achieve again sub-pixel precision, we actually find the intersection between the epipolar line r and the line passing through the two nearest detected laser ponts, denoted as $m_{\rm top}$ and $m_{\rm bottom}$ (Figure 4).

Left-right consistency check The same process is repeated starting from image B, and only matches found in both images are retained (left-right consistency check) (Figure 5).

Triangulation Finally, the 3-D coordinates of points are computed by triangulation, thereby obtaining a 3-D view of the object (Figure 6).

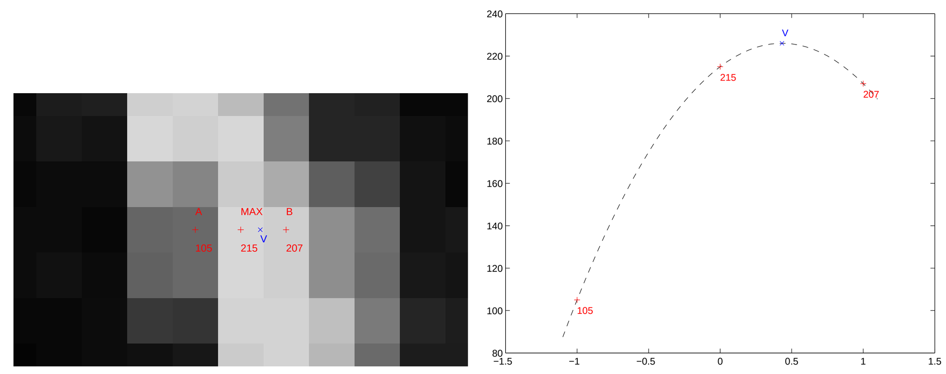

Figure 3: Left: laser detection with sub-pixel precision, detail. Right: the parabola fitted using graylevel values as function values. The vertex V is detected as the maximum intensity laser point, shown in both images.

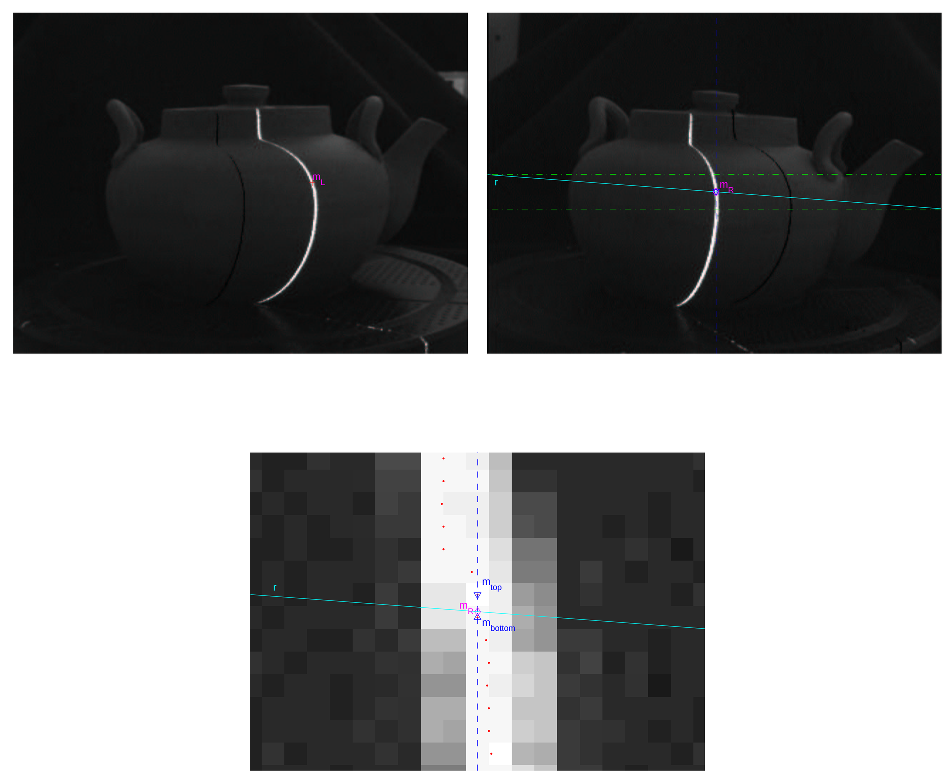

Figure 4: Top Left: a point m_L on the laser stripe on the left image. Top Right: the intersection between the laser stripe and the epipolar line r of m_L determines its corresponding point m_R. Bottom: the laser-stripe intersection, detail.

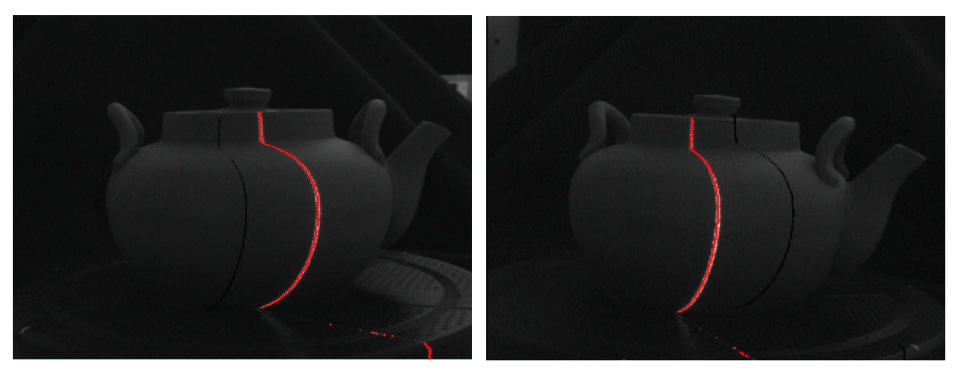

Figure 5: Corresponding points.

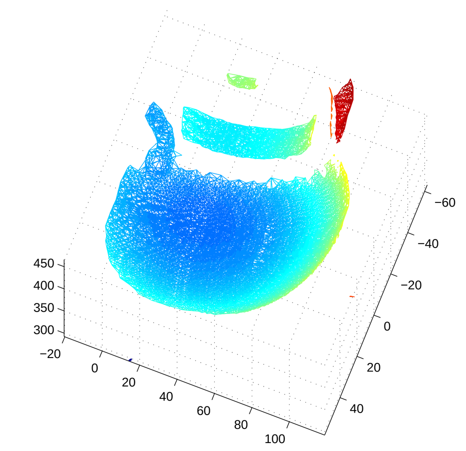

Figure 6: Given the corresponding points and the fundamental matrix F obtained after stereo calibration, we can recover the 3D position of the detected points; finally, a mesh is obtained using a Delaunay triangulation.

Model acquisition

From each view a surface is recovered by Delaunay triangulation in the image plane (Figure 6). Spurious triangles are removed using an outlier rejection rule (the X84 rule). Then, the following steps are: mesh smoothing, simplification, registration and fusion.

Mesh smoothing and semplification The mesh reconstructed from the data points suffers from a certain amount of noise, which can be partially removed using both a smoothing and surface interpolation technique. Also, since the number of triangles could still be too large for the effective complexity of the mesh, it's possible to use a simplification algorithm to reduce them. (Figure 7).

Mesh registration The surfaces corresponding to several views of the object are aligned first with ICP and then with a global registration technique that reduces the error accumulation (Figure 8).

Mesh fusion A full 3-D model of the object is obtained after the geometrical fusion of the different views with a variant of the *zippering* algorithm. The final model can be easily converted and used in standard graphics environment, such as VRML (Figure 9, top) and openGL (Figure 9, bottom).

As a work in progress, a third color camera will provide color images in order to reconstruct textured meshes.

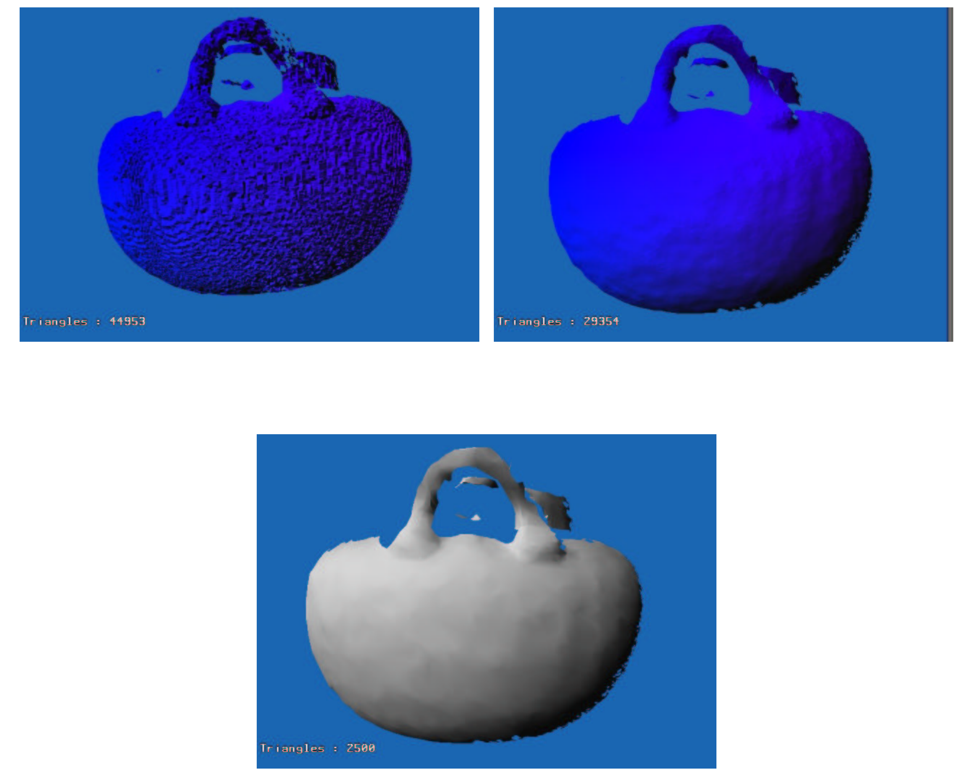

Figure 7: Top Left: original (noisy) mesh reconstructed from the data points (more than 40K triangles). Top Right: the same mesh, after smoothing and surface interpolation (less than 30K triangles). Bottom: the mesh after simplification (2.5K triangles only).

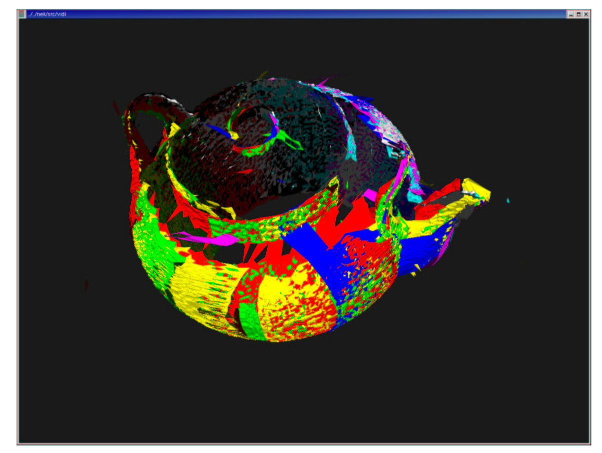

Figure 8: Registration of 12 different views of the teapot; each view is displayed with a different color.

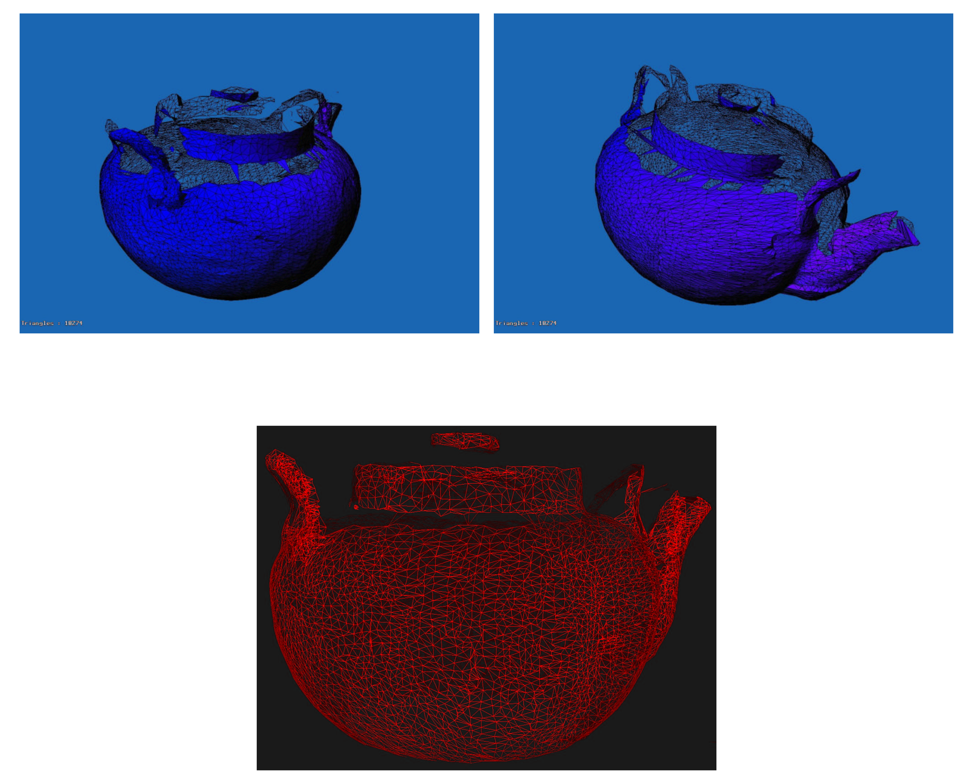

Figure 9: The final zippered mesh (about 18K triangles). The "top" and the "bottom" of the teapot are still missing.