Simple 3D Surface Reconstruction Using Flatbed Scanner and 3D Print

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1. Introduction

Reconstruction of nearly flat 3D objects can be used in many applications, e.g. getting 3D surface for games, reconstruction of historical fragments etc. The presented approach uses a flatbed scanner to reconstruct a surface of nearly flat objects without calibration and produce a 3D copy of the scanned object using a 3D printer.

Position of the light source and CCD sensor in 2D flatbed scanners is not the same, i.e. light is coming under some angle α, which causes small "shadowed" contours in scanned images. The given object is scanned in four orthogonal positions and the four scanned images are aligned.

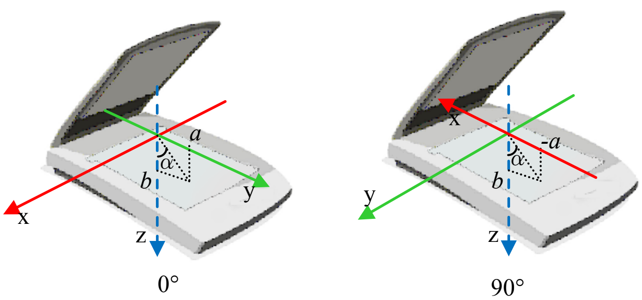

Figure 1: Two of four fundamental orientations in scanning

2. Normal Vector Reconstruction

The CCD sensor of the flatbed scanner is linear and the light source is fixed under α angle. Therefore it is possible to reconstruct normal vector $\boldsymbol{n}$ for each point on the surface as the scanned pixel's intensity I_0 is given as:

$$I_0 = \rho \int_{-l}^{l} \langle \boldsymbol{n}, \boldsymbol{l} \rangle \, dx = \rho\left(n_y a + n_z b\right) \int_{-l}^{l} \frac{1}{\sqrt{x^2 + a^2 + b^2}} dx$$
$$= \rho s\left(n_y a + n_z b\right)$$

where: $\boldsymbol{l} = [x, a, b]^T / \sqrt{x^2 + a^2 + b^2}$ is the normalized lighting vector and

$$s = \int_{-l}^{l} \frac{1}{\sqrt{x^2 + a^2 + b^2}} dx = 2ln \frac{l + \sqrt{l^2 + a^2 + b^2}}{\sqrt{a^2 + b^2}}$$

Similarly it can be computed for other positions. This leads to equations:

$$\begin{bmatrix} 0 & \tan\alpha & 1 \\ 0 & -\tan\alpha & 1 \\ -\tan\alpha & 0 & 1 \\ \tan\alpha & 0 & 1 \end{bmatrix} \begin{bmatrix} \rho sbn_x \\ \rho sbn_y \\ \rho sbn_z \end{bmatrix} = \begin{bmatrix} I_0 \\ I_{180} \\ I_{90} \\ I_{270} \end{bmatrix}$$

where:

$$\rho sbn_x = \frac{I_{270} - I_{90}}{2\tan\alpha} \qquad \rho sbn_y = \frac{I_0 - I_{180}}{2\tan\alpha}$$

$$\rho sbn_x = \frac{I_0 + I_{180} + I_{90} + I_{270}}{4} \qquad \tan\alpha = \frac{a}{b}$$

A curvature optimization can also be made to obtain better results. However the crucial step is the surface reconstruction from the obtained map of normal's and boundary conditions, actually height on the object boundary.

2. Surface Reconstruction

As we expect nearly flat 3D objects, known height on a boundary is assumed. The inner part, i.e. 3D profile, is given by the normal vector reconstruction part. It means that it is a "classical" 2D boundary problem known from Finite Elements Methods, which leads to solution of a sparse linear system of equations $\boldsymbol{Ax} = \boldsymbol{b}$ in general. However, the normal reconstruction process is still very noisy. Therefore for the reconstruction two orthogonal 1D reconstructions were used, i.e. for x and y axes. This leads to over-determined linear system of equations and least square error was used for solution. When a surface is reconstructed, a triangular mesh is generated so that the volume was closed. In Fig.2, the scanned coin was of a diameter of 25 mm. The reconstructed object was scaled to a diameter of 55mm since the 3D printer's grain we used is 0.2 mm.

Figure 2: Original object and reconstructed surface

3. Conclusion and Acknowledgment

The presented concept was experimentally verified and 3D reconstructed object was printed on a 3D printer. It should be noted that some 2D scanners produce images with small non-linearity which should be corrected to get better results.

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