A Portable Low-Cost Archaeological 3D Imaging and Cataloging System

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Abstract. This paper introduces a cross-platform low-cost system for 3D object reconstruction using a projection-based laser scanner. It uses contact-free measurement techniques for 3D object reconstruction and fast surface registration using Iterative Closest Point (ICP). The only hardware requirements are a simple commercial hand-held laser and a standard camera. The camera is initially calibrated using Zhang's camera calibration method so that its external and internal parameters are exactly known. The visible intersection with the background is used to find the exact 3D pose of the laser plane. This laser plane is used to triangulate new 3D point coordinates of the object's surface. The point clouds obtained are processed using 3D Toolkit (3DTK) which includes an automatic high-accurate registration process and a fast 3D viewer.

Keywords: Camera Calibration, Hough Transformation, 3D Reconstruction, Scan Registration, Hand-Held Laser, Image Filters, Color Models

1 Introduction

introduction

2 Related Work

related work

3 Approach

elevator pitch

3.1 Data Acquisition

We used a standard digital camera to capture multiple runs of a hand-held laser sweeping across the object as shown in figure 3.1. Since the videos were stored in raw format which cannot be directly processed by OpenCV, we used `mplayer` to extract individual frames at the rate of 5 frames per second.

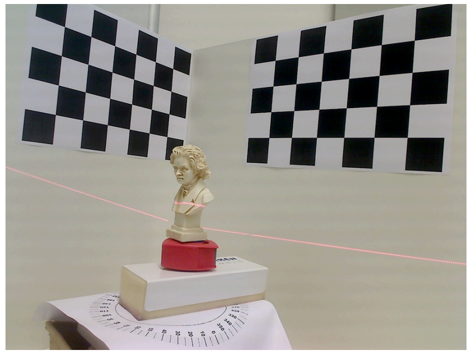


Fig. 1. Data Acquisition

```
$ mplayer -demuxer rawvideo \
          -rawvideo fps=5:w=1600:h=1200:yuy2 \
          -vo pnm:ppm $FILE
```

These frames were then later read into memory by calling the OpenCV routine `cvLoadImage()` with a `CV_LOAD_IMAGE_UNCHANGED` flag. The routine allocates an image data structure and returns a pointer to a struct of type `IplImage`

3.2 Camera Calibration

The first step in the process of reconstructing the 3D geometry of the object is to establish a mathematical relationship between the natural units of the camera with the physical units of the 3D world. We used camera calibration to learn the internal parameters of the camera and its distortion coefficients. The geometry is described in terms of camera's optical center and focal length.

We used OpenCV routines that are based on [1] [2] and used a planar chessboard pattern as our calibration object. We rotated and translated the pattern to provide multiple views to get the precise information about the intrinsic parameters of the camera as shown in figure 3.2. We used OpenCV routine `cvFindChessboardCorners()` to locate the corners and once we had enough corners from multiple view images, we used `cvCalibrateCamera2()` to get the intrinsic matrix A as shown in equation 1.

$$s \times \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A \times \begin{bmatrix} R \mid T \end{bmatrix} \times \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \tag{1}$$

$$\text{where } A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

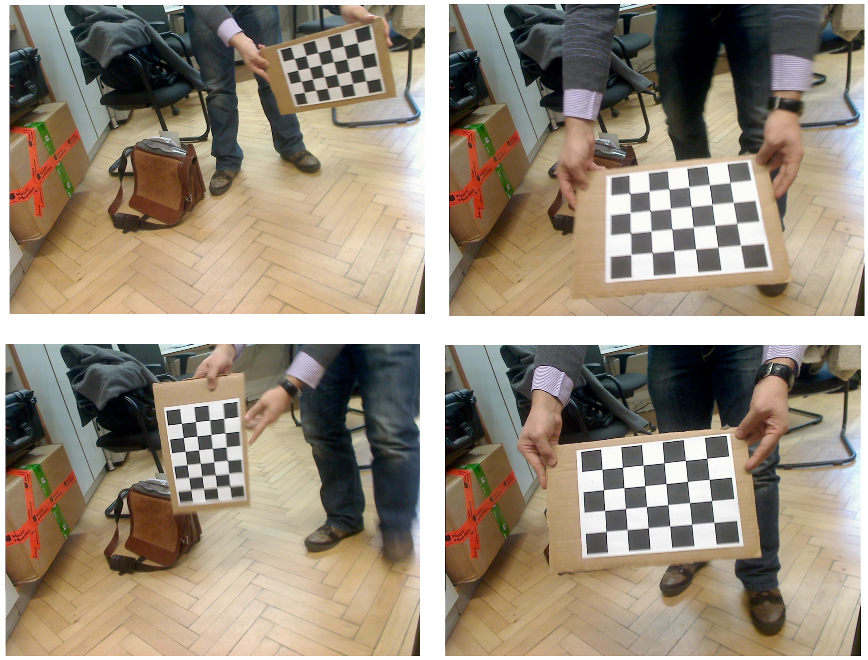
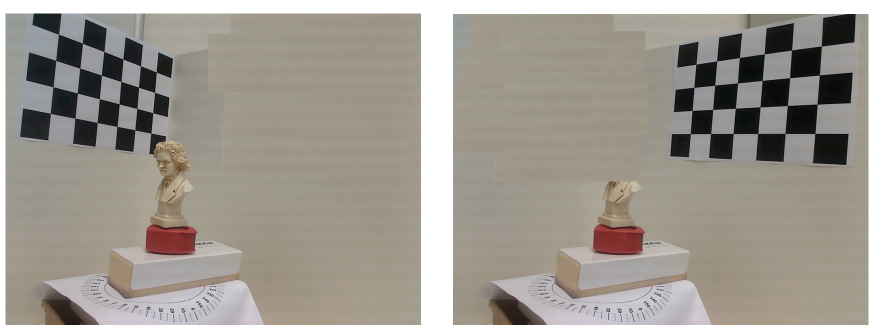


Fig. 2. Calculating the Camera's Intrinsic Parameters

The intrinsic matrix A was later used to describe the *pose* of the objects being scanned by the laser relative to the coordinate system of the camera. In order to determine this pose on both sides of the target object, the patterns were masked out to allow individual calculation as shown in figure 3.2. The parameters represented by $\left[R \mid T\right]$ could then be separately calculated for both the sides by calling the OpenCV routine `cvFindExtrinsicCameraParams2()`.



(a) $R_1 \mid T_1$ (b) $R_2 \mid T_2$

Fig. 3. Calculating the Camera's Extrinsic Parameters

3.3 Identification of 2D Laser Lines and Object Points

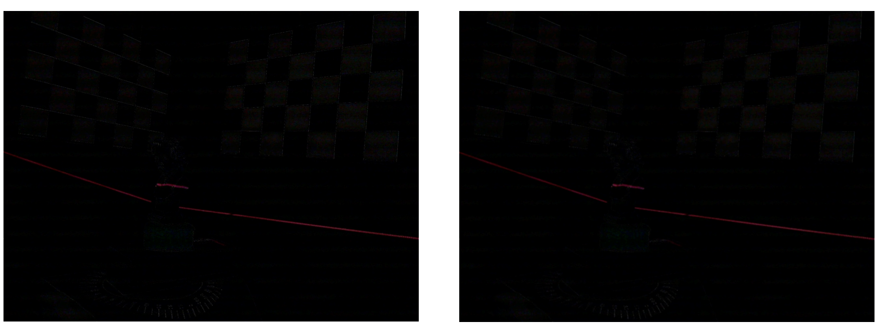
We used OpenCV routine `cvAbsDiff()` to calculate the single-channel image difference of the laser image from the reference image using equation 2. The resulted image difference is shown in figure 3.3

$$C = A - B \tag{2}$$

where A is the laser image in figure 4(a) and
B is the reference image in figure 4(b) and
C is the difference image in figure 4(b)

(a) A (b) B (c) C

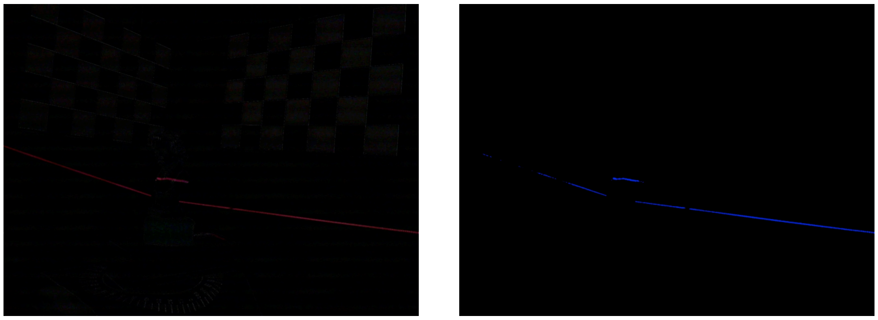
Fig. 4. Using Image Difference to Find the Laser



(a) Difference Image (b) Gaussian Smoothened Image

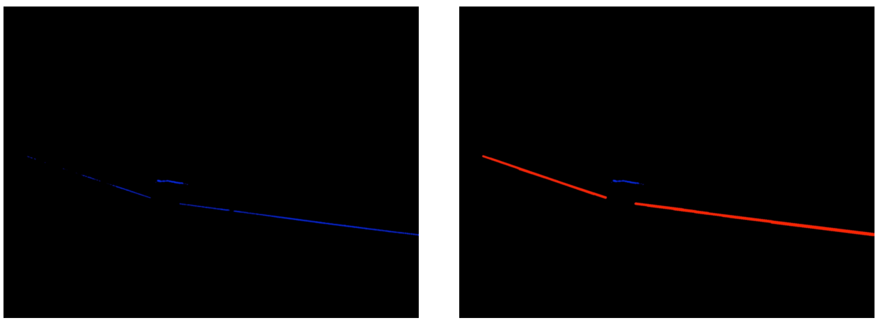
Fig. 5. Gaussian Smoothing the Difference Image

- Take a Difference Image to find the Laser
- Smoothen the Difference Image



(a) Image with Outliers (b) Image without Outliers

Fig. 6. Color Thresholding to Remove Outliers



(a) Before Transformation (b) After Transformation

Fig. 7. Hough Transformation

- Color Threshold to remove everything else
- Apply Hough Transform
- Wrap the Points and Return the results

3.4 Generation of Point Cloud

- Transform the Right Laser Points to Left Coordinate System
- Get the 3D Laser Points using Camera Extrinsics
- Get the Laser Plane Equation using 3 Laser Points
- Get the 3D Object Point by intersecting the Laser Plane with Light Ray
- Save the 3D Object Points with their color values using Reference Image

$$P_w = \underbrace{s \times R^{-1} \times A^{-1} \times \begin{pmatrix} u \\ v \\ 1 \end{pmatrix}}_{\overrightarrow{b}} - \underbrace{R^{-1} \times T}_{\overrightarrow{a}} \tag{3}$$

$$\text{where } \overrightarrow{a} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix}, \overrightarrow{b} = \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} \text{ and } s = \frac{a_z}{b_z}$$

$$P_c = R_1^{-1} \times P_k - R_1^{-1} T_1 \tag{4}$$

$$\text{where } P_k = \begin{bmatrix} R_2 \mid T_2 \end{bmatrix} \times P_w$$

$$A_x + B_y + C_z + D = 0 \tag{5}$$

$$\text{where } \overrightarrow{N} = \begin{pmatrix} A \\ B \\ C \end{pmatrix}$$

$$P_w = s \times R^{-1} \times A^{-1} \times \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} - R^{-1} \times T \tag{6}$$

$$\text{where } s = \frac{\overrightarrow{N} \times \overrightarrow{a} - D}{\overrightarrow{b} \times \overrightarrow{N}}$$

3.5 Point Cloud Processing and Registration

– 3DTK

4 Some Experimental Results

results

5 Evaluation and Comparison (maybe?)

evaluation-comparison

6 Conclusion

conclusion

Fig. 8. Results

References

1. Zhang, Z.: A Flexible New Technique for Camera Calibration. Pattern Analysis and Machine Intelligence, IEEE Transactions on **22**(11) (nov 2000) 1330 – 1334
2. Brown, D.C.: Close-Range Camera Calibration. Photogrammetric Engineering **37**(8) (1971) 855–866