Measuring the Tilt Angle of an Inclined Wall Based on Image Processing

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ABSTRACT

A simple method is discussed in this paper to measure the parameters of an inclined wall. By using a simple USB camera and three laser projectors, we can evaluate the distance between a target wall and the camera. We can also measure the tilt angle of the wall.

Pixel counts between the image’s center point and the laser spots in images taken at different photographing distances will be different. By identifying the positions of the laser-projected spots in images, the pixel counts between the laser-projected spots and the image center point can be calculated for measuring the distance and tilt angle.

From experimental results we have found that the measuring method is more suitable for short distance measurements, such as the architectural sketch, indoor decoration or retaining wall detection.

INTRODUCTION

To measure the tilt angle of an inclined wall, one must first measure the distance between the wall and the observer. There are many ways to measure this distance, the most prominent method utilizes laser [1]. Another methods use a camera to measure distance and other parameters [2, 3].

To measure the tilt angle, Huang [4] used a digital camera with two parallel laser beams to measure the distance and horizontal direction of tilt of an inclined plane. Huang [5] proposed a non-contact optical measuring system for an inclined surface. We [6] extend this work by proposing a new system that can simultaneously measure the distance and tilt angle, either horizontal or vertical.
Our work relies on the theorem of digital image processing, not only can we measure the distance between the wall and the camera, but also measure any direction of tilt angle of the wall.

SYSTEM ARCHITECTURE

This paper relies on a single CCD camera (or digital camera) and three laser pens to construct a simple image-based distance and tilt angle measurement system, as shown in Figure 1(a). In the figure, the CCD camera and laser pens: Laser A, Laser B, and Laser C, are fixated on the same base, and the laser beams performed by the three pens are adjusted to be parallel to the optical axis of the lens. As a result, the projector spots from the three laser devices will be situated on the same horizontal scan line as the center of the monitor. Moreover, regardless of how this system tilts or rotates, the relative positions of the laser devices and the CCD camera remains stationary. In other words, regardless of how the entire system moves, they will appear on the same horizontal scan line of the image.

TILT ANGLE OF AN ARBITRARILY ORIENTED WALL

Let the 3D space coordinated of an image center is \((0, 0, 0)\), then the equations of the three laser beams are

\[
\begin{align*}
LA & : x = D_s, \quad y = 0 \\
LB & : x = -D_s, \quad y = 0 \\
LC & : x = 0, \quad y = \sqrt{3} D_s
\end{align*}
\]

Suppose the target wall’s tilt angle is as illustrated in Figure 2, where \(\mathbf{n}\) is the normal vector of the wall, \(\theta_H\) is the horizontal tilt angle, \(\theta_V\) is the vertical tilt angle,
and $S_s$ is the distance between the wall and the image plane center. As can be observed from the figure, the equation of the inclined wall is $n_x x + n_y y + n_z z = n_z S_s$.

The intersection point of the inclined wall and LA is projected onto the image with coordinate

$$ (x_A, y_A) = \left( \frac{-f \times D_s}{f + z_{AS}}, 0 \right) \Rightarrow \left( \frac{-f \times D_s}{z_{AS}}, 0 \right) \quad (2) $$

where $z_{AS} = S_s \tan(\theta_H)D_s >> f$. The image between this point and the image center is shown below

$$ d_{as} = k \frac{k}{|z_{AS}|} = \frac{k}{|S_s - \tan(\theta_H)D_s|} \quad (3) $$
Similarly, the distance between the image center and the intersections of the tilt wall and LB and LC can be obtained as, respectively

\[ d_{BS} = \frac{k}{z_{BS}} = \frac{k}{S_S + \tan(\theta_H)D_S} \]

\[ d_{CS} = \frac{\sqrt{3}k}{z_{CS}} = \frac{\sqrt{3}k}{S_S + \sqrt{3}\tan(\theta_V)D_S} \]

From the equations (3) and (4), we can evaluate the parameters of the tilt wall.

\[ S_S = \frac{d_{BS} + d_{CS}}{2d_{BS}d_{CS}} k, \quad \theta_H = \tan^{-1}\left(\frac{k(d_{BS} - d_{CS})}{2d_{BS}d_{CS}D_S}\right), \quad \theta_V = \tan^{-1}\left(\frac{\cos\theta_H}{D_S}\left(\frac{k}{d_{CS}} - \frac{S_S}{\sqrt{3}}\right)\right) \]

### EXPERIMENTAL RESULTS

<table>
<thead>
<tr>
<th>Tile Angle</th>
<th>(x_A)</th>
<th>(x_B)</th>
<th>(y_C)</th>
<th>(S_S)</th>
<th>(\theta_H)</th>
<th>(\theta_V)</th>
<th>Error (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>Vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>69</td>
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<tr>
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<td>405</td>
<td>235</td>
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<td>44</td>
</tr>
</tbody>
</table>

The implementation of the proposed measurement system is shown in Figure 1(b), where \(D_S=10\text{cm}\). Table 1 contains the experimental results under various rotating angles, as prescribed in the previous section.

### CONCLUSIONS

We propose a new system to measure the distance and tilt angle of a target wall based on image processing techniques. From the experimental results we have found that the system is more suitable for short distance measurement, such as architectural sketch, indoor decoration or retaining wall detection. The accuracy of the system will be improved when using a camera with higher resolution.
REFERENCES