Liquid-level measurement using a single digital camera

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A B S T R A C T

An image-based measurement system using a single digital camera and a circular float to measure fill levels in liquid tanks is proposed in this paper. By choosing the float in a different color from that of the liquid in the tank, pixel counts of the float in the image captured by the camera can be calculated with the use of chrominance filtering and thresholding techniques. Based on an established relationship between the pixel counts of the diameter of the float in the image and the photographing distance, the measuring system can effectively measure the liquid level based on the images captured. Because pixel counts of the float in the image are first determined for calculating the diameter of the float, a subpixel resolution during the measurement can be achieved. As a result, measuring precision as well as accuracy via the proposed system can be significantly improved.

1. Introduction

The determination of fill levels in liquid tanks is still under development as the measurement techniques have to meet the increasing requirements of modern processes in chemistry, food industry or biotechnology. In some applications, it is not possible to install mechanical measurement devices, e.g., pressure sensors. For this reason, contactless and non-invasive methods [1–3] which do not include electrical connections inside tanks [4–7] have been developed over the past years. These techniques, however, cannot record images for monitoring chemical reactions occurring within the liquid tank during the measurement. Existing image-based measuring techniques [8–13], though worked to some extents in recording images while measuring the liquid level, required two laser beams precisely formed in parallel from the projectors. Furthermore, the float needed to be centrally positioned on the liquid surface in the tank by wires, which inevitably imposed a critical constraint on liquid-level measurement. As a result, the establishment and calibration of these measuring systems were generally difficult for practical implementations.

To improve measuring performance and overcome the above-mentioned difficulties, this paper presents a novel liquid-level measurement system using a single digital camera (or digital video camera) and a circular float. The setup of the measuring system is simple and straightforward that the digital camera is mounted above the liquid tank for capturing images of the circular float on the liquid surface. An appropriate size of the circular float is chosen in accordance with the dimension of the liquid tank to obtain better measuring performance. Color of the float should be different from that of the liquid for easier identification of the float. With the use of the chrominance filtering and thresholding (binarization) techniques, pixel counts of the float in the image captured by the camera can be easily identified for calculation. Subsequently, the diameter of the float in the image in terms of pixel counts can be determined with better precision. Based on an established relationship between the pixel counts of the diameter of the float in the image and the photographing distance, the proposed system can effectively measure the liquid level (volume) while recording images for...
monitoring process occurring in the tank. Because pixel counts of the float in the image are first calculated for determining the diameter of the float, a subpixel resolution during the measurement can be achieved. As a result, measuring precision as well as accuracy via the proposed system can be significantly improved. It is worthy noting that the measuring system performs satisfactorily in measuring liquid levels irrelevant to the shape of the tank under measurement.

The paper is organized as follows. Section 2 introduces the proposed liquid-level measurement system based on images captured by a digital camera. Relationship between pixel counts of the diameter of a circular float in an image frame and the photographing distance will be described in details in this section. The determination of intrinsic parameters for digital cameras is given in Section 3. Experiment results mimicking the measurement process of fill levels in a liquid tank are presented in Section 4. Conclusions are drawn in Section 5.

2. Measurement of liquid level based on images

Because of the linear relationship between the pixel counts of objects in an image frame and the photographing distance, we can then use a digital camera to capture images for measuring fill levels in liquid tanks.

2.1. Setup of the proposed liquid-level measuring system

Fig. 1 shows the proposed liquid-level measuring system, in which a digital camera (or digital video camera) with a maximum view angle, \(2\theta_{\text{max}}\), is mounted above the liquid tank in such a way that the optical axis of the camera is perpendicular to the surface plane of the liquid. To achieve better measuring accuracy, the distance between the optical origin (OP) and the front end of the digital camera, \(h_0\), needs to be taken into account. How the critical parameter \(h_0\) is obtained for a specific camera will be described in details later in this paper. Note that the digital camera has a distance \(h_1\) moved backward to circumvent the near depth of field (DOF) limit inevitably encountered via existing approaches [13]. To prevent possible contact with the liquid, a tempered glass can be positioned between the camera and liquid in the tank, forming a non-contact measuring system. A mask can also be mounted covering the digital camera to prevent negative influence from the environment to the digital camera and liquid. Two spot lights are installed for providing lighting within the tank so as to enhance image quality. A circular float made of non-corrosive floating material with a known diameter will be used as a means for measuring the liquid level. To provide better stabilization, a sinker is positioned underneath the float to reduce fluctuation of the float on the surface of the liquid. The float is basically a disc with mono color on its surface, preferably different from that of the liquid in the tank, for easier identification from the image. The thickness of the float is \(H_{\text{float}}\) when it sits on the bottom in the tank. As shown in Fig. 1, the pixel counts of the diameter of the float in an image frame, \(N(h_a)\) and \(N(h_b)\), at positions \(P_a\) and \(P_b\), are a function of the photographing distance, \(h_a\) and \(h_b\), respectively. Based on the relationship between the photographing distance and the pixel counts in the image, the liquid level can then be determined on the basis of the pixel counts of the diameter of the float in the image captured by the camera.

2.2. Relationship between pixel counts and photographing distance

Because of the disposition of the circular float on the surface of the liquid, the pixel counts of the diameter of
the float, \(N(h_a)\) (or \(N(h_b)\)), can be calculated from the horizontal scan line of the image. Based on a triangular relationship between the photographing distance and pixel counts of objects in an image frame, the distance between the float and the digital camera can then be determined for calculating the liquid level, and subsequently the volume of the liquid. Fig. 2 shows the relationship between the photographing distance and pixel counts of the diameter of the float in an image captured by the digital camera via the proposed liquid-level measuring system. A muzzle limiting the view angle to \(2\theta_s\) is used to reduce the radial distortion of the lens. Because of the linear relationship between pixel counts of an object in an image frame and its horizontal distance, we have

\[
\frac{D_{m1}}{R} = \frac{N_{\text{max}}}{N(h_a)},
\]

where \(R\) is the diameter of the float, \(N_{\text{max}}\) is the maximal pixel counts in a horizontal scan line of an image frame which is fixed and known as a priori irrelevant of photographing distances, and \(N(h_a)\) is the pixel count of the diameter of the float at photographing distance \(h_a\), respectively. Based on a triangular relationship as depicted in Fig. 2, we have:

\[h_0 + h_a = \frac{1}{2} D_{m1} \cot(\theta_s),\]

where \(D_{m1}\) is the real-world horizontal distance formed by the field of view at liquid level 1. Substituting Eq. (1) into Eq. (2), we obtain the distance measurement between the camera and the liquid level at position \(P_a\) (liquid level 1) without \(D_{m1}\) as:

\[h_0 + h_a = \frac{1}{2} \left( \frac{N_{\text{max}}}{N(h_a)} R \right) \cot(\theta_s)\]

2.3. Subpixel resolution in determining the diameter of the float

Though \(N(h_a)\) can be obtained by a direct counting of the pixels of the diameter of the float from the horizontal scan line of the image, the resolution is not satisfactory, particularly when there is a long photographing distance. To improve measuring accuracy, \(N(h_a)\) can be alternatively obtained via the pixel counts of the circular float in the image as:

\[N(h_a) = 2 \times \sqrt{\frac{\sum N_{\text{float}}}{\pi}}\]

based on the relationship between the radius and area of a circle, where \(\sum N_{\text{float}}\) is the total pixel counts of the circular float in the image frame at photographing distance \(h_a\). By doing so, the measuring precision of the diameter of the float in terms of pixel counts has achieved a subpixel resolution. As a result, the measuring precision and accuracy of the proposed approach can be significantly improved.

2.4. Measurement of the liquid level

Note that liquid level is referred to as the distance between the bottom of the tank and the surface plane of the liquid. For example, \(h_1 - h_a\) and \(h_1 - h_b\) stand for liquid levels 1 and 2, respectively. Because the distance \(h_g\) is generally known as a priori when the float sits on the bottom of the tank, we can use this parameter to further simplify the derivation of the liquid level.

Based on Eq. (3), the liquid level at position \(P_a\) (liquid level 1) can be written as:

\[h_1 - h_a + H_{\text{float}} = \frac{1}{2} \left( \frac{N_{\text{max}}}{N(h_g)} - \frac{N_{\text{max}}}{N(h_a)} \right) \cdot R \cdot \cot(\theta_s) + H_{\text{float}}\]
Note that the intrinsic parameter \( h_0 \) is no longer required in calculating the liquid level via Eq. (5). That is, measurement via the proposed approach will not be affected by the optical origin (OP) of the digital camera. Any kinds of digital camera can be used to measure the liquid level via the proposed approach.

2.5. Flow chart in measuring liquid level via the proposed approach

Fig. 3 shows the procedures to measure fill levels in a liquid tank via the proposed approach. The image captured by the camera is first fetched for chrominance filtering so as to better identify the float in the image from the background color of the liquid. We then threshold the image by a value \( T \) via a binarization process for counting pixels of the float in the image. The diameter of the float is then calculated based on the pixel counts of the float to improve measuring precision and accuracy. When pixel counts of the diameter of the float become available, the liquid level can be obtained via Eq. (5).

3. Intrinsic parameters of digital cameras

To construct a measuring system suitable for all kinds of digital cameras, two intrinsic parameters \( h_0 \) and \( \cot h_s \) of the camera need to be established. Fig. 4 shows the proposed method for obtaining an accurate \( h_0 \) and \( \cot h_s \) for a digital camera, in which a muzzle limiting the view angle of \( 2h_s \) is imposed on the camera.

With reference to Fig. 4, when the horizontal ruler is positioned at \( (A_1, A_2) \) and \( (B_1, B_2) \), the distance between the front end of the CCD camera and \( (A_1, A_2) \) and \( (B_1, B_2) \) is \( h_{m1} \) and \( h_{m2} \), respectively. Based on a triangular relationship, we have:

\[
\begin{align*}
    h_0 + h_{m2} &= \frac{1}{2} D_{m2} \cot \theta_s \\
    h_0 + h_{m1} &= \frac{1}{2} D_{m1} \cot \theta_s
\end{align*}
\]

Subtracting Eq. (6) from Eq. (7), we obtain:

\[
\begin{align*}
    h_{m1} - h_{m2} &= \frac{1}{2} (D_{m1} - D_{m2}) \cot \theta_s \\
    \cot \theta_s &= \frac{2(h_{m1} - h_{m2})}{D_{m1} - D_{m2}}
\end{align*}
\]

Alternatively, we can obtain:

\[
\begin{align*}
    \frac{h_{m1} - h_{m2}}{D_{m1}} &= \frac{1}{2} \frac{D_{m2}}{D_{m1}} \\
    \frac{h_{m1} + h_{m2}}{D_{m1}} &= \frac{1}{2} \frac{D_{m2}}{D_{m1}}
\end{align*}
\]

by dividing Eq. (6) by Eq. (7). Thus, the intrinsic parameter of the distance between the optical origin and front end of the camera for a specific camera can be obtained as:

\[
    h_0 = \frac{h_{m1} D_{m2} - h_{m2} D_{m1}}{D_{m1} - D_{m2}}
\]

When the intrinsic parameters \( h_0 \) and \( \cot \theta_s \) become available via the proposed approach, the distance between the float and the digital camera can be determined by Eq. (3), and subsequently the liquid level by Eq. (5).

4. Experiment results

In this section, we present experimental results to demonstrate the effectiveness of the proposed liquid-level measuring system. To reduce the radial distortion effect of lens, a muzzle can be mounted on the camera, limiting the field of view of the camera. As a result, edges of the image frame, where larger radial distortion generally occurs, will not deteriorate the measuring results. Though the resolution is decreased by doing so, it is, however, not a serious problem as total pixels of digital cameras are continuously increased.

4.1. Key steps of the proposed measuring method

For practical implementation, key steps below can be followed to establish the proposed measuring system according to the schematic diagram in Fig. 1:

(1) A digital camera is mounted above the liquid tank in such a way that the optical axis of the camera is perpendicular to the surface plane of the liquid.
(2) The digital camera has a distance \( h_1 \) moved backward to circumvent the near depth of field (DOF) limit.
(3) A circular float with a thickness \( H_{float} \) is deployed on the surface of the liquid.
(4) Obtain the distance measurement \( h_0 + h_{g} \) between the camera and the liquid level at position \( P_g \) via Eq. (3), which is generally known as a priori when the float sits on the bottom of the tank.

![Fig. 3. Determination of liquid level based on images captured by the digital camera using the proposed measuring system.](image-url)
4.2. Preparations for the experiments

(1) Digital camera used: Panasonic DMC-LX1 digital camera, with horizontal resolution of 3248 pixels and vertical resolution of 2160 pixels.

(2) By limiting the field of view of the camera, 3/4 of the total pixels around the central area in the horizontal scan line are used to reduce the radial distortion effect. That is, 2436 pixels in terms of horizontal resolution.

(3) Intrinsic parameters obtained: \( h_s = 0.4 \text{ cm, } \cot(\theta_s) = 2.352 \).

4.3. Experiment results

In an attempt to simulate the measurement of liquid level in a tank, experiments are set up to measure the distance between three blue discs and the digital camera at various distances as shown in Fig. 5, where the discs having an identical diameter of 10 cm are deployed in such a way that A1 lies perpendicular to the optical axis of the digital camera, and A2 and A3 each has a 10 cm difference from A1 in vertical and horizontal directions, respectively. This is to verify the measuring accuracy of the proposed approach by mimicking the disposition of the circular float in different places in the tank. As shown in Table 1 the measurements at various photographing distances between the camera and the three blue discs differently positioned all yield a mean error of less than \( \pm1\% \). This suffices to show that the disposition of the blue discs has an insignificant effect on the measuring accuracy. As a result, we conclude that the drift of the float in a liquid tank has no significant effect on the measurement accuracy of liquid level via the proposed approach as long as the float is positioned not far from the optical axis, which can be easily achieved with the use of extension arms constructed underneath the float limiting its drifting range on the surface of the liquid. In comparison to existing researches [9–12], where mean error in measurement is up to \( \pm8.8\% \), the proposed approach has a much satisfactory measuring performance.

5. Conclusions

In this paper, a novel image-based measuring system is proposed for measuring fill levels in liquid tanks while recording images for monitoring physical status in the tank. The proposed approach has substantially overcome problems and difficulties encountered in the previous researches and demonstrated itself as a simple yet accurate way in measuring liquid level for real-world applications. The simplicity of the proposed approach, where any digital cameras can be adopted as long as the intrinsic parameters are obtained via the proposed identification method, has made the proposed measuring system attractive for practical applications. Because pixel counts of the float in the image are first determined for calculating the diameter of the float, a subpixel resolution during the measurement can be achieved. As shown in the paper, measurement performance has nothing to do with the mounting amplitude and horizontal movements of the camera in the proposed measurement system. As a result, precision calibration equipment is no longer required and measuring precision as well as accuracy via the proposed system can be significantly improved. As demonstrated in this paper, the proposed measurement method has no contact with the liquid while measuring the liquid level. This advantage
has made the proposed approach attractive for use in real-world applications, preventing safety concerns such as linkages, exploration, erosion, etc. Simulation results have shown that measuring performance is irrelevant to the shape of the liquid tank.

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**Fig. 5.** Images of three blue discs at different photographing distances mimicking the measurement process of distance between the float in a liquid tank and the camera.

**Table 1**

<table>
<thead>
<tr>
<th>Actual distance (cm)</th>
<th>Disc A1</th>
<th>Disc A2</th>
<th>Disc A3</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Measured distance</td>
<td>Error (%)</td>
<td>Measured distance</td>
</tr>
<tr>
<td>80</td>
<td>80.0200</td>
<td>0.0250</td>
<td>80.0803</td>
</tr>
<tr>
<td>100</td>
<td>99.6464</td>
<td>0.3536</td>
<td>99.5634</td>
</tr>
<tr>
<td>120</td>
<td>119.2064</td>
<td>-0.6613</td>
<td>119.0564</td>
</tr>
<tr>
<td>140</td>
<td>138.5641</td>
<td>-1.0257</td>
<td>138.3812</td>
</tr>
<tr>
<td>160</td>
<td>158.1681</td>
<td>-1.1449</td>
<td>158.1403</td>
</tr>
<tr>
<td>180</td>
<td>177.8394</td>
<td>-1.2003</td>
<td>178.1817</td>
</tr>
<tr>
<td>200</td>
<td>197.7060</td>
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<td>198.0316</td>
</tr>
<tr>
<td>240</td>
<td>237.2227</td>
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<td>237.2565</td>
</tr>
<tr>
<td>280</td>
<td>276.1171</td>
<td>-1.3867</td>
<td>276.3632</td>
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<tr>
<td>320</td>
<td>315.9127</td>
<td>-1.2773</td>
<td>316.8547</td>
</tr>
<tr>
<td>360</td>
<td>356.2217</td>
<td>-1.0495</td>
<td>356.9352</td>
</tr>
<tr>
<td>400</td>
<td>396.0580</td>
<td>-0.9855</td>
<td>397.1778</td>
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<tr>
<td>600</td>
<td>600.6874</td>
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<td>705.9626</td>
<td>0.8518</td>
<td>710.7848</td>
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<td>803.4414</td>
<td>0.4302</td>
<td>803.8542</td>
</tr>
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Mean error (%) 0.8490 0.8666 0.7795

**References**


