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Liquid level detection in standard capacity measures with computer vision

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Abstract

The article presents a computer vision system for liquid level detection in standard capacity measures that can be used for automating measurements or preforming them in inaccessible places. The developed computer vision system consists of a digital camera and a computer program in the LabVIEW environment. The acquired images are processed and corrected for different distortions (parallax, lens and tilt distortion). By using the edge detection method, liquid level is detected and corrected for all distortions. The computer vision system was tested using water in a laboratory environment on the standard capacity measure with a nominal capacity of 100 l. The measurement results acquired with the automated computer vision system were compared with the readings made by an operator and the agreement is found to be satisfactory.

1. Introduction

Standard capacity measures are commonly used volume standards for testing measuring systems for liquids other than water. A typical standard capacity measure has a transparent neck with scale marks corresponding to its nominal capacity, and to the volumes below and above the nominal capacity [1]. Liquid level detection and obtaining readings from the measuring scale can often be difficult due to the location of the capacity measure or to the nature of the measured liquid. The purpose of this paper is to present a computer vision system that automatically detects the liquid level and reads the volume from the capacity measure. If we want to use this system as a substitution for a human operator, it has to achieve or surpass the accuracy of manual reading. This has been tested by making measurements by computer vision and then comparing them to the ones taken by an operator.

The developed computer vision system consists of a digital camera and a computer program in the LabVIEW environment. Figure 1 show the measuring system with the camera and the capacity measure under test. The acquired images are processed and corrected for different distortions. After all image corrections are done, liquid level is detected using edge detection. Although the accuracy of the system can be compared with the accuracy of a human, it is very susceptible to lightning conditions.

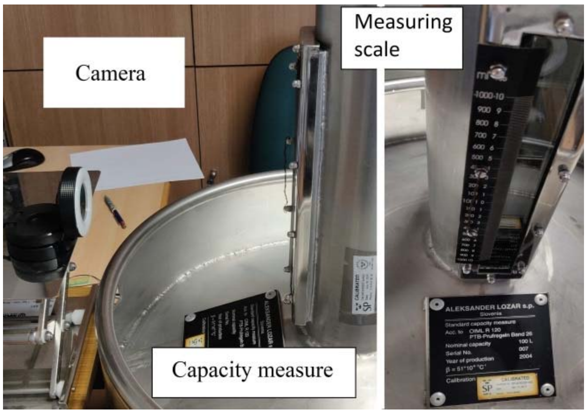

Figure 1: Measuring system for liquid level detection and reading from the measuring scale of the capacity measure.

2. Image corrections

2.1 Parallax

The first distortion effect is parallax that causes a shift of the liquid level's apparent position in the background regarding the measuring scale positioned in the foreground. It occurs due to the distance between the liquid and the measuring scale. Therefore, when the liquid level is not in line with the central axis of the camera, the measurement error occurs. In order to avoid this, the camera should be moved, so it can be constantly in line with the liquid level, or the corrections should be performed after the reading is taken [2].

In standard capacity measures the glass is often thick relative to the gap between the measuring scale and the fluid. This means that a different amount of parallax that occurs in the glass due to a different angle of light is significant enough and cannot be neglected. Consequently, parallax correction is done in two steps, firstly, correcting for the distance between measuring scale and glass, *d*, and, secondly, by correcting for the thickness of the glass, *s* (Figure 2). When viewing from angel α, an error of h_1 is made. Red line represents where the liquid level would be seen, if there was no glass. Green line represents the true path of the light from the liquid level to the camera.

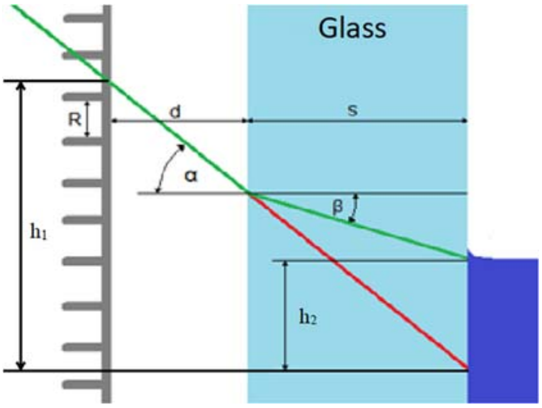

Figure 2: Schematic representation of the parallax effect when viewing from angle α.

2.2 Lens distortion

Lens distortion is present in every lens, some of it appears due to the manufacturing errors and imperfections, other distortions are consequences of physical properties of light. There are many types of lens distortion, but for our purposes we will focus on the ones that change ratios of an image, barrel and pincushion distortion (Figure 3). Barrel distortion is common with wide angle lenses. Image magnification decreases with the distance and we get images that appear to be mapped around the barrel. With pincushion distortion it is the other way around, image magnification increases further from the center of the image. Most lenses have a combination of those effects [3].

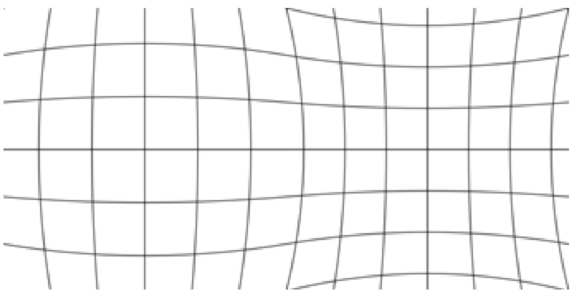

Figure 3: Barrel (left) and pincushion (right) distortion

To get the information about the lens distortion a calibration is needed before the first measurement, the results of which are then used for all subsequent measurements to properly correct the image. The majority of image correction models are based on polynomial corrections. We must be aware that the true lens distortion cannot be fully described by some function, because of the small random defects in lens that are caused by manufacturing and physical properties of a light, so all distortions are merely approximations. In our case we only need to correct the image in a narrow band (where the measuring scale and liquid level are located), therefore we will perform lens correction only in one dimension using cubic polynomial.

First, we must make sure that camera plane is parallel to the plane of measuring scale. Because we will perform correction only in one dimension, it is preferable that the measuring scale is in the centre of the image. Positions of measuring scale marks are read and cubic polynomial is approximated through them. We can say that the image is not distorted at the center, how far from the center of an image we can neglect distortion depends on the camera and the lens we are using. After choosing our distortion "free" zone, we approximate linear function through the points in this zone. Subtracting cubic and linear functions will result in function that describes how pixels are shifted when we move from the center.

2.3 Tilt of the camera

When trying to do measurements from an image, it is important that ratios between objects in the image match ones in the real world. After correcting the lens distortion, the camera should work as mirroring through a point. Therefore, all ratios should be preserved as long as planes (in our case the measuring scale and the camera sensor) are parallel.

But sometimes this cannot be achieved; therefore we have to make another correction for camera tilt. Based on trigonometry we can get a relation that describes how the angle of camera effects distribution of the mirrored points:

$$L = \frac{\tan\left(\arctan\left(\frac{r}{f}\right)-\gamma\right)s}{R} + LS, \qquad (1)$$

where L is the value of the scale, r is the read position of a liquid level (distance from the centre of an image), f is the focal length of the camera in pixel units, γ is the camera angle, s is the distance between the camera and the measuring scale, R is the distance between the individual lines of the measuring scale. LS stands for a possible shift of the measuring scale, if for instance a zero is not the first read line of the scale.

3. Liquid level detection and reading

Before its first use, a camera must be calibrated and some basic information about setup must be known, the distance between the camera and the fluid; e.g., the distance between the fluid and the measuring scale, and the distance between individual scale marks. If for some reason distance between the camera and the measuring scale cannot be obtained, or when it is not constant, information about the field of view can be used instead.

Detection and reading is done in few steps; firstly, the measuring scale is detected either by using pattern recognition or by using the predefined area (marked by red lines in Figure 4) if the camera is not expected to move. Next, all scale marks are read along the green line in Figure 4. Every mark line is detected at the upper and the lower bound, and these points are used for calculation of the line's centreline. For small distances (only a few pixels), we can assume both points are equally distorted. After the positions of all mark lines are determined, lens correction is performed (using previously obtained correction), after which the function for tilt distortion is approximated over the corrected points and the camera angle is determined.

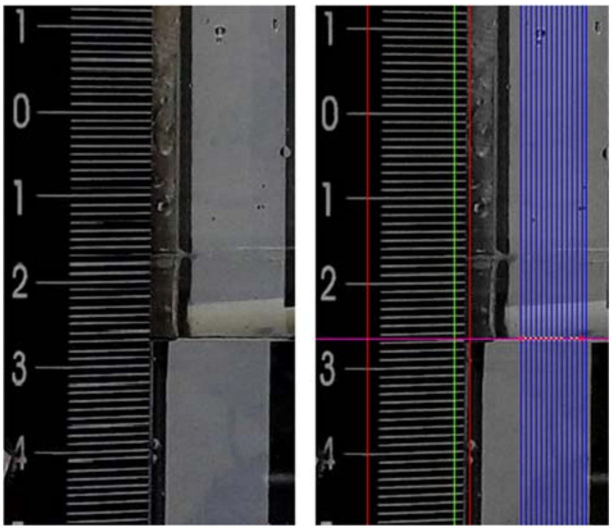

Figure 4: Measuring scale and liquid level; raw image (left) and processed image (right).

Simultaneously, liquid level is detected using the edge detection procedure. Edge detection is carried out on multiple vertical lines across the fluid area (blue lines in Figure 4), so that discrete air bubbles or droplets that might be present in the area do not influence the results. When the height of the liquid level is determined (purple line in Figure 4), it is corrected for the lens distortion. Then the angle between the liquid level and the horizontal plane is determined, using information about the camera setup and the camera angle. This is then used to make corrections for the parallax effect.

4. Testing and results

Images were captured using a standard web camera (Razer, Kiyo). The computer vision system was tested in a laboratory environment on the standard capacity measure with the nominal capacity of 100 l using water. Although the developed system is intendent for measurements of liquids other than water, water was chosen as a testing medium to take up the challenge of level detection of more transparent liquids. Figure 4 shows an example of the captured image of the measuring scale in its raw (left) and processed form (right). The scale interval represents 10 ml, which is equal to 0.01% of the nominal capacity (one scale interval is approximately 1 mm).

The standard capacity measure was gradually filled with the water. Readings were taken for different liquid levels (from –0.7% to 0.7% of the nominal capacity) by the operator and the computer vision system. The maximum error of the reading of the liquid level by an operator is estimated to not to exceed one scale interval. Figure 5 shows the deviation between the results read by the computer vision system and the operator for different liquid levels in % of the nominal capacity.

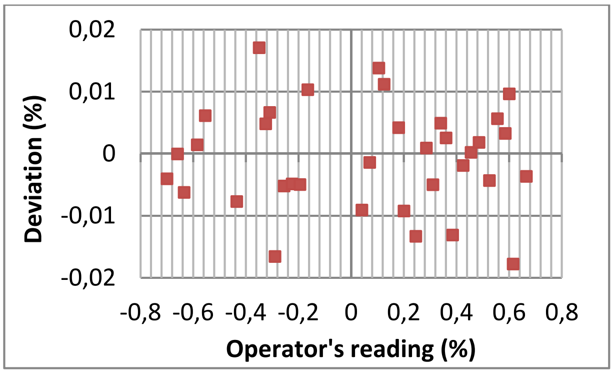

Figure 5: Deviations between the readings by the computer vision system and the operator for different liquid levels.

It is evident that the measurement deviations do not exceed 0.02%, which is satisfying considering the scale resolution. When using standard capacity measures in legal metrology, the target expanded uncertainty is of the order of 0.1%, so the achieved quality of readings can be considered acceptable for such applications.

Nevertheless, the system still struggles when lightning conditions are poor or when they change constantly. Nevertheless, since we were using water as a test liquid, detection of the liquid level was more difficult and more dependent on lightning than in case of coloured fluids. Figure 6 shows an example of the captured image of the measuring scale for diesel fuel (other capacity measure as in the presented tests). It is evident that a much clearer edge of the liquid level can be obtained, which decreases the lighting effects.

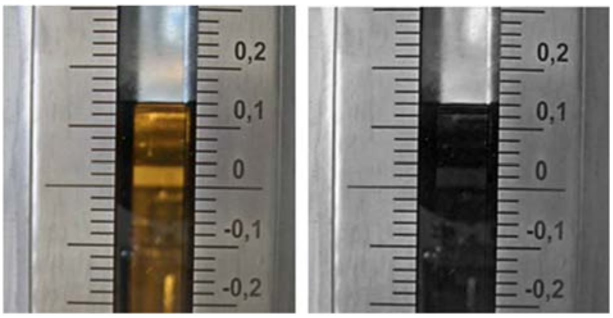

Figure 6: Image of the capacity measure scale for diesel fuel; raw image (left) and monochrome image (right).

5. Conclusion

The computer vision system was tested in a laboratory environment on the standard capacity measure with the nominal capacity of 100 l using water. The measurement results obtained with the computer vision system show relatively small deviations from the readings made by the operator (< 0.02% of the nominal capacity). We anticipate that with proper lightning the automated measurements can be at least as accurate as the manual ones. Therefore, the developed measuring system has a potential for inexpensive and nonintrusive automation of standard capacity measures that are used for calibration and verification of the measuring system for fuels or other liquids.

References

[1] OIML R120: *Standard capacity measures for testing measuring systems for liquids other than water,* 2010.
[2] Szeliski, R., *Computer Vision: Algorithms and Applications* (Springer), 2010.
[3] Hornberg, Alexander., *Handbook of Machine Vision* (Wiley-VCH-Verl.), 2011.