Drop volume measurements by vision

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ABSTRACT

A specific configuration for liquid flow metrology consists of a flow of falling drops coupled with a preferred measuring method that derives the flow directly from the drop count. Given the inaccuracy of this counting method, alternative methods have been proposed that measure the volume of each falling drop. The principle consists in deriving the volume from geometric measurements obtained by vision and the basic problem can be described as the estimation of the volume of a drop from its projection. This paper reviews methods previously used and provides an analysis of qualitative and quantitative aspects of drop volume estimation for flow metrology. Three drop shape models and the related volume estimation methods are defined in a first part. A second part is devoted to an experimental analysis of drop shape variations. In a final experimental part, the presented methods are compared and the good performance of a volume measurement method is experimentally demonstrated. It shows a rms-error of 1% in normal measurement conditions. These figures speak for the interest of the measurement by vision and represent a good base for predicting the suitability of the method in various applications.

Keywords: Metrology, liquid flow, flow measurement, measurement by vision, drop volumetry, volume measurement, drop vision

1. INTRODUCTION

Various principles and methods support liquid flow metrology. A specific configuration consists of a flow of falling drops coupled with a measuring method. A preferred method of this kind proceeds by deriving the flow from the drop count. Due to its simplicity, the method is widely used. But as the method relies on the hypothesis of constant drop volume, it shows real practical limitations in all cases where identical drops cannot be generated. A means to overcome the limitations of this method is to proceed by a direct measurement of the volume of each falling drop.

The drop chamber is the classical device used to generate a flow of falling drops. Its purpose it to permit a visualization of the liquid flow and, at the same time, to keep the liquid confined. Under these constraints, optical measurement of the falling drops is a preferred configuration and the question arises how well vision is suited to perform drop volume measurements.

Imaging is an obvious way to get access to the geometry of a drop. In the general case of an arbitrary shape, a large number of images are possibly required[1], but this number can be reduced to few or even a single image if a priori knowledge is available which permits to resolve the ambiguities. With a priori knowledge represented by simple drop models, the geometric measurements can be reduced even more, as to the measurement of a single diameter in the case of a spherical drop model. Little measurement effort goes with limited accuracy. High accuracy goes with more measurement effort. A practical solution to the drop volume measurement problem is a compromise in-between.

Many drop volume measurements methods have been proposed in the past, which rely on various geometric measures[3,4,5,6,7]. Basic features like drop diameter, elongation, area are interesting because easily accessible. With a full 2D silhouette, more general geometric measures are available permitting more advanced drop models. So far, little work has been published on the respective quality and practical performance of the different methods. This paper therefore proposes to experimentally analyze the drop volume measurement problem and to provide a qualitative and quantitative comparison of several available methods.

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A fundamental aspect of this approach is bound to the physics of drops and to the question of the validity of physically motivated drop models. So far, the drop formation process and the behavior of a falling drop appear to be rather complex[2]. To our knowledge, a realistic useable model is still missing.

Next section introduces three drop models and derives the respective methods for drop volume computation. Then the experimental setup is described. Section 4 provides insight in the drop variability by presenting results of an experimental analysis of drop shape variations. Finally, section 5 is devoted to the experimental comparison of the three presented methods and to the characterization of real performances of a successful method.

2. DROP VOLUME MEASURMENT METHODS

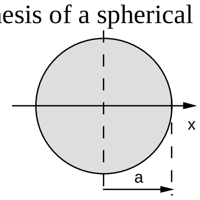
The falling drop passes in front of an imaging device that records a silhouette corresponding to its projection on a vertical plane. Three different methods for estimating the drop volume out of the silhouette are reviewed. Each is based on hypotheses about the shape of the drops.

2.1 Drop Models

Different models are defined for the shape of the drop, starting with the simplest one.

2.1.1 Spherical model

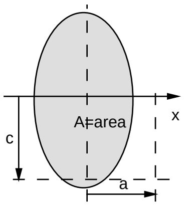
Under the hypothesis of a spherical drop, its volume derives directly from the radius *a* of the two-dimensional silhouette



$$V = \frac{4\pi}{3} a^3$$

2.1.2 Ellipsoidal model

Under the hypothesis of a rotational symmetric ellipsoid with vertical axis for the drop shape, its volume derives from two measurements in the two-dimensional silhouette as given in formula.

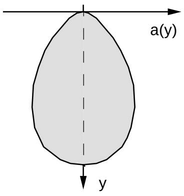


$$V = \frac{4\pi}{3} a^2 c = \frac{4}{3} aA$$

The first form uses the two half axis lengths a and c of the two-dimensional ellipse. The second form uses half-axis length a and the ellipse area A.

2.1.3 Arbitrary rotational symmetric model

Under the less restrictive hypothesis of a drop given by a general rotational symmetric shape with vertical axis, the volume derives from the integrated squared contour function a(y).



$$V = \pi \int_{y_1}^{y_2} a(y)^2 \, dy$$

2.2 Volume Estimation Methods

Based respectively on above models, three methods are defined for computing the volume out of the drop silhouette. The computation refers to a discrete representation of the silhouette defined as a convex blob in a homogeneous rectangular bitmap as shown in figure 1. The blob has N pixels with integer coordinates (x, y).

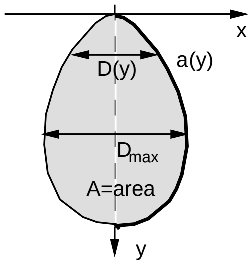


Fig. 1: Geometric features of the observed drop silhouette

2.2.1 Method 1

This method relies on the spherical model and requires knowing the radius of the drop. Practically, setting it equal to the half-maximal diameter of the falling drop silhouette, which measurement is very easily obtainable, determines it. With this, the volume writes:

$$V = \frac{\pi}{6} D_{max}^3 \quad \text{with} \quad D_{max} = \max_y D(y)$$

2.2.2 Method 2

This method uses the ellipsoidal shape model. It requires two measurements of the drop silhouette. Taking from above the second form, which is based on the area A, as well as the maximum diameter D_{max} of the drop silhouette, the measured drop volume for this method writes

$$V = \frac{2}{3} A D_{max} \quad \text{with} \quad A = N \quad \text{and} \quad D_{max} = \max_y D(y)$$

2.2.3 Method 3

This method uses the arbitrary rotational symmetric shape model. It requires knowing the contour function a(y) of the drop silhouette. The idea is to proceed practically by setting it equal to the half silhouette diameter function D(y). The formula for the volume becomes, in discrete form:

$$V = \frac{\pi}{4} \sum_{y=0}^{y_{max}} D^2(y) \quad \text{with} \quad D(y) = x_{max} - x_{min}$$

3. EXPERIMENTAL DROP VOLUMETRY

The section describes the configuration set up for testing drop volumetry. It relates to the classical dispenser with drop chamber and uses ad hoc image processing for silhouette extraction.

3.1 Dispenser with drop chamber

The drop chamber is used in many practical liquid-dispensing devices, namely for infusion in medicine. Typically, liquid coming from some source like a dispenser bag flows into a tube that insures its transport to the destination, like the infusion needle. A drop chamber inserted in the tube makes the liquid flow visible. The drop chamber is only partially filled with liquid such that the liquid flow consists of single drops falling under gravity from the dispensing tube to the chamber bottom, partially filled with liquid. As the chamber walls are transparent, the flow is directly visible to an observer. Visual drop counting devices and visual volume measurement devices can thus be directly coupled to this drop chamber.

3.2 Experimental setup

The experimental setup uses a standard liquid dispenser bag as a source of liquid (fig. 2). The liquid flows under gravity in the tube and then into the drop chamber. A drop control device is mounted onto the tube, which consists of a simple mechanism that permits to increase or decrease the liquid flow by displacing a ruler. Note that the liquid flow results from the drop volume V and the drop rate f:

$$\Phi = f * v$$

Changing the ruler mainly modifies f, but V changes also. Furthermore, V depends on various other factors like the liquid viscosity, the pressure, and the tube geometry.

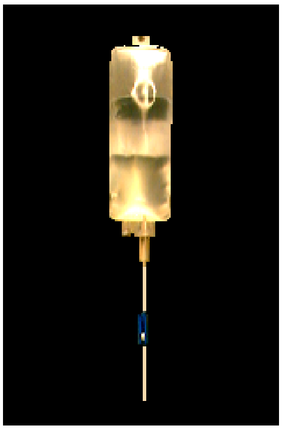


Fig. 2: Dispenser bag and manual flow control

Fig. 3: Drop chamber and imaging section

The falling drop is imaged onto a video camera through the transparent drop chamber walls (fig. 3). The scene is backlight illuminated such that the camera perceives the drop as a dark shape with a clear surrounding. The camera exposure is started by a trigger signal that results from a light barrier that traverses the chamber and is opened by each falling drop. The exposure time is 1/16'000 s.

In this experimental setup, after leaving the imaging section, the drop does not continue in the tube but falls onto a precision balance. Each drop can thus be weighted individually and its weight can be related with the measurements obtained by vision.

3.3 Image processing

The acquired image of the falling drop requires several steps of processing to end up with the pure shape of the drop silhouette. A first preprocessing step aims at removing the effects of inhomogeneous illumination and nonunifomities in the drop chamber wall. It consists mainly of an image intensity transform during which the drop image is compensated for these effects by subtraction of a reference image representative of the scene inhomogeneities.

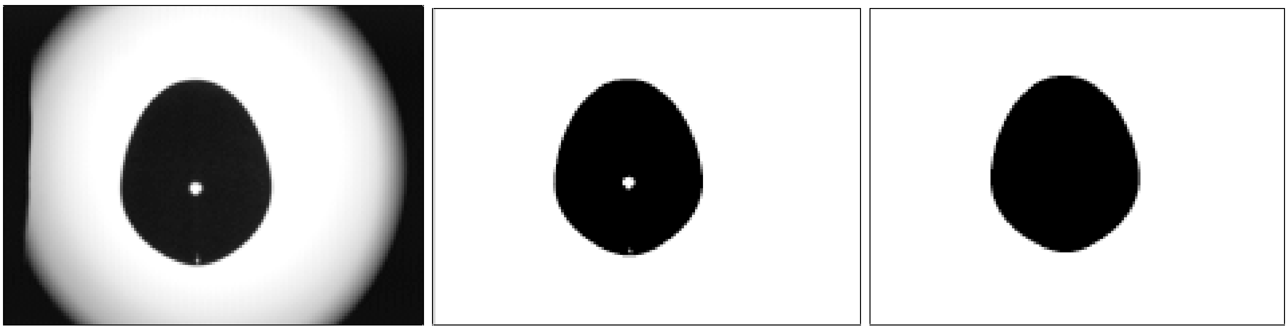


Fig. 4: Image preprocessing steps

In a second step, the drop image is segmented by an adaptive binarisation that derives its threshold in a way that optimally separates the peaks of the image intensity histogram.

A final step is required in order to clean the silhouette from "holes" which appear in transparent liquids. These holes consist in fact of bright spots that appear inside the drop image as a result of the lens effect produced by the transparent liquid. Mathematical image morphology offers the necessary closing operation that removes holes without changing the overall drop shape.

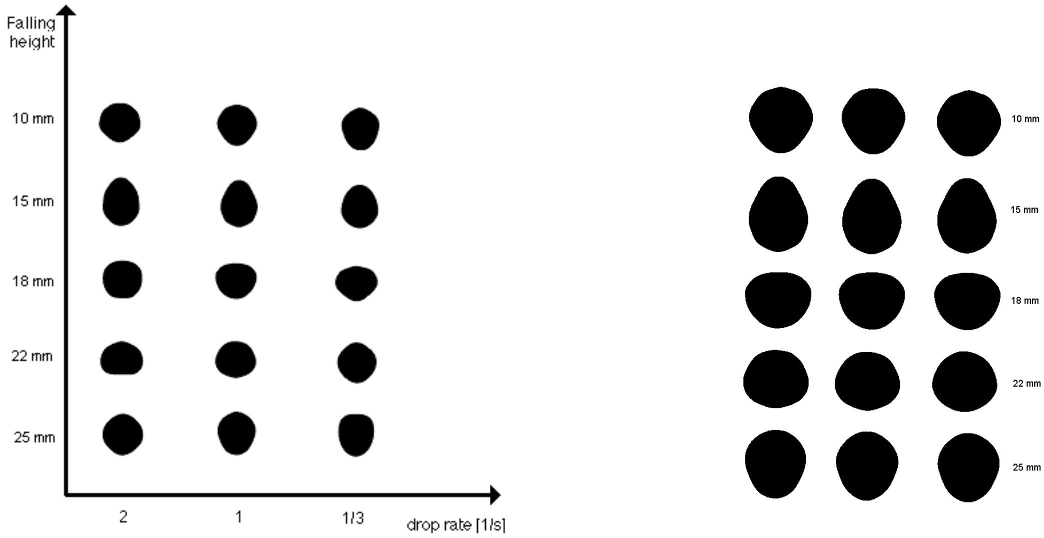
4. EVALUATION OF DROP GEOMETRY

The simple observation of falling drops reveals the existence of variable shapes. This section illustrates specific aspects of these variations by reporting results of an experimental analysis.

4.1 Shape variation

A first series of experiments, conducted with above described experimental setup, concerns the shape variation of drops as a function of the rate and the falling height. The experiments refer to a given configuration of the experimental setup and always uses the same liquid water. The change of rate is obtained by manually changing the flow control setting. The change of the falling height by changing the imaging section height with respect to the drop chamber.

Figure 5a shows the drop shape variations for falling heights of 10, 15, 18, 22 and 25 mm as well as drop rates of 2, 1 and 1/3 Hz. Clearly the shape varies significantly with both parameters. The shape variations visible in this image give a good insight in the process going on during the drop fall. In fact, when the drop leaves the tube tip, the sudden fall initiates an oscillation of the drop mass which goes on during the fall and is responsible for shape changes all along the falling path. The alternating change of the drop shape between a prolate and oblate type of spheroid is clearly visible (fig. 5a).



a) b)

Fig. 5: Drop shape variation

4.2 Shape constancy

A second series of experiments, conducted with above described experimental setup, concerns the statistical shape variation of drops. The experiments refer to a given configuration of the experimental setup and always uses the same liquid water. For a given drop rate and falling height, the obtained shape are compared in order to examine individual shape variations. Figure 5b, which displays five sets of three measurements, shows the constancy of shape.

4.3 Expected shape geometry

Given above observed shape variations which appear to be unavoidable, given also additional shape variations which may result from other factors like viscosity, density, pressure, etc, it is clear that volume estimation methods must take shape variation into account in order to perform well.

5. PERFORMANCE OF DROP VOLUMETRY

A first series of experiments concerns the comparison of the exposed methods for drop volumetry. A second series concerns the effective performance of method 3, the more advanced method.

5.1 Quantitative performance comparison

In order to compare the performance of the exposed method for drop volumetry, four series of 20 drops were recorded and weighted. Each set named A to D refers to measurements with same falling height. The sets A, B, C and D correspond successively to heights of 12, 17, 22 and 27 mm. Individual drop volume variations range between 45 and 55 µl. Figure 6 shows examples of each set and illustrates the variation in shape. The sets for heights A and D show a dominance for the prolate spheroid and set B and C a dominance for the oblate spheroid type.

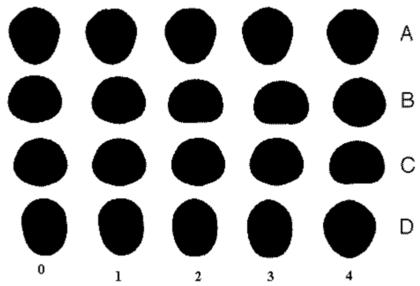


Fig. 6: Drop shapes of some individuals of sets A, B, C and D

Figure 7 reports the estimation errors of the three methods and provides a comparison. As expected, method 3 performs much better than method 1 and 2. In fact, methods 1 and 2 show real poor performance, reflecting the inadequacy of the primitive models to cope with the nature of the varying drop shape.

	method 1	method 2	method 3
set A	5%	15%	1%
set B	15%	12%	0%
set C	17%	17%	1%
set D	20%	8%	0%

Fig. 7: Relative error of the drop volume measurement methods (rounded % value)

5.2 Quantitative performance of method 3

The second series of experiment reported here concerns the effective performance of the advanced method 3. In order to estimate the real performance of this method, the test experiments involve variations that are sufficiently large to reflect a typical future application. The first variation is the change of the falling height, a variable extensively used in previous example in order to modify the drop shape. The second variation is the drop rate which now is modified in a range of about 1:10. Increasing the drop rate increases the individual drop volume. An additional variation relates to the modification of the overall configuration. In this precise case, drop volume relates to the change of liquid pressure due to the progressive emptying of the dispenser bag.

Figure 8 compares the reference volume data obtained from the precision balance with the drop volume measurement obtained by vision. Outlier excepting, the performance is good. The rms-error is less than 1%.

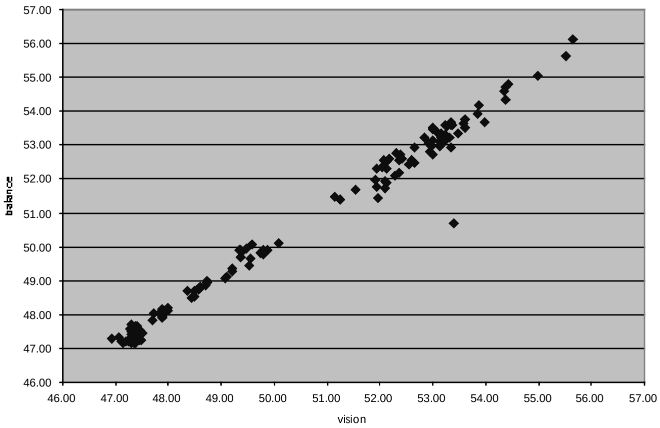


Fig. 8: Performance of method 3

6. CONCLUSIONS

Drop volume measurement by vision was considered in the context of liquid flow metrology. It requires to record the silhouette of a falling drop and to estimate from it the unknown volume. Three volume computation algorithms were defined and compared. First experiments reveal typical drop shapes and the nature of the problem. Further series of experiments compare the computed volume obtained by vision of single drops with their volume obtained by weighting. The results reveal that simpler methods are clearly inefficient while the advanced method performs well. It reaches an rms-error is below 1% in normal measurement conditions. These figures speak for the interest of the measurement by vision and represent a good base for predicting the suitability of the method in various applications.

7. REFERENCES

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