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Surface tension measurement with a smartphone using a pendant drop

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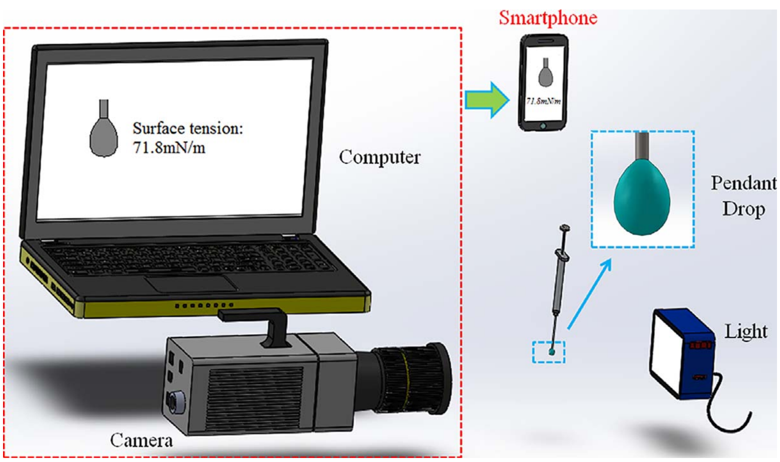
GRAPHICAL ABSTRACT



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ABSTRACT

In this study, a novel powerful mobile surface tension instrument based on a smartphone (mobile-phone or handy) is developed. Axisymmetric drop shape analysis method was implemented on a smart-phone (mobile-phone) for surface or interfacial tension measurements. The novelty of this work is that we have been able to implement all the needed calculations on a smartphone, and used the smartphone hardware for image acquisition and display purposes. As such we have been able to create an instrument that is significantly more economical compared to current systems; also it is compact, and can be mobile for field work. It is shown that the accuracy of our method can be 0.001% with ideal synthetic drop profiles (750 synthetic droplets representing a wide range of surface tension values were used). The performance of this instrument was also compared with a high-end commercial surface tension measurement instrument. We used various liquids (from high to low surface tension), and show that our instrument and the developed methodology can provide surface tension measurements as precise and accurate as current commercial instruments.

1. Introduction

Liquid surface tension is a fundamental physical property indicating the tendency of a fluid surface acquiring the smallest possible surface area [1]. It is the key parameter governing the interaction between liquid and another bulk phase. As such, accurate measurement of liquid

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surface tension is of both fundamental and practical interest in a wide range of scientific and industrial areas, such as material science, polymer, semiconductor industry, coating, colloids, emulsions and printing industry [2–7]. The knowledge of surface tension can also be helpful in daily life. For example, the pure water has a large surface tension (~73 mN/m). When the water is contaminated by a chemical agent, the surface tension changes (usually decreases); then, the surface tension measurement can serve as a way for water quality testing [8].

Various techniques for surface tension measurement has been developed for a long time [1,9–12]. In general, these methods can be categorized into two groups, force tensiometer methods (e.g. Wilhelmy plate technique) and optical methods (e.g. axisymmetric drop shape analysis (ADSA)). The force tensiometer methods typically obtain the liquid surface tension by measuring the force acting between the liquid and a solid. In contrast, optical methods determine the surface tension from the image of an axisymmetric droplet by drop shape analysis (e.g. finding the drop outline by image processing and then calculating numerically the surface tension by fitting the drop outline to the solution of the Laplace equation). Compared with the force tensiometer methods, the optical methods have the advantages of a small sample liquid requirement, an improved accuracy, and convenience [1,9]. As such, the optical methods become the preferred method in many occasions.

Fig. 1 schematically shows a typical drop shape analysis system. A pendant droplet which is generated with a needle/capillary is positioned between a camera connected to a lens, and a light source [1,9]. Once the image of the pendant drop is taken by a capture device, it is imported into a computer for image processing, numerical calculation and data display. Such arrangement results in typically large instruments. Large bench bound instruments are also not suited to the increased demand for on-site (field) measurements in industry. Given the number of components involved in a standard setup, such instruments are also fairly costly.

In recent years, a number of studies have been reported the use of a smartphone for conducting advanced measurements, e.g. image processing, data treatment, clinical diagnosis, and environmental monitoring [13–16], profiting the advanced processing capabilities. These studies have shown that a smartphone can be utilized as a powerful instrument for advanced scientific measurements. In this study, we present an innovative surface tension measurement instrument based on smartphone platform. Many smart-phone models have large random-access memory (RAM), powerful central processor unit (CPU), high resolution screen and camera. Hence, any smart-phone platform is capable to execute all functions needed on a drop shape based surface tension tensiometer: image acquisition, image analysis, numerical calculation, data display and storage in a compact and durable form factor. All these lead to three major advantages over current commercial tensiometers. First, a drastic price reduction of the instrument is found since there is no need to set mechanical fixtures, elaborate chassis, lens, computer, etc. All mechanical parts and devices of the instrument is available in a hand palm. Second, the complete instrument is very compact and portable, giving to researchers the possibility to measure and analyze the surface tension close to its users. Third, its mobility capabilities are very useful for working anywhere (in the field, lab, or a classroom) and its connectivity allows sharing the results in multiple formats. Furthermore, extra embedded functions of the smartphone, e.g. auto focus and touch screen zoom in/out, can be used to provide a better user experience compared with traditional systems.

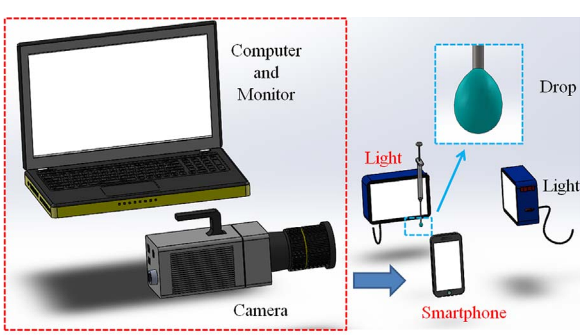

Fig. 1. Schematic for a typical surface tension measurement instrument based on drop shape method compared with the typical size of smartphone.

The application of the drop shape analysis method in a smart-phone requires to solve several technical challenges. First, the large variability of the smartphone models on the market regarding shape, size and specification (e.g. CPU, RAM and camera) can cause potential difficulties during the instrument development in order to adjust its execution to the capabilities of each smartphone specification. For example, camera with different specifications can acquire images with varying quality, which can lead to inconsistent measurement results. Another difficulty is the calibration and adjustment process which can be challenging with the smart-phone system. Even though drop shape method is a convenient method, delicate calibration and adjustments are still needed. For example, in the typical surface tension measurement, camera must be levelled. However, it is difficult for one to take an image with a perfect levelled smartphone. Therefore, the smartphone version of the drop shape analysis is not simply installing the program found in a traditional computer based system onto smartphone, but significant development is needed, especially in the image acquisition and analysis. It is necessary to emphasize that the smartphone requires a minimum quality camera and other sensors like accelerometer to guarantee the accuracy on the measure.

We present a novel surface tension measurement based on smartphone platform. We selected the Android operating system, as it is the most widespread operating system for mobile platforms. In the rest of this paper, we first introduce the surface tension measurement based on drop shape analysis method, then we explain the adaptation of drop shape analysis to the smartphone platform. At the end, the performance of this novel instrument is presented first with ideal synthetic drops, and then a comparison with a traditional commercial surface tension measurement instrument through experimentation with various liquids.

2. Methods

The shape of a liquid drop is governed by the competition between gravity and the surface tension of the liquid. The surface tension tries to maintain the drop shape as a sphere while the gravity tends to stretch a pendent drop. Therefore, theoretically, by knowing the shape of drop, the surface tension can be calculated. Fig. 2a shows the general procedures of drop shape methods. To proceed with surface tension measurement, an image of a pendant drop (generated using a needle connected with syringe) is obtained with the smart-phone camera. The outline of the drop (experimental profile, see Fig. 2b for yellow line) in an image was detected by using a variety of image analysis methods. The profile of a pendant drop can also be calculated (theoretical profile, see Fig. 2b for red line) by solving the differential equation, Laplace equation, [1] with knowing physical properties of the liquid drop, i.e. density difference between two fluids $\Delta\rho$, the gravity acceleration (g), surface tension (γ), length of drop profile (s), and the Laplace pressure difference (ΔP). For each measurement, the values of $\Delta\rho$ and g are needed as the initial input. Initial guesses for γ, s, and ΔP are also needed.

By comparing the theoretical and experimental profiles (yellow and green lines in Fig. 2b), the summation ($\boldsymbol{F}$) of the Euclidean distance between experimental profile points and the theoretical profile can be calculated. The minimal value of $\boldsymbol{F}$ (varying all the three initial guess values) can be found by an optimization method of choice. The liquid surface tension of this liquid should be the guess values which give the minimal value of $\boldsymbol{F}$.

In this study, the programming language used for smartphone