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VOLUME-BASED FIBER DROP FINGERPRINT BASED ON OPTOELECTRONIC LIQUID SIGNATURE ANALYZER

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By merging the light intensity signal from the fiber drop analysis and the drop volume signal from the capacitive drop analysis or image drop analysis, a volume-based fiber drop fingerprint (VFDF) can be obtained. VFDF ensures the reproducibility of measurement against the variation of the feeding speed of the pump and improves the comparability of the VFDFs for different liquids. Preliminary sampling tests have been carried out. Visual features and qualitative differences can be observed in VFDFs of different kinds of liquids. Different brands of the same kind of liquid have different VFDFs too. The same liquid with different concentrations will also produce different VFDFs. Experimental results prove that it is feasible to measure the properties of liquids and to discriminate liquids based on VFDF.

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1 Introduction

Liquid signature analyzer is based on drop monitoring technology such as fiber drop analysis [1], capacitive drop analysis [2,3], image drop analysis [4] and spectral drop analysis [5] in the process of drop formation, to study the liquid properties and to discriminate different liquids. Its multifunctional, pollution-free features and capability in carrying real-time measurements make it of extensive prospect in the fields of environmental quality monitoring, pharmaceutical technology, food, beverage and other related industries.

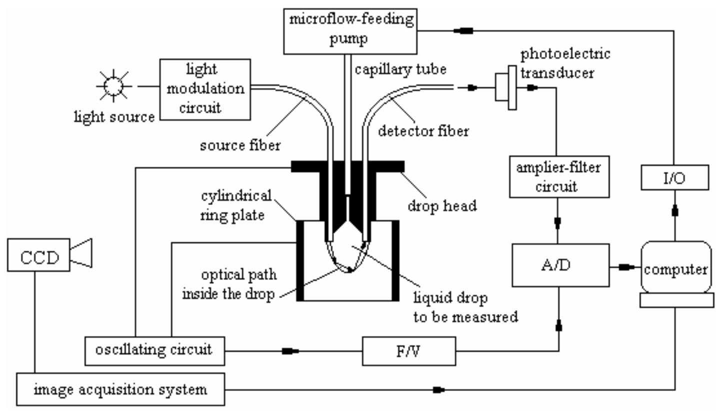

Fig. 1. The schematic diagram of the optoelectronic liquid signature analyzer.

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Fig. 1 shows the schematic diagram of the optoelectronic liquid signature analyzer. The tested liquid is slowly delivered by the software-controlled micro-flow feeding pump and shaped into a satiated and uniform drop after being pumped into the drop head through a capillary tube. The modulated infrared light is injected into the liquid drop by a source fiber positioned in the drop head and is collected by a detector fiber on the opposite side of the drop head after various reflection, refraction and absorption of the optical signal inside the drop. The coupled light intensity changes along with the drop growing and produces a curve named the time-based fiber drop fingerprint (FDF).

In addition, the specially designed capacitive sensor uses the drop head as one of its plate and a cylindrical ring plate, which surrounds the drop head and the space occupied by the formed drop, as another. The drop, which can be seen either as an extension of the drop head plate if the liquid is highly conductive, or as a dielectric material if it is less conductive, changes the capacitance along with drop growth. The instant drop volume can be obtained through a simplified mathematics model between the capacitance and the drop volume.

CCD image processing provides another choice for drop volume measurement and drop growth monitoring by making records of the instant drop shape during its formation directly based on real-time image acquisition and image storage technology. Drop volume can be determined by using Soble or Laplacian edge detection method and image processing technology.

It is the purpose of this paper to put an emphasis on the construction of the volume-based fiber drop fingerprint (VFDF) and its significance, and also to present the experimental results of some typical samples. Volume-based FDF shows the relation between the light intensity passing through the liquid drop and the instant drop volume, instead of time. It makes the time-based FDF independent from the speed of drop growth and the volatility of liquid, and accordingly ensures the reproducibility of measurement against the variation of the feeding speed of the pump. What's more, the volume-based FDF is more favorable for fine discrimination of liquids since it improves the comparability of the FDFs of different liquids.

2. The significance of volume-based fiber drop fingerprint

A fiber drop fingerprint (FDF) can be got by fiber drop analysis, which is the intensity change of collected light signal with the change of time. FDF can be used for liquid property study and fine discrimination among different liquids, because it is affected by mechanical and optical properties of the tested liquids and is unique under certain conditions.

Because FDF is related with time, the speed of drop growth must be quite small and quite stable so that the drop is under quasi-equilibrium condition, on which the drop analysis is based. Since the speed of drop growth essentially depends on the flow control by the feeding pump, it inevitably leads to a heavy demand on the design and manufacturing of the pump in practice. If the speed cannot be controlled precisely, the reproducibility of measurement and the uniqueness of FDF cannot be ensured. This problem is even more serious when a volatile liquid is measured.

Fig. 2(a) shows the time-based FDF of the pure water under the condition that the feeding speed becomes slower gradually. There are obviously some differences in the four continuous FDFs because of the variation of the feeding speed, which then produces a problem that the FDF is irreproducible for a certain liquid and is incomparable for different liquids. It is an essential trouble of the drop analysis based on FDF in measuring property parameters and in discriminating liquids.

A new representation of volume-based fiber drop fingerprint (VFDF) is developed to solve this problem, which is the FDF using the instant drop volume as the horizontal axis instead of time.

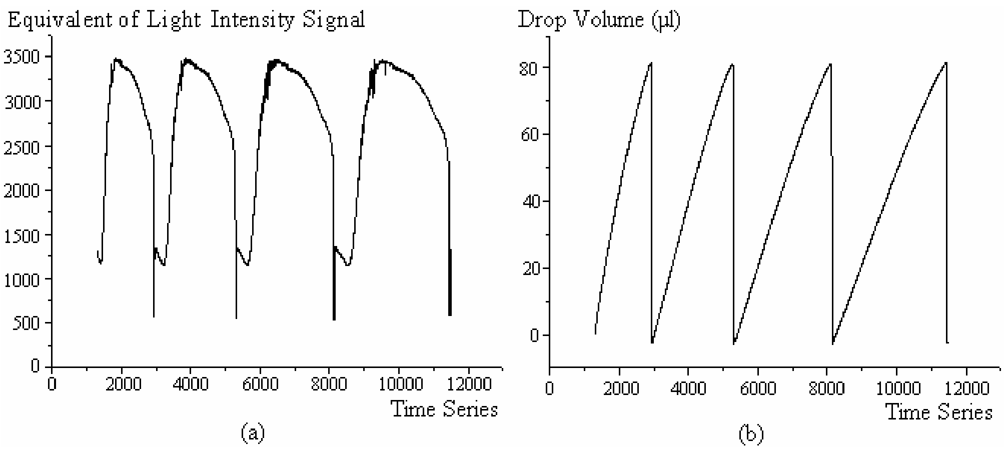

Fig. 2. The experimental graphic results of the pure water under nonconstant delivery speed: (a) The light intensity signal or time-based fiber drop fingerprint, (b) The drop volume signal.

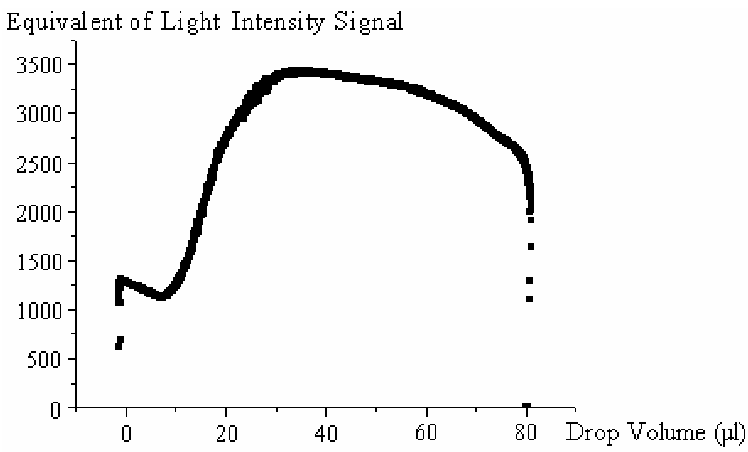

Fig. 3. The volume-based fiber drop fingerprint (VFDF) o of the pure water.

Fig. 2(b) shows the variation of the drop volume of the pure water on the condition that the feeding speed becomes slower gradually. Drop volume can be obtained by capacitive drop analysis or image drop analysis. Fig. 3 shows the VFDF with data corresponding to those shown in Fig. 2(a) and 2(b).

VFDF is actually an overlapping curve of time-based FDF in some successive periods of drop growth based on the drop volume. It can be found that the VFDF is of excellent repeatability, which proves the VFDF is no longer influenced by the variation of feeding speed.

This can be accounted for by the following qualitative explanation: the light intensity detected by the fiber after TIR (total internal reflection) inside the drop depends on the instant shape or volume of the drop, which determines the optical path, no matter how long to form this instant shape. So it is found that the VFDF is independent from the speed of drop growth or the feeding speed. VFDF can be called the liquid drop fingerprint (LDF) directly.

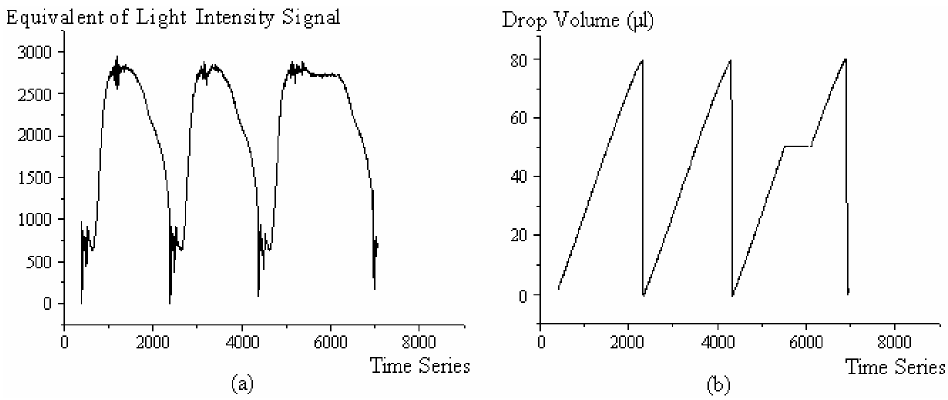

Fig. 4. The experimental graphic results when stop feeding for some time: (a) The light intensity signal or time-based fiber drop fingerprint, (b) The drop volume signal.

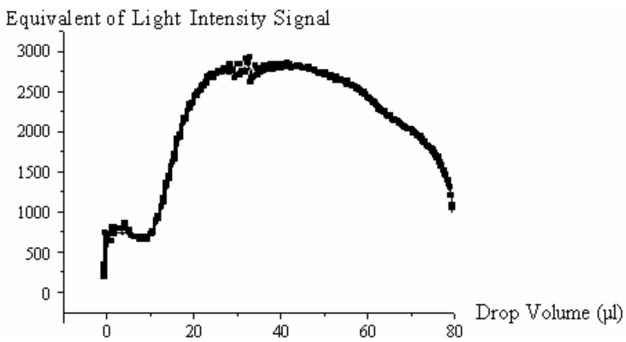

Fig. 5. The volume-based fiber drop fingerprint (VFDF) when stop feeding for some time.

If the feeding flow is stopped at some position during the drop growth, the drop will fall into the complete equilibrium condition and its profile and volume are fixed. It can be deduced that in this case, the coupled light signal from the source fiber to the detector fiber is then fixed. When the pump goes on to supply the liquid, the drop volume and the light signal go on to change with time from the position of equilibrium condition, which has nothing to do with how long to stop feeding. Fig. 4 shows the signals when stop feeding for some time during the third drop formation. The light intensity and the drop volume both become a horizontal line in this period. It is obvious that the third time-based FDF is different from the first two ones. But VFDF is irrelated with the flow variation and it is well repeatable, as shown in Fig. 5.

3. Sampling testes and qualitative analysis on VFDF

In this part, Fig. 6 and 7 shows the experimental graphic results carried out in the Photonic Sensor Research Laboratory in Kingston University of UK. Because of the large size of the original data, only diagrammatic representations, qualitative comparison and analysis are presented here.

3.1 VFDF of different kinds of liquids

Fig. 6(a) shows the VFDFs of some kinds of liquids. It can be seen that the drop volumes of different kinds of liquids are different: the biggest is that of the pure water, the second biggest is that of 25% NaCl solution, the smallest is that of ethanol. The light intensities of different kinds of liquids are different too: the weakest is that of the pure water, the strongest are those of ethanol and CHARCONNAY. Moreover, the peak heights and the peak shapes, and the areas surrounded by the VFDF curves and the horizontal axis are different. In general, VFDF is powerful for fine discrimination among different liquids by using the information extracted from the VFDF of samples and constructing a mathematical model or database for identification.

It is worth noting that the pure water and 25% NaCl solution have almost the same appearance and physical characteristics, and their drop volumes and shapes of VFDF are very close. However, their light intensities, and the areas surrounded by the VFDF curves and the horizontal axis, are widely divergent, which may be explained by the fact of their different chemical compositions. So this proves that the VFDF indicates some chemical properties of liquids besides physical properties.

Fig. 6(b) shows VFDFs of three brands of ratafee. CHARCONNAY and VALENCIA are similar and they are quite distinctive from RATAFEE in London. According to the gustatory sense, the first two taste alike and the last one tastes relatively hard.

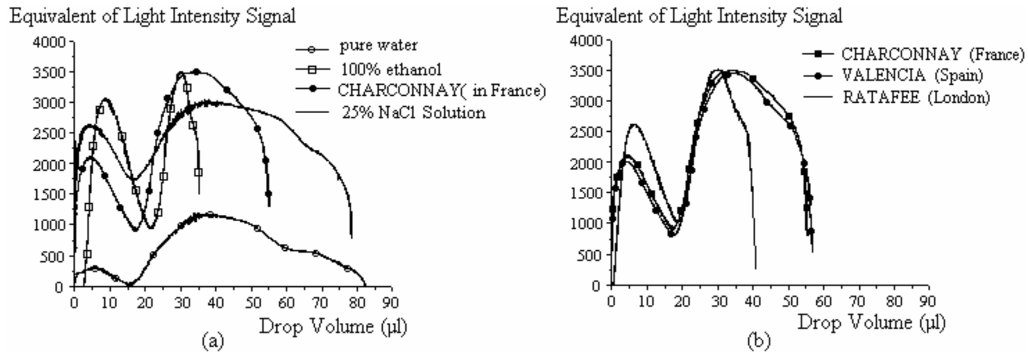

Fig. 6. (a) VFDFs of different kinds of liquids. (b) VFDFs of different kinds of ratafee.

3. 2 VFDF of the same liquid with different concentrations

Even though the same liquid is tested, their VFDF have some difference if their concentrations are different. The VFDF curves of ethanol solution with different concentrations are shown in Fig. 7(a). The drop volume increases with the decrease of the concentration and the rainbow peak (the first peak) attenuates with the decrease of the concentration. Fig. 7(b) shows the VFDFs of the NaCl solution with different concentrations. The variations of the light intensities are the main differences in their VFDFs. The same conclusion can be derived that the rainbow peak (the first peak) attenuates with the decrease of the concentration.

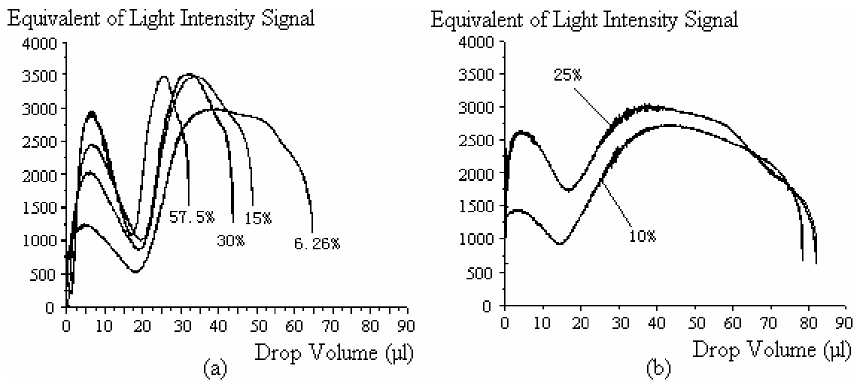

Fig. 7. VFDFs of the same liquid with different concentrations: (a) VFDFs of ethanol solution, (b) VFDFs of NaCl solution.

4. Conclusions

Fiber drop analysis (FDA) produces a fiber drop fingerprint (FDF), which shows the light intensity change during the drop growth. FDF externalizes the overall properties of tested liquids and is unique under certain conditions. But it is limitative in practice because the speed of drop growth cannot be controlled precisely by a common feeding pump. A representation of volume-based fiber drop fingerprint (VFDF) is then developed by merging FDA and capacitive drop analysis (CDA) or image drop analysis (IDA), which shows the relation between the light intensity and the instant drop volume, instead of time. VFDF ensures the reproducibility of measurement against the variation of the feeding speed of the pump and improves the comparability of the FDFs of different liquids.

Preliminary sampling tests have been carried out in Kingston University of UK. Visual features and qualitative differences can be observed in VFDFs of different kinds of liquids. Furthermore, different brands of the same kind of liquid have different VFDFs. Another conclusion is that the same liquid with different concentrations will also produce different VFDFs. Experimental results prove that it is feasible to measure the properties of liquids and to discriminate liquids based on VFDF.

Future development of VFDF is normalization and characterization, in order to quantitate fine discrimination and measurement of liquid properties.

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