Micro droplet distribution monitoring system based on imaging of stroboscopic and delay

Bo Huang[1,2,a], Yu Liu[1,b], and Ming Zhong[1,c]
[1]Harbin Institute of Technology (Weihai), Shandong 264209,China
[2] Weihai Industrial Research Institute of Robotics and Intelligent Equipment,Shandong 264209,China
[a]huangbo74@163.com, [b]liuyuinhit@163.com,[c]zhongming@hit.edu.cn

Key words: Micro droplet dispensing, image process, droplets parameter detection

Abstract: Micro droplet dispensing has great potential in biopharmaceuticals, drug screening, printed electronics and other fields. Its distribution speed, size, and direction is the main factor affecting the quality of the distribution, but it is too difficult to monitor these parameters above when the droplet distributes in high frequency. This paper presents a monitoring method based on imaging of stroboscopic and delay, this method adjusts the delay time between the control signal of nozzle and CCD and LED, to obtain images at different positions of cycle. Then LabVIEW applies the image processing algorithm to the image for online processing to achieve monitoring the parameters above of the droplet distribution online. This paper uses the monitoring system designed to measure the parameters above, and then explored the impact of the driving wave, air pressure, voltage needed for the droplet dispensing on distribution. Experiments found that the method using the monitoring system based on imaging of stroboscopic and delay achieve monitoring the motion parameters in droplet distribution online, and the system measures the volume error within 2%, the deflection direction within ±2 °under steady distribution of droplet; At present the analysis processing speed of monitoring system is 20 frames per second, it will feedback the monitoring parameters in the fastest 0.05 second, and provides technical support for the realization of a closed-loop regulation of the droplet distribution

Introduction

Micro droplet ejection technology is a precision dispensing technology, and this technology has many advantages[1], such as short manufacturing process, non-contact, high efficiency, less waste material and so on[2]. With the in-depth research on micro droplet technology[3], micro droplet distribution has a broad applications in electronic packaging, MEMS, micro-optics manufacturing and bio-manufacturing engineering and other fields[4-5], so that there is an urgent need for a fast, accurate and stable distribution of droplet distribution system. Micro droplet distribution speed, size, and direction is the main factor affecting the quality of the distribution, so it is very necessary to monitor these parameters .

In order to measure the droplet size, velocity, diameter, and other parameters of the distribution process of deflection direction, a lot of universities and research organizations launched a study. University of Kentucky[6] uses a laser Doppler particle analyzer technology for droplet size and velocity measurements, but the technique requires high precision instrument, expensive equipment, and requires a lighttransmitting liquid droplets. Arizona State University [7] uses the image measurement software on diameter of experimental metal particle collected offline, and uses precision scales to weigh the quality of the metal within a certain time of the injection, then calculate the speed of the melt inside the nozzle, and takes it as particle jetting speed. Qi Lehua[8] usee high-speed CCD camera to shoot the droplet stream, and uses a variety of algorithms for image information processing, then measures a micro-droplet diameter, jet velocity and deflection distance parameters.

In the above method, the offline measurement of Arizona state university is low efficiency and poor precision, Laser Doppler particle analysis technique for measuring requires high property for liquids and the equipment costs too high. High-speed cameras chosen by Qi Lehua for measurement also costs up to hundreds of thousands. This paper presents a monitoring technology based on imaging of stroboscopic and delay, which uses image acquisition and image processing technology to measure the speed, size, deflection direction and other parameters of the dispensing process online. We explored the impact of the driving wave, air pressure, voltage needed for the droplet dispensing on the process of distribution with the monitoring system, which laid the foundations for stable and controllable droplet distribution.

Design of monitoring system

We have MJ-AL-01-50 piezoelectric nozzle and realized micro droplet distribution. In order to measure the speed, size, deflection direction and other parameters of the droplet dispensing process, we design a monitoring system, which uses image acquisition and image processing method to measure these parameters online. The scheme of the monitoring system of droplet distribution is shown in figure 1, which is mainly composed of image acquisition module, image processing module, control module, the droplet generation module. Computer controls to produce three pulse signals, which individually control piezo head, LED and CCD; Droplet generator module consists of manifold controller and drive waveform module, these two modules work together so that the droplet will distribute; In the image acquisition module, the LED provide strobe light environment for CCD, auxiliary CCD can get image of droplets with zoom lens; The image processing module uses an image processing software to program the image processing algorithm for image processing and analysis, measure the speed, volume and direction of droplet distribution process online.

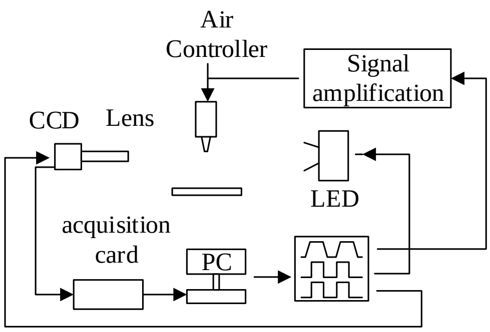


Fig.1 Scheme of distribution monitoring system

The distribution droplet diameter of the piezo nozzle is about 50μm, and the speed may be up to 10m/s, so that this requires that not only the CCD can capture tiny droplets in the acquired images, but also the LED will reduced the blur generated from the high-speed movement.

Design of image acquisition module. Based on the above requirements and in order to reduce costs of high-speed camera, we selected Basler industrial cameras scA780-54fm/fc, with a photosensitive cell size of 8.3μm, shooting speeds of up to 58 frames per second. 50μm droplet is about 6 pixels on image, so that it will cause a relatively large deviation in image processing. We choose Moritex telecentric zoom lens, on one hand it can enlarge the image, on the other hand it can reduce the distortion of the droplet imaging process. Strobe light SL073-WHIC2 model is selected from US AI companies, using the controller S4000 can achieve high frequency strobe LED lighting, and its light intensity can be adjusted, strobe lighting duration time can adjust to 1μs. The LED on one hand can ensure the captured image has good contrast, on the other hand reduces the blurring droplet imaging and improves accuracy.

Since the maximum photographing speed CCD camera 58 frames per second, it is difficult to obtain a different distribution of the droplets at high frequency image and calculates the dispensing speed of the droplet, this paper presents a method of shooting of strobe and delay. This method adjust the delay time between the control signal of nozzle and CCD and LED to obtain droplets image at different position in the cycle. The specific control signal is as shown in Figure 2. The bipolar trapezoidal wave triggered by the first column can drive the piezoelectric nozzle and the nozzle will distribute droplets. The second column wave can trigger the LED to stroboscopic illumination and provide a suitable environment for the CCD shooting. The third column has a lower frequency and it will control CCD shooting at the given frequency.The delay between trigger signal of LED and trigger signal of CCD is varied, so that we will get the droplet image at different position.

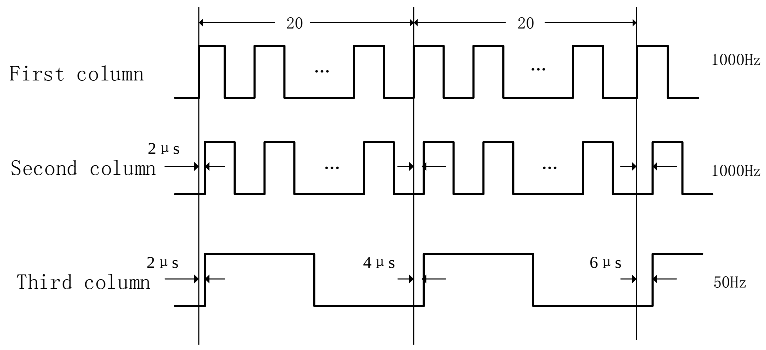
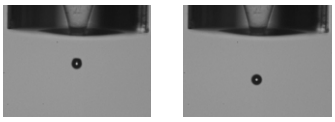


Fig.2 Design principle of the delay signal

Fig.3 shows droplet images acquired at different delay times. Figure (a) is for a certain 4μs motion position after ejection from the nozzle, figure (b) is for a certain 6μs motion position after ejection from the nozzle in another cycle. A complete cycle image of the droplet dispensing obtained by imaging of stroboscopic and delay is shown in Fig.4. This shows that the method of imaging of stroboscopic and delay for getting droplet cycle is feasible.



(a) 4 μ s delay (b) 6 μ s delay

Fig.3 droplets images acquired at different delay time

Fig.4 Droplet distribution cycle obtained by system

Design of image processing algorithm. Image acquisition acquired images of different locations of the droplet dispensing process, in order to measure speed, size, deflection direction of the droplet dispensing process, we need to process and analyze the images acquired in real time. The core task of image processing is to design the image processing algorithms, then we use programming to realize the functions of image processing and analysis. The algorithm designed is shown in Figure 5.

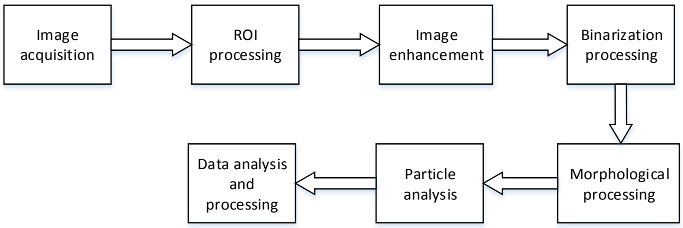


Fig.5 Image processing algorithms

We will extracts an image containing droplet after the image acquired processed by ROI (Region of interest), and the iamge we extract is called region of interest, this can reduce the computer analysis tasks and improve the speed of image processing. Image enhancement methods will improve the contrast between the droplet and the surrounding background using median filtering, and it will reduce the post-processing error. Binary processing change the image into a binary image, which only contains 0 and 1, using an automatic threshold, on one hand it can improve the contrast of the background and objectives, on the other hand only binary image is available for post-processing and particle morphology analysis. Morphological processing is mainly for the defect may in image, uses particle filtration to remove the non-image smaller particle droplets or uses filling hole method to fill the hole in the small hole in droplets binary image, this can reduce the error brought by particle analysis. Particle analysis analyzes the binary image and obtain the XY coordinates of the center of the droplet, the image area and other information. Finally, data analysis and processing will show us the size, speed and direction of droplet distribution.

Experimental Analysis

In order to validate the monitoring system of droplet distribution, the paper uses ethanol as experimental injection material and take experiments. Using the monitoring system designed, we measure the motion parameters of droplet distribution. Then research the influence of the rise time, hold time of the required driving waveform, pressure, voltage on the droplet distribution.

By adjusting the pressure, driving waveform, driving voltage and other parameters, we can realize the distribution of the droplets. In order to achieve piezo injection, the selected driving waveform is bipolar trapezoidal wave. When the rise time, hold time, fall time respectively is 4、40、4 microseconds, the pressure is -0.6kPa, the voltage is 40.8V, we realize the distribution at the 1000Hz frequency. The motion parameter of droplet dispensing proceed obtained by the monitoring system is shown in Figure 6, Figure 7, Figure 8. Through the chart we can know that the system measures the volume error within 2%, the deflection direction within ±2 °under steady distribution of droplet, we think that we have achieved the stability of the droplet distribution. This shows that it is feasible to measure the motion parameters of droplet dispensing process by the monitoring system based on imaging of stroboscopic and delay.

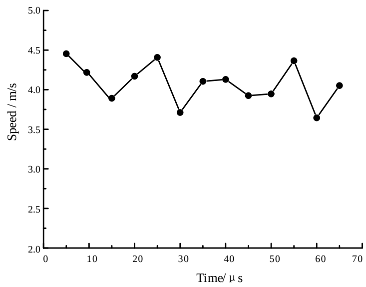


Fig.6 velocity curve of the droplet distribution

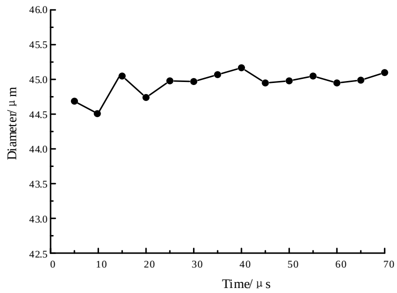


Fig.7 Diameter curve of the droplet distribution

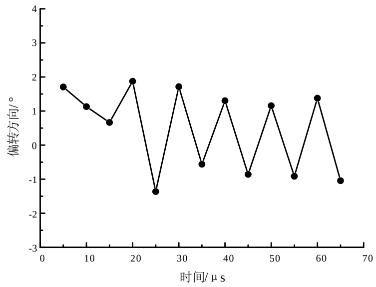


Fig.8 Diameter curve of the droplet distribution

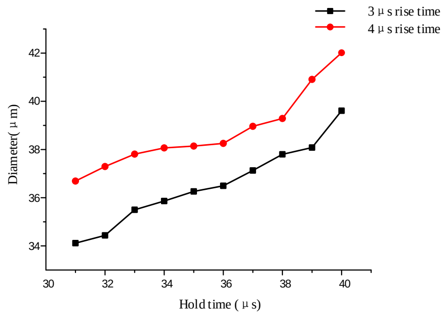
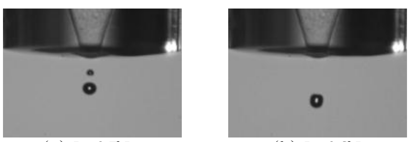


Fig.9 Diameter of different rise time and hold time

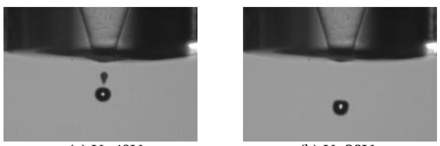
In addition, we study the influence of the rise time and holding time of the bipolar trapezoidal wave on the droplet distribution. In this paper, ethanol is selected as the experimental material of droplet distribution. The diameter data at different rise time and different holding time of stable droplet distribution is shown in figure9. Through the figure we can conclude the relationship between the diameter and the rise time and hold time. When the rise time is same, the shorter the holding time is, the smaller the droplet diameter of stable distribution is; When hold time is same, the shorter the rise time is, the smaller the droplet diameter of stable distribution is.

At last we use the monitoring system designed to explore the factors affecting the droplet generation of satellites. Figure. 10 and Figure 11 are images captured when rise time, hold time and fall time respectively is 4μs, 39μs and 4μs, but pressure and voltage are different. We can conclude through the figure that when voltage amplitude is same, the higher the pressure is within a certain range, easier to generate unstable distribution of satellites it is; When pressure is the same, the larger the voltage amplitude is, easier to generate unstable distribution of satellites it is.



（a）P=-0.7kPa （b）P=-0.6kPa

Fig.10 Droplet distribution under different pressure



(a) U=40V (b) U=38V

Fig.11 Droplet distribution under different voltage

Summary

Using image acquisition module and image processing module, we design a droplet distribution monitoring system based on imaging of stroboscopic and delay. With the system, we can measure the size, speed and direction of the droplet distribution proceed online and in real-time.

Using the monitoring system, we explore the influence of the rise time, hold time of the required driving waveform, pressure, voltage on the droplet distribution. And we discussed the reason of the generation of satellites. We come to a conclusion that when a single parameter changes, the shorter the rise time and the hold time is, the smaller the droplet diameter of distribution will be; the higher the pressure and the higher the voltage are, the more easily satellite droplets will generate, the more difficult to achieve a stable distribution.

Using monitoring system designed we achieve an online real-time monitoring of the volume, speed, direction and other parameters of the droplet distribution. We achieve monitoring the speed, volume, deflection direction in the process of droplet distribution online, and the system measures the volume error within 2%, the deflection direction within ±2° under steady distribution of droplet; At present the analysis processing speed of monitoring system is 20 frames per second, it will feedback the monitoring parameters in the fastest 0.05 second, and provides technical support for the realization of a closed-loop regulation of the droplet distribution.

Acknowledgements

This project is supported by Key research and development program of Shandong Province（2015GGA10022），by Major science and technology projects in Weihai City(2015ZD01)，by Independent innovation of Shandong Province（2013CXC20502）.

Reference：

[1] Shigui Zhou，Juntong Xi，Simulation and Experimental Study on Piezoelectric Diaphragm-driven Microdroplet Jetting Technology[J].Journal of mechanical engineering, 2013, 49(8):187-185

[2] Yuan Xiao, Yachao Huang. Experimental study of the injection process simulation and uniform size pneumatic microtiter [J].The Chinese mechanical engineering, 2014(21).

[3] Guanghuai Xue, Yong He, Jianzhong Fu. Piezoelectric nozzle droplet ejection behavior and its influencing factors [J]. Optical precision engineering 2014, 22(8):2166-2172.

[4] Park B K, Kim D, Jeong S,et al. Direct writing of copper conductive patterns by ink-jet printing [J]. Thin Solid Films, 2007, 515(19):7706-7711.

[5] Danzebrink R, Aegerter M A. Deposition of optical microlens arrays by ink-jet processes[J]. Thin Solid Films, 2001, 392(2):223-225.

[6] T Li, An experimental study of particle charge and charge exchange related to triboelectrostatic beneficiation,[D], University of Kentucky, 1999:88-89

[7] Lee M. Design and operation of a droplet deposition system for freeform fabrication of metal parts /[J]. Journal of Engineering Materials & Technology,

2001, 123(1):74-84.
[8] Guan Yang, Lehua Qi, Jun Luo, Uniform droplet spray forming slightly soluble drop key online testing system [J]. Chinese Journal of Scientific Instrument, 2009, 30(3):590-595.