USING TANGO FOR CONTROLLING A MICROFLUIDIC SYSTEM WITH AUTOMATIC IMAGE ANALYSIS AND DROPLET DETECTION

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Abstract

The microfluidics is the science and technology of systems that process or manipulate small amounts of fluids, using channels with dimensions of tens to hundreds of micrometers. Since a decade microfluidics has become a powerful tool for fundamental and applied researches. Microfluidics influence subject areas from chemical synthesis and biological analysis to optics and information technology. At CEA / LIONS, we integrate microfluidics technology in several research projects. The present work deals with the development of tools for the detection and the analysis of complex calibrated micro-drops.

Although this technique uses small volume of chemicals, it requires the use of numbers of accurate electronic equipments such as motorized syringes, valve, pressure sensors and video cameras with fast frame rate coupled to microscopes.

We use a TANGO control system [1] for all these heterogeneous equipments in microfluidics experiments and video acquisition. We have developed a set of device servers which allow image acquisition and droplets detection (size, number, velocity) almost in real time.

Using TANGO, we are able to provide feedback to actuators, in order to adjust the size and the rate of the droplet formation.

MICROFLUIDIC PRINCIPLES

This technology is based on the manipulation of continuous liquid flow through microfabricated channels. In the lab we use rapid prototyping of polymer (polydimethylsiloxane-pdms) casting [2] and we designed original microfluidic chips for droplet formation.

The basic principle is the following. Two immiscible fluids (oil and water for instance) meet at a cross junction (see Figure 1a-b). Due to the viscous shear the liquid/liquid interface is deformed until a drop is created. In this particular case the local shear is well controlled leading to a very reproducible process [3]. The straightforward consequence is the formation of a monodisperse emulsion as it can be seen on the Figure 1c where a droplet crystal is shown.
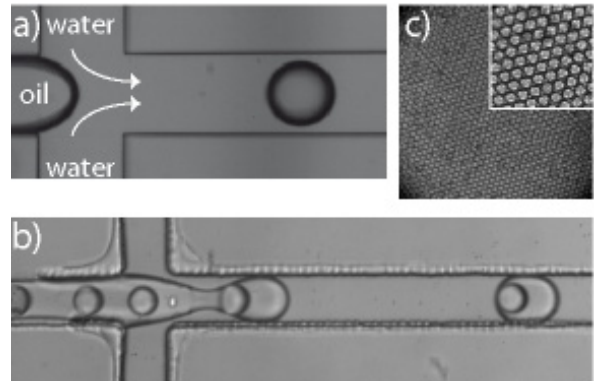

Figure 1: a- Droplet formation at a cross junction. b- Complex droplet formation at a cross junction (double emulsion). c- Crystal of droplets.

MICROFLUIDIC SYSTEM DESCRIPTION

The microfluidic system used here (see Figure 2) is composed by Nemesys [4] motorized syringes, an inverted microscope (Olympus IMT-2) with a x10 magnification objective and a fast video camera Phantom from Vision Research [5]. Syringes system and video camera are controlled by the computer. This combination gives a pixel size on images of 1.92µm.

For producing oil drops we use two syringes filled with water+surfactant and one filled with oil. Products are injected in a dedicated microfluidic chip designed in the laboratory. Flow rate can vary typically from 0.1µl/min to 50µl/min.
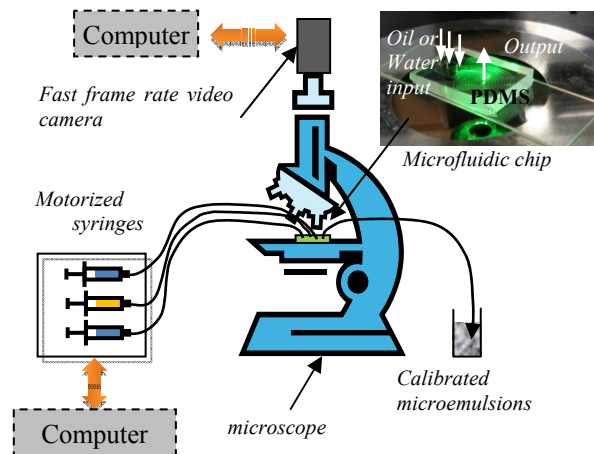

Figure 2: Sketch of the experimental microfluidic system.

CONTROL-COMMAND SYSTEM DESCRIPTION

We use TANGO as the control-command system. TANGO is an object oriented distributed control system based on CORBA and is being actively developed as a collaborative effort between the Alba, Desy, Elettra, ESRF, FRM II, MAX-lab and Soleil institutes.

This system can interface each component of the experience, whether hardware (sensors, motors...) or software, and distribute them over a network. TANGO operates like a software bus, allowing all system components (called device servers) to communicate (see Figure 3).

TANGO provides generic tools for configuration, testing, deployment, supervision. This facilitates the developments and changes to the experiments.

LIONS have developed a package of tools in Python language; enable us to write Python scripts in order to control TANGO device servers in command line.

TANGO Device Servers

The Phantom video camera is interfaced with a C++ device server based on PhCon (control libraries for the Phantom high speed cameras given by Vision Research). For testing, we also use TANGO devices that can publish previously recorded images or video on image attributes.
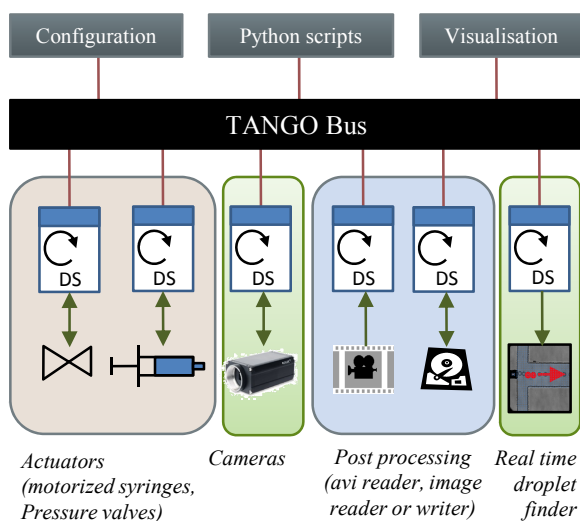

Figure 3: Scheme of the different TANGO layers. Device Servers (DS) are programmed in C++ or Python languages and have the TANGO interface (blue).

Droplet Detection

The "droplets finder" application developed in the present work can connect to all these devices and process the image to find drops. The software is developed in C++, for providing fast results, and is based on the OpenCV [6] (Open Source Computer Vision) libraries, which give programming functions for real time computer vision.

From these libraries, we are using the cvHoughCircle function which implements a Hough [7] algorithm and can find circles on a grayscale image. Some parameters have to be specified: maximal radii of circles, minimal distance between circles, and two method (Hough) specific parameters. The function returns a list of circles with their centres coordinates and radii. A post processing (for brightness and contrast) is made on the image for improving the results.

The user can tunes parameters through TANGO. The finding process can be paused in order to test some parameters on the same image. The program yields the averaged radii of found circles and the distance between drops (centres coordinates are sorted vertically or horizontally).

We used Jdraw application (which is a rapid interface designer tool provided with TANGO) for testing the system (see Figure 6), and display the video camera image and the processed image. Circles are drawn over detected droplets.

TIMING CONSIDERATIONS

Image Acquisition

The exposure time on the Phantom camera is typically in between 0.01ms and 0.1ms, and one drop is typically formed in 1ms. This video camera acquires 2000 images/s in full resolution (512x512) and more when decreasing the picture size. For the present application, it is sufficient to have few measurements per second.

We consider that a TANGO device server must respond in less than 300 ms (value widely accepted in the TANGO community and beyond that, a multi-threading system must be programmed). As the acquisition time was very short, we decided to acquire a new image on the camera each time it is asked by a remote TANGO client (when reading the image attribute).

Droplet Detection

The droplet detection device server is compiled with Microsoft Visual C++ 2008 express version, in "debug" mode, and "release" mode, with the corresponding TANGO and OpenCV libraries. Execution times of the droplet detection (see Table 1) are given by the software, and have been obtained on a simple laptop computer with the following configuration: Intel Core 2 Duo P8600 @2.40 GHz and 4 Go ram.

Table 1 : Processing Time for Droplet Detection

Number of detected circles	Detection time	Complete processing time
6 (debug mode)	170ms	240ms
6 (release mode)	80ms	120ms
17 (debug mode)	430ms	500ms
17 (released mode)	200ms	240ms

The complete process consists of image access from remote device (on the same computer), a pre-processing of image, search of circles, sort of circles, and a publication of the results over the TANGO device server. This process is separated in his own thread on the device server in order to let the server answer to remote clients.

We can notice that detection time is increasing when there are more circles to find on the image. As we can expect, the software is quicker in "releases" mode of C++ compilation, and processing time is reduce by twice.

Image access to remote servers and all the pre-processing procedure takes only around 70ms in the debug mode, and 40ms in the released mode, which is really acceptable for 512x512 pixels by image. There is no difference of timing when the device server is started as a Windows service by the TANGO starter application.

RESULTS

Drops are produced in the microfluidic chip. We have check that number of drops, sizes and distances given by the software are corresponding to real values by a remote analysis of the images with ImageJ [8], an open source image processing program. The device server can also detect a high number of drops with different radii (from 10µm to 30µm).

By varying rate of water or oil in injected by motorized syringes, we can measure in real time the variation of size (Figure 4), the number of drops (Figure 5) or the distance between drops. During measurements, the parameters for detection are not changed. Values have been obtains by averaging 10 images for each rate.
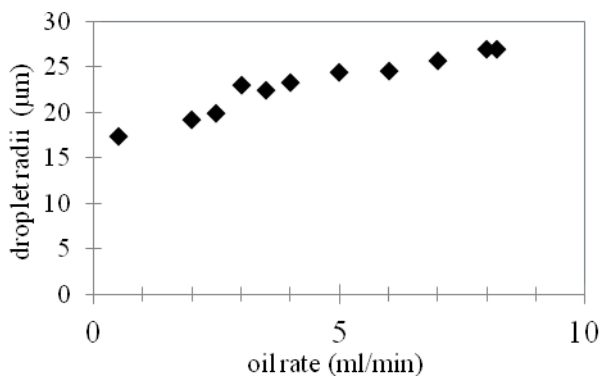

Figure 4: Measured droplet radii obtained by detection when oil rate is varying. The water rate is constant (5µl/min and 80µl/min).
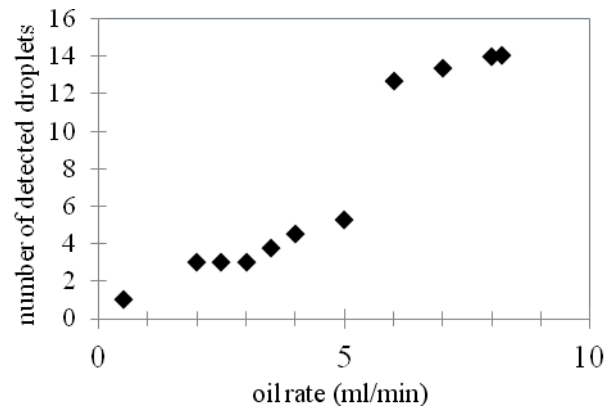

Figure 5: Number of detected droplets when the oil rate is varying. The water rate is constant (5µl/min and 80µl/min). The gap observed is due to real evolution of droplets, and not of detection errors.

Discussion and Future Work

The droplet detection system is working and allows the records of droplets evolution. However for the moment only 80% of droplets are detected. Moreover, the size measured is not always correct. This is the reason why we decided to average the result over 10 images. One possibility to avoid such errors will be to upgrade the software, i.e. by adding a system of averaging on the past images.

Detection process could also be improved: for the moment we try to find circles but; it could be interesting to detect "joined lines", and make a selection by fitting circles or ellipses. OpenCV offer some functions to do that. We could also try to detect "blobs", regions in the image that are either brighter or darker than the surrounding.

CONCLUSION

We have developed an automatic image analysis software with droplet detection for microfluidic systems. Microfluidic is a technic where electronic equipments are important. We demonstrate here that TANGO control command system, normally designed for synchrotron, is usable for more simple laboratory applications.

Our droplet detection is fully functional. Averaged radii and number of droplets are displayed almost in real time. This application can help researchers to control the micro fabrication parameters.
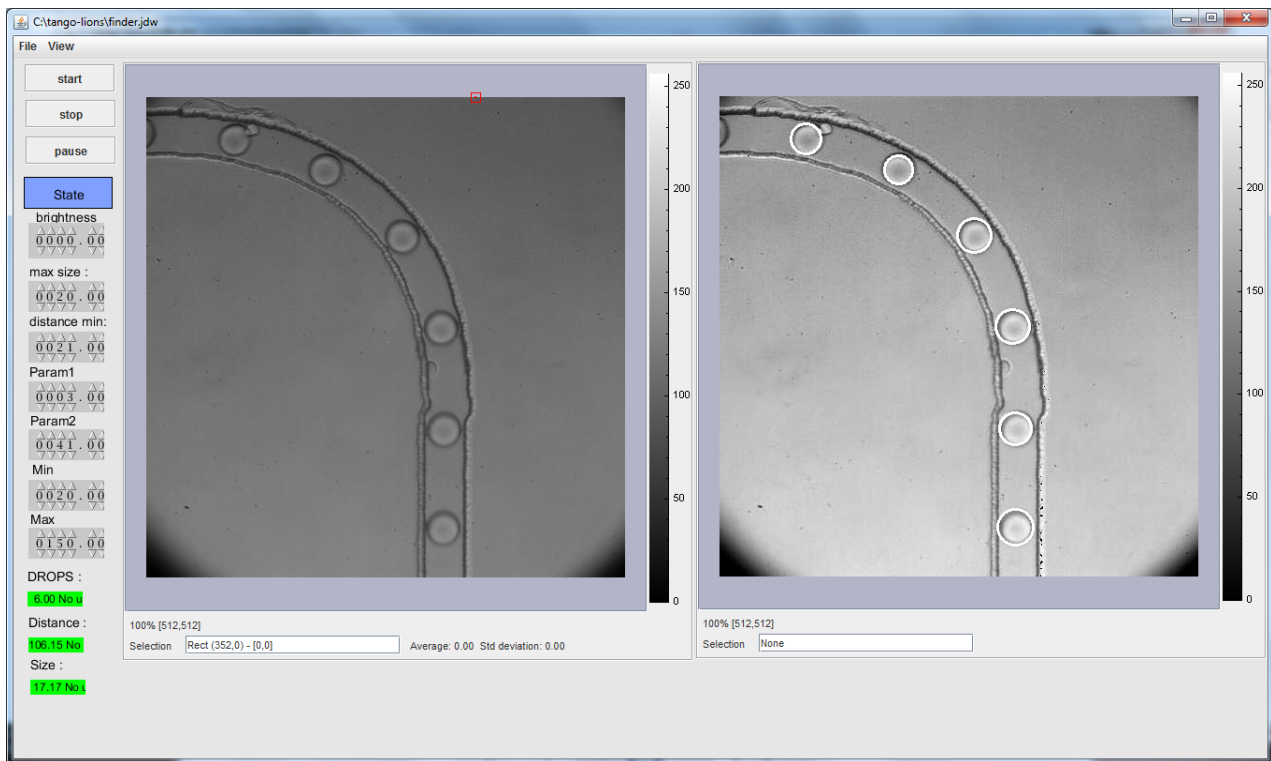
Figure 6: Interface of the application. On the left, the user can start the detection process and tune parameters in real time. Left image is the video camera display. Right image is the processed image, with detected circles drawn on it. Number, size (radii) of drops, and averaged distance between drops are indicated.

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