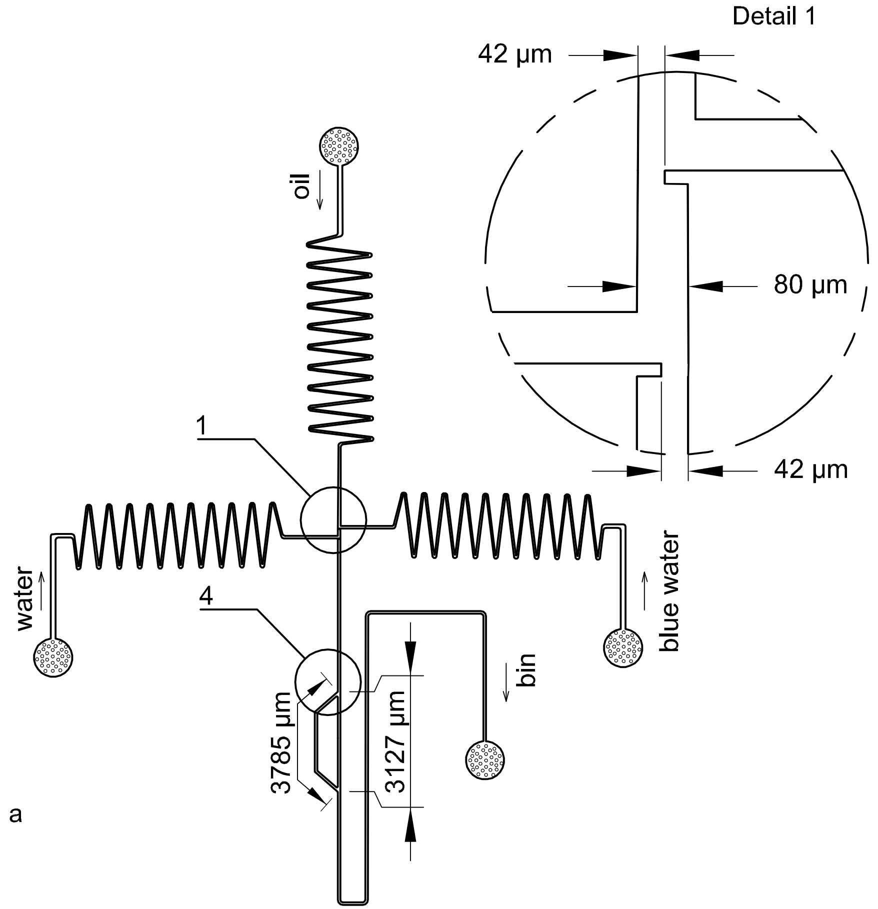
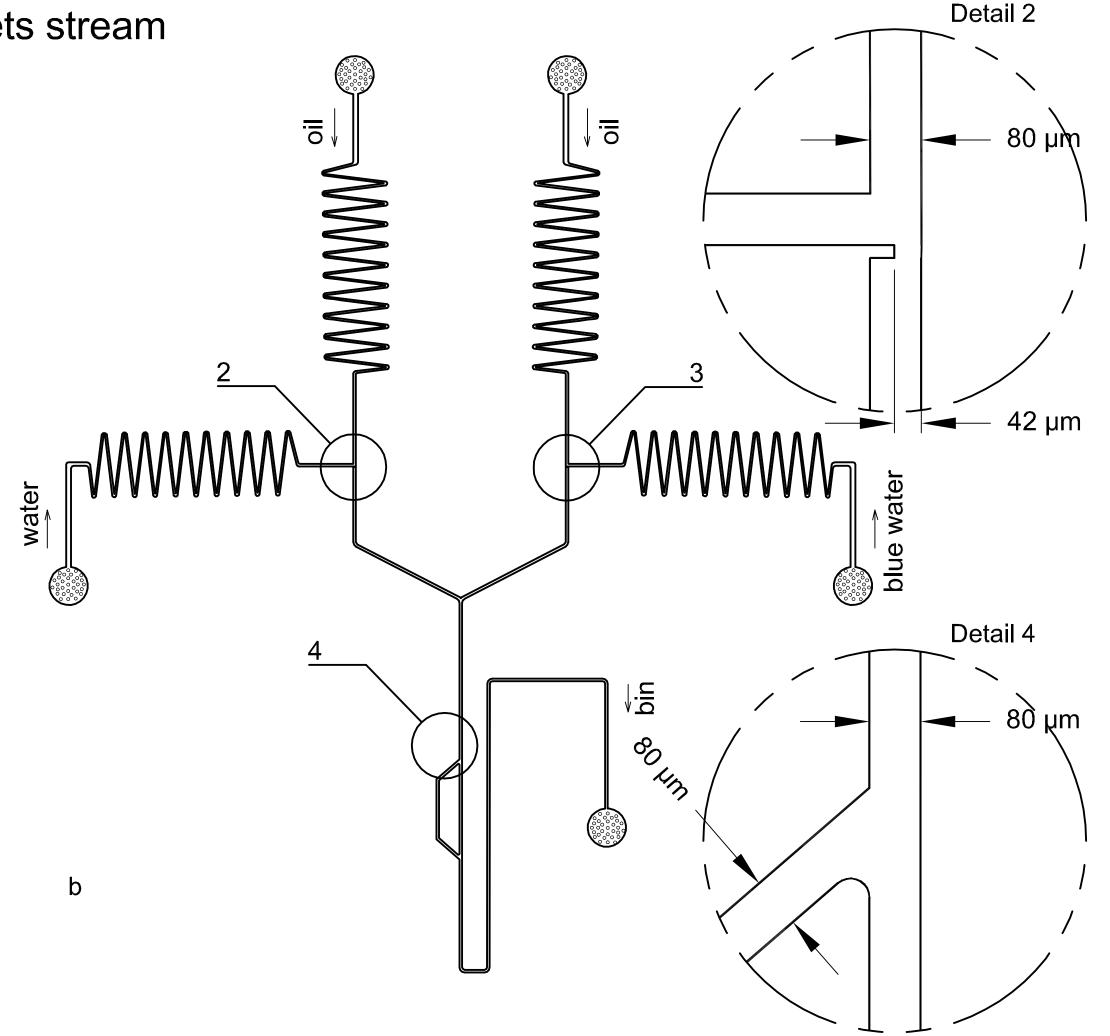
Figure 1 : Generation of a polydisperse water droplets stream



a



b

a) Autocad templates of the microfluidic circuits that produce two sorts of droplets dependently. The continuous phase (mineral oil with 1% of SPAN 80 surfactant) is introduced through a catheter connected to a pressure monitor (Fluigent microfluidic flow control system MFCS-EZ). The catheter is placed on the upper tip, the ones on the right and on the left being water inputs. The pressure of each fluid is stabilized by a coil. When the volume of water incoming in the continuous phase exceeds a certain level predetermined by the oil throughput, the oil shears the water flow to create a droplet. Droplet shearing is enhanced by a narrowing of the channel by more than 50% (80 to 42 µm) called nozzle (*detail 1*). After the first droplet is formed, it creates a decrease of pressure in the main channel that allows the formation of the following droplets. Droplets then reach a bifurcation of 3127 µm (*detail 4*) with a rounded corner to conserve the number of droplets. All fluids are finally collected in a bin placed on the lower tip.

b) Autocad templates of the microfluidic circuits that produce two sorts of droplets independently. To avoid the problems of coupling between the droplet sources, we use two independent oil flows. The length and frequency of the droplets can be controlled by modifying input pressures of oil and / or water. Both streams are then gathered without control before reaching the bifurcation *(detail 4)* in the same way than in *(a)*.

Figure 2 : principle and results of the image processing algorithm.

The microfluidic circuit forms a fork where a droplet can choose to go in either of the two channels. The droplet always chooses the path of least resistance. When the channels are empty and the first droplet arrives, the path of least resistance is the shortest channel. Entering the channel, the droplet adds its own resistance to it. Following droplets will then enter one of the two channels depending on the number of droplets already present in the circuit. In order to follow the path of each droplet, we developed an algorithm that processes the images obtained with a Leica DM4M microscope. We use the circuit that produces droplets separately and use only one colour of droplets. (a) Droplets positions are extracted by a Python algorithm that applies morphological operations to the images. (b) Images are processed by using five markers A,B,C,D and E in order to detect the passing of a droplet in each channel. (c) The presence or not of a droplet is coded into a binary signal, 1 meaning that a droplet is on the marker, 0 not. The oil flow rate is set at 136.8 mbar, clear water at 69.35 mbar and dark water at 105.9 mbar. (d) Considering the entries and exits in the channels (markers A,B,C and D) we go up to the number of droplets in each channel. Both (c) and (d) present periodic signals. In (d), the number of droplets oscillates around a mean value that represents the balance of resistance between the short and the long channel. This balance cannot be reached in practice since the resistance added by a droplet is a discrete value. It would eventually be reached if this resistance was a multiple of ΔL (difference of length between the channels).

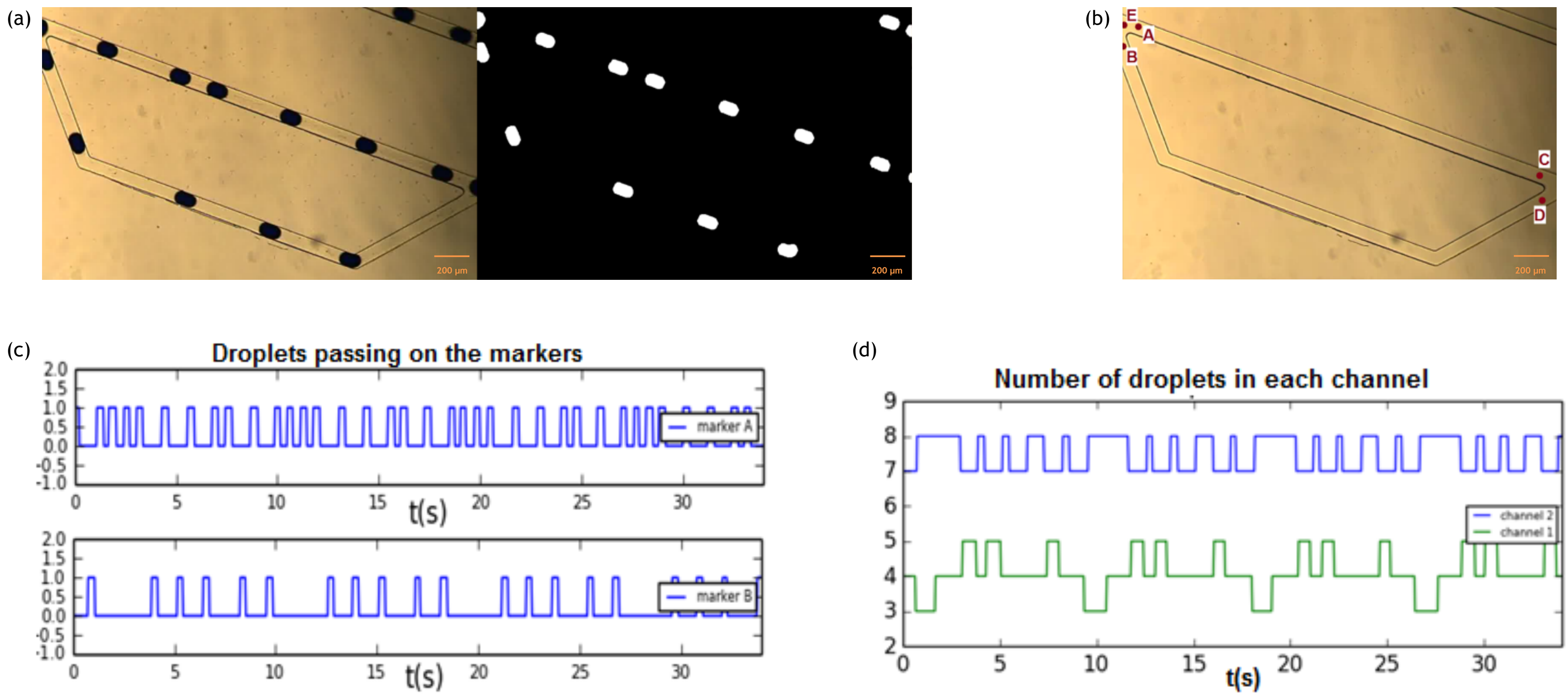
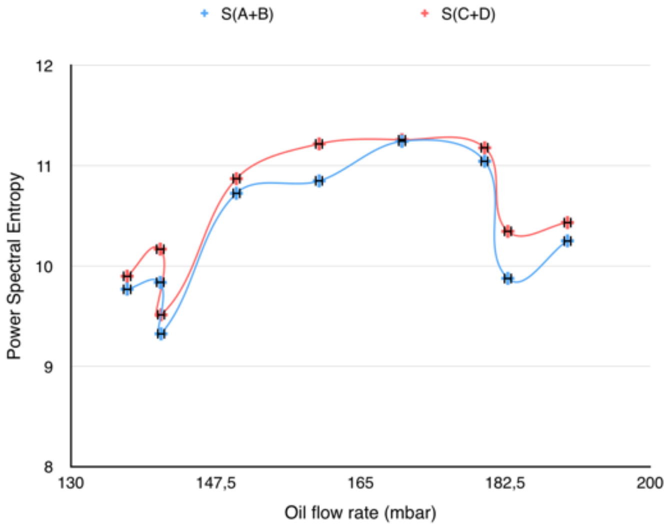


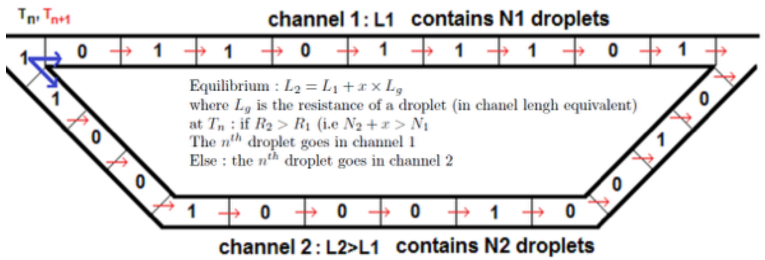
Figure 3 : numerical modeling of the droplets' behaviour.

Using the circuits that produce droplets independently, we maintain the clear and dark water inputs at 69.35 and 110.9 mbar (in order to produce only dark droplets) and vary the oil input between 136.8 and 190.0 mbar. The images show that the droplets have a more or less chaotic behaviour depending on the oil flow rate. (a) In order to quantify this chaos, we plot the Power Spectral Entropy[1] of the entrance (markers A and B) and exit (markers C and D) as a function of the oil flow rate. Error bars are estimated as ± 0.5 mbar. (b) We wrote a program in order to simulate droplets' behaviour. We simplified the problem up to a single parameter : the resistance of one droplet. Since the hydraulic resistance R of a channel is proportionate to its length, the excess resistance added by a droplet when it enters a channel can be seen as an addition of a portion of length L_g to the channel. We note that $(L_2\text{-}L_1)/L_g = x$, where x is the number of droplets needed in channel 1 to have $R_1 = R_2$, but it is not an integer. The initial conditions are read on the first picture of an experiment and the x is found using $\langle N_1\rangle\text{-}\langle N_2\rangle = x$. (c) Confrontation of the results with the simulation for an oil flow rate of 183 mbar (entrance PSE = 9.877). The pattern is very similar although there is a slight deviation of the period. (d) Confrontation of the results with the stimulation for an oil flow rate of 180 mbar (entrance PSE = 11.05). The simulation gives a periodic result which is not representative of the droplets' behaviour. We concluded that the algorithm can be used to simulate a dynamic movement of droplets if the conditions are such that the system is not too chaotic.

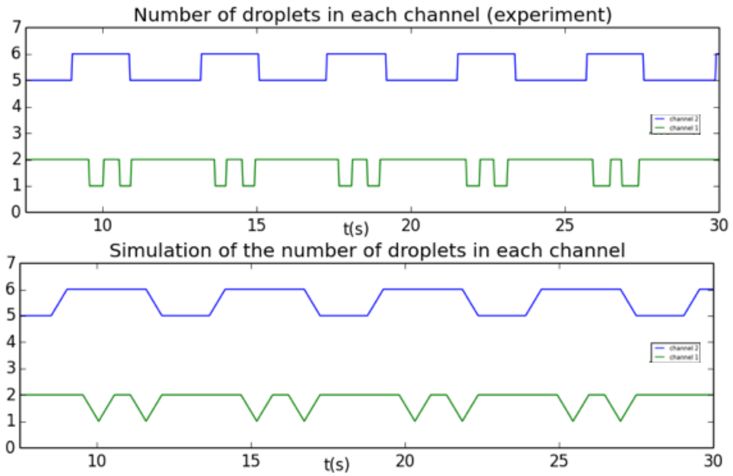
(a)



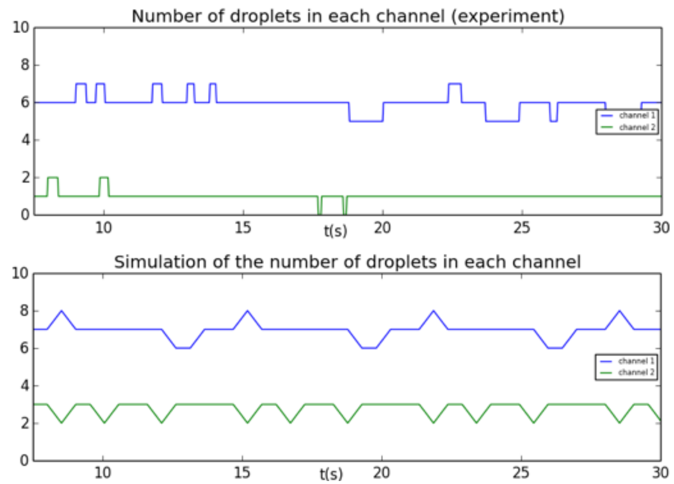
(b)



(c)



(d)



[1] A. Zhang, B. Yang and L. Huang « Feature Extraction of EEG Signals Using Power Spectral Entropy », International Conference on BioMedical Engineering and Informatics, 2008.