Particle Tracking & Soft Condensed Matter

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The overall goals of our laboratory module are to show you the motion of a soft material flowing under the microscope, and to teach you a bit of how particle tracking works. For the particle tracking, we will use software our laboratory has helped develop. The software is available on the web at http://www.physics.emory.edu/~weeks/idl/ and includes a tutorial there. So, we will not try to teach you everything about how to use the particle tracking software today, but rather, emphasize the sorts of results you can get from particle tracking. Of course, please ask questions if you'd like to learn more!

Section 1: Flow of Emulsion

An emulsion is made from droplets of one liquid mixed in with another liquid. We will use oil droplets in water, and see how this emulsion flows through different types of channels. The device has a channel that is roughly 100 micrometers tall, a few millimeters wide, and several centimeters long. Then we put the sample under a microscope and use a digital camera to record the motion of these oil droplets when we pump them through the channel. Based on the movie, we will use particle tracking software to see how the droplet velocities vary depending on their position in the channel.

I. Make Sample

First, we need to make emulsion (oil droplets in water). We have some distilled water, mineral oil and dishwashing detergent, which is a surfactant to stabilize the oil droplets in water. Mix these liquids in a vial and just shake it gently for about 10 seconds. Now you can see the layer of oil droplets on top of water. This is a simple way to create polydisperse emulsion. In our lab, we use microfluidic device and syringe pumps, which can control the droplets size pretty well.

Then we make the flow-channel device, in which the oil droplets will move around. Clean two pieces of glass slides with water and ethanol and dry it with air flow. Cut a piece of parafilm into the shape you want and place it between two glass slides. Then heat it up using the hot plate so that the parafilm can melt and seal the chamber.

Now we can load the droplets into the channel using a pipette. Note that we need very dense droplets by holding the pipette vertically for a while so that the droplets will float up due to the buoyant force. Also, try your best to avoid putting air bubbles into the sample.

II. Record Droplet Motion

Record the motion of the oil droplets for about a minute. Eric or Xia will help you position and accurately image the slide in the microscope. Use the OpenBox software to record a movie of the droplets flowing on the screen. Be sure to note the amount of time between each frame is typically 0.5 seconds. Meanwhile, we need to make the droplets flow. For simplicity, we can use a small piece of transparent film to slowly push the droplets. (For more accurate control, we use syringe pump to drive the emulsion flow. If you are interested in that, we can try developing it with syringe after this module.)

III. Identify Droplets Position

The movie should be saved as a "TIFF stack" or a series of images in a single file, like the frames of a movie.

Begin by reading the movie file into the IDL environment:

```
IDL> mov = readtiffstack('movie.tif')
```

Type "`help, mov`" and you'll get something like the following result:

```
mov            BYTE     = Array[640, 486, 1200]
```

The above output says that we have a movie that is 640 pixels wide, 486 tall and 1200 frames long. IDL has converted our TIFF image into a 3D array, where each pixel's brightness is represented by an integer value between 0 and 255.

Next we run the *xpre_emulsion_track_ss* program, which will look at each frame of our stack identifying the positions of each individual droplet. Basically, the program looks for the droplets, which are defined by a black boundary and enclose a region of white pixels, and then compute its center of mass. Enter the command at the command prompt as follows:

```
IDL> xpre_emulsion_track_ss, thres, minr, minp, pretrack
```

Let's look at the different parts of this code. First is the command itself, *xpre_emulsion_track_ss*. Next we have 'thres', which is a threshold that we set all pixels below equal to 0 and above equal to 1 in order to simplify the process of identifying the droplets. Then 'minr' is the minimum radius of the droplets that we are interested in. And, the 'minp' are used to distinguish the droplets and voids between droplets since we wish to only study the oil droplets. Then 'pretrack' is the name of the output file and you can call it whatever you like.

IV. Tracking

Before tracking the motion of droplets, we need to read in our data:

```
IDL> f = read_gdf('pretrack.gdf')
```

Our next task is to connect the positions of the particles in successive frames. As it stands above, the *f* array contains the positions of the centers of the droplets in our field of view. We must keep track of how much each droplet moves between frames. This is done by assigning an ID number to each droplet, and then determining how much the particle has displaced between successive frames. This process is appropriately called *tracking*. Before we start to track, it might be good idea to determine the maximum displacement in pixels that we expect each particle to make between two frames.

We can plot the positions of droplets based on the *f* array to estimate the value of this *max_disp*

```
IDL> plotp,f[*,0:1000]
IDL> max_disp = 30
```

Then we can use this *max_disp* in tracking:

```
IDL> xemulsion_track_ss, f, contacts, Los, Ros, max_disp, t, cnt, cnt_map,tri
```

Here, we run the track function. The *t* array would be the output file and has been saved as file '*track.gdf'*. The other three outputs would not be used in this session but in another optional session.

We can plot the trajectory of droplets using different colors to indicate different droplets.

```
IDL> gplotp,t
```

V. Velocity Field

After tracking, all the information for each droplets at each time frame have been stored in the *t* array including the x, y- position, radius, sphericity, area, radius of curvature, deformation, ID (an index or 'name' for each droplet), time, etc. Based on this array, we can calculate the velocity for each droplets and further obtain the velocity field.

Use the function *emulsion_avg_flow* to get the flow field.

```
IDL> flow = emulsion_avg_flow(t, [0.,100.,10],3)
```

The variables as 'inputs' of this function is adjustable. The numbers above mean that we compute the average velocity of each bin with the bin size 10 from the 0^{th} frame to 100^{th} frame. The velocity is defined as the ratio of displacement during a unit time *dt*, which is *dt=3* shown above.

Then we can show the flow field with function *display_flow* . It plots a picture with many arrows, which actually indicates the velocity vectors at different places. Also, the color indicates the magnitude of the velocity (from red to blue means from small to big speed).

```
IDL> display_flow, flow, scale=1/4., spacing=4, /o
```

In this function, the keyword *scale* and *spacing* is to adjust the lengths of arrows and the spacing between arrows, respectively, in order to better display the flow field. And, the keyword */o* means 'overplot', which tells the function to plot arrows without erasing the previous plot.

Section 2: Flow of water with tracer particles

In this section, we will simply look at 2 micrometer particles suspended in pure water and study its motion in a flow. Now, we change the emulsion (a soft matter) to a pure liquid. The goal is to see the difference between a simple liquid and emulsion, though both of them are composed of liquids.

The procedure of making a sample of small particles is similar. Know that a microscope objective with higher magnification is required since the colloids (2 micrometers) are much smaller than the oil droplets.

After we make the movie recording the motion of these tracer particles in a flow, we will use basically the same particle tracking routines as before, but with slightly different codes.

Read in our movie with the same function used before and it's stored in array *mov*.

```
IDL>  mov = readtiffstack('movie.tif')
```

Then use function *epretrack* to identify particles:

```
IDL>  epretrack, mov, prefix='pt.data.gdf', bplo=1, bphi=7, dia=9, mass=3000
```

Let's look at the different parts of this code. First is the command itself, *epretrack*. Next we tell it the name of the array *mov*. Then we have "prefix" where we store the name of the output file. Specifically, the program will save the positions of all the particles that it sees in this file, "pt.data.gdf" in a binary file format. Next, are the *bp* parameters, which stand for High and Low bandpass. Then there's the diameter parameter, which I've set to 9 pixels. Finally, we tell the program to ignore anything with a brightness, or "mass", of 3000 or less. The mass parameter relates to the total brightness of a particle, and is a good way to ignore artifacts or out-of-focus particles, as they typically are dimmer.

Then read in our data and track the particles motion with function *track*.

```
IDL>  pt = read_gdf('pt.data.gdf')
IDL>  t = track(pt, 0.7, goodenough=5, memory=5)
```

So, we can use the same function to calculate the flow field and display it in a picture with colored arrows.

```
IDL> flow = emulsion_avg_flow(t, [0.,50.,10],3)
IDL> display_flow, flow, scale=10., spacing=2, /o
```

With this approach you have just learnt, you can look at the different motion of different complex fluid flows. Then, you can study what factors would affect the flow, like the shape of constraint, the size of droplets in emulsion, the polydispersity of the droplets, and ect.

SUPPLEMENTAL INFORMATION:

Below is a list of websites with more detailed information on how to do particle tracking experiments, and the different kinds of analysis that are possible with this technique.

Particle Tracking using IDL: http://www.physics.emory.edu/~weeks/idl/

A good place to start if you are interested in tracking particles using the IDL programming language. This page provides links to other useful particle tracking pages, and even some IDL programs that we use to do the tracking and also some analysis.

There are also some links to websites that explain how to do particle tracking using other programs, such as MatLab.

IDL Manual: http://www.astro.princeton.edu/~esirko/idl_html_help/idl_alph_class.html

A giant list of every built-in IDL command or function in alphabetical order. Sometimes you will find very useful functions here, saving you the time and bother of writing it yourself.

Introduction to Squishy Materials: http://www.physics.emory.edu/~weeks/squishy/

A general introduction to squishy material (click the linkage) including shear-thickening, shear-thinning, Bingham liquids and granular materials. Inter-particle force network is an explanation for the microscopic origins of the behaviors of these squishy materials.

Introduction to Microrheology: http://www.seas.harvard.edu/projects/weitzlab/research/micrheo.html

Here is a page describing an advanced technique that uses particle tracking to determine the rheological properties of samples. They investigate the properties and structure of soft materials such as colloids, emulsions, drops and gels.

Basics of Microscopy: http://www.microscopyu.com/articles/formulas/formulasindex.html

The entire Microscopy U website, provided by Nikon, has a wealth of information describing how typical optical microscopes work. Understanding the basics behind a microscope's operation will let you produce higher quality images, resulting in more precise data and easier analysis.

Weeks Lab Page: http://www.physics.emory.edu/~weeks/lab/index.html

If you are simply curious in general, then go here. There you will find a broad range of experiments conducted in our group. Primarily we focus on the physics of glassy materials, or randomly-ordered solids, but we also study things like particle flow and the microrheology of various materials.