Walking Droplet Memory States and Single-Slit Experiment

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Abstract

The quantum-like behavior of the walking droplet raises the interest in research. For this project, we examined the behavior of the walking droplet within the boundary and the single slit experiment using the walking droplet. Basically we are trying to replicate previous works. Results show that though the data is not as good as expected, we are still able to see the diffraction patterns for the velocity in random walking, as well as the diffraction though single slit.

Introduction

Normally when a droplet falls into the fluid made with the same substances, it will coalesce immediately. However, if the bath oscillates with a frequency, we can observe the phenomenon that the droplet bounces on the surface, or even walks in a pattern or randomly. We study the droplet not only because their fascinating motions and behaviors, but also its possible analog to the quantum mechanics. Previous studies show that the bouncing droplets have diffraction pattern of its velocity in random walking, and have the similar diffraction pattern when going through the single slit. In addition, the structures of whole system– that a single droplet generates waves that can result to walking in certain conditions – might give support to the pilot wave theory, although it remains to be controversial.

The droplet is produced by stirring up the bath of the same fluid. The droplet can have various behaviors such as coalesce, bouncing, walking, and chaotic motion, depending on its shape and its relation to the faraday wave generated by oscillation. A small enough droplet with large amplitude of oscillation does not coalesce since the air under the droplet servers as a cushion and prevents it from contacting the fluid.(Figure 1) Droplets are able to walk since it generates waves that are bounced by the boundary, and that wave interacts with the droplets and make it go further.

To study the behavior of the walking droplet, we did the project with two different objectives. One is using a circular corral with boundaries to see the walking/velocity patterns. The concept called memory is introduced. 'Memory' is the droplet bouncing on/with a superposition of waves created by its previous bounces. It is related to the speed that wave decays and is determined by Γ, which is a dimensionless parameter. The calculation is $\Gamma = (\gamma_F - \gamma_{peak}) / \gamma_F$. In the equation,

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γ_F is the faraday wave threshold acceleration; γ_{peak} is the peak acceleration of bath. For a 1D wave y(t) = A sin(2πft), the acceleration a(t) = $\frac{d^2y(t)}{dt^2}$ = - $4\pi^2 f^2 A\sin(2\pi ft)$, and $\gamma_{peak} = 4\pi\ f^2A^2$. There are three memory states. The low memory state corresponds to low amplitude, and therefore larger Γ. In this situation, the peak acceleration is far from the faraday threshold, and waves decay very fast, and the pattern is simple. For medium memory state, the walking path have more complicated pattern. For the high memory state, the droplet walks randomly in terms of its path, but interestingly, its velocity generates a diffraction pattern which we will show in our result section.

Second project is the single slit experiment using walking droplet. The droplet is able to having the similar pattern with the electron beam through single slit experiment. One major difference is that in the quantum realm, the electron beam goes through the slit, as in the macroscopic view, only one droplet goes through the slit at a time. We are interested in the deviation angle of the droplet after it go through the single slit.

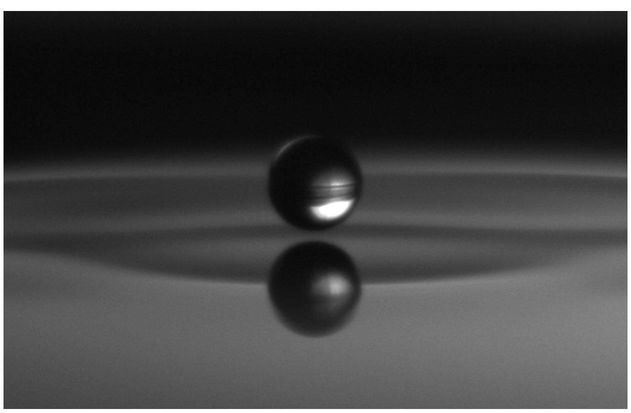


Figure 1: a photo of the bouncing droplet on the bath

Method

A mechanical vibrator (Pasco SF-9324) was used for oscillation. The frequency and amplitude can be controlled by the knob. Silicon oil was used for both projects. It has the viscosity of 20 cSt, density of 949 kg m^{-3}, A camera is used for filming (eo mount) with a TV zoom lens (18-108 mm, F2.5). The Close up filming of single bouncing droplets had the camera fixed on the side. The path of the droplet for random walking and single slit are shoot from the top, with the distance around 40cm above the plane and the lens focused on the plane. The film rate is 29 frames /s. All droplets are around 0.8-1 mm diameters. For the Circular corral, the inner well has dimension of radius of 14mm and 6mm height and the outer boundary with radius of 30mm and 3mm higher than the inner well. We fill the inner well with silicon oils and the outer well with around .6mm oils. . For the single droplet, the length of the square is 70mm for the boundary. The slits are in the diagonal line of the square and are 14mms apart with the height of 6mm.

For processing the videos, adobe premiere pro and iMovie was used for cutting and speeding up the video demos. Matlab was used for tracking the droplet place and velocity. We used Matlab for histograms, diffraction patterns and Mathematica for plotting functions.

Results

I. Different memory states and velocity diffraction pattern

[2] The amplitude A can be measure using various ways, such as using a shaker that oscillates the camera with the same frequency as the bath. (Malacek and Bush,2013). Yet in this project we were not able to measure the amplitude, though several methods are attempted.

First we mapped out low memory states pattern and the medium memory states pattern. Low memory pattern is circles around the boundary. Medium memory states are more oval shape, but it barely go through the center. (it is expected to have a better looking patter such as the one in the paper. The reason that it does not look as expected will be discussed in the next section)

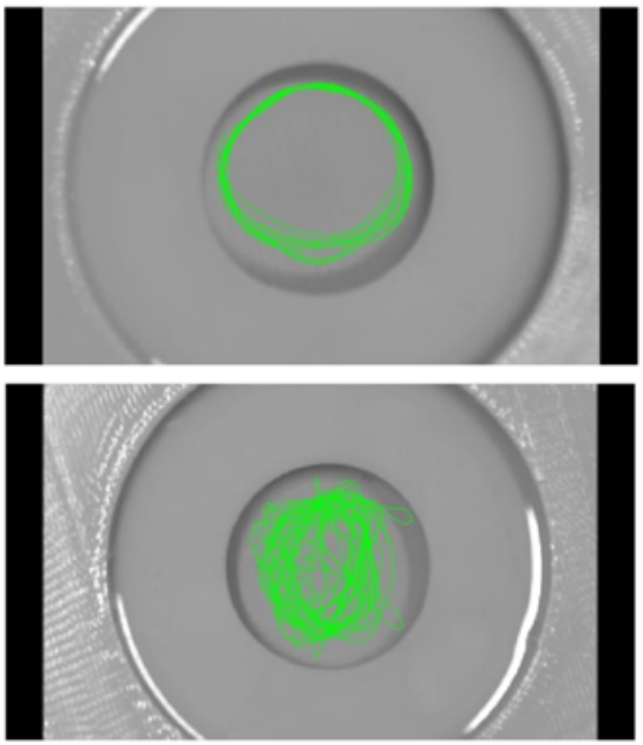


Figure 2 low memory state path(left), medium memory state path(right) (both 5 minutes recording)

For the high memory state, particle has the random walking. What's interesting is it 's behavior.

The velocity is 60mm/600pixels* 0.2 pixel /(1/(29 frames/s)) =0.58 mm /s in the picture for the velocity denoted as 1.For the simplicity in data visualization, we use the relative speed where 1 equals to 0.58 mm/s, 2 indicates 1.16 mm/s and so on.

Most velocity is around 1 and 2 (Figure3), with several peaks. For most of the time, droplet went through half of the radius of the inner well.

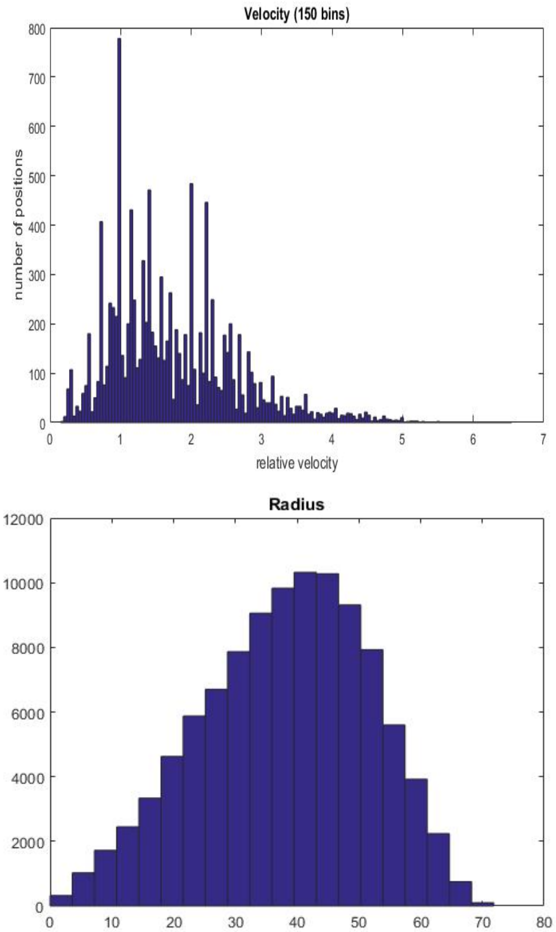


Figure 3 velocity distribution histogram (left), radius distribution histogram (right)

The first trial we plot velocity as following. The red line denotes velocity larger than 5 *0.58mm = 2.9mm/s, green indicates velocity larger than 2.5 but smaller than 5, and blue indicates velocity smaller than 2.5. (Figure 4)

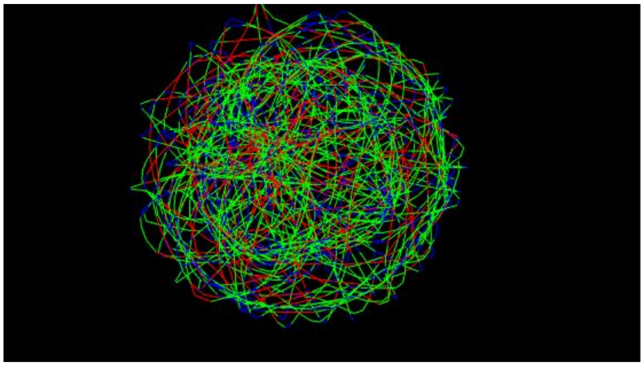


Figure 4 Velocity pattern (1)

The second trial has the recording with longer time, approximately 1.5 hour. It is very difficult to see the diffraction pattern. However, when decomposing different colors that indicate different range of the speed, we are still able to see that at least two ranges of speed have ring-like structure. (Figure 5)

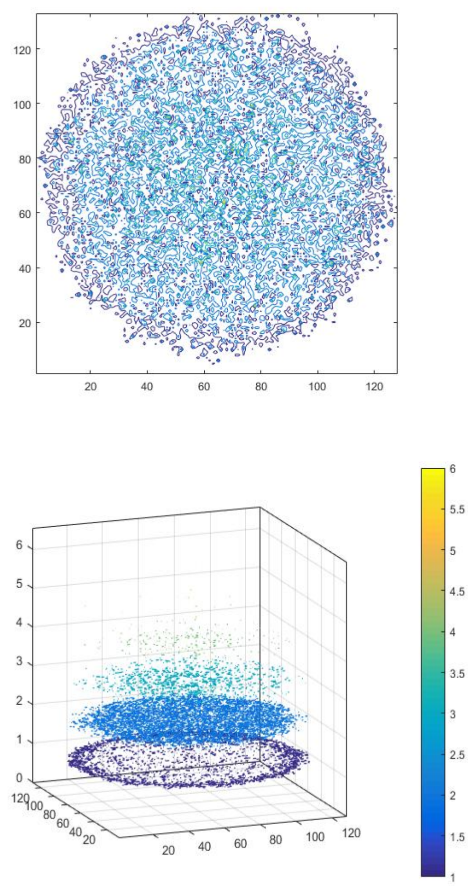
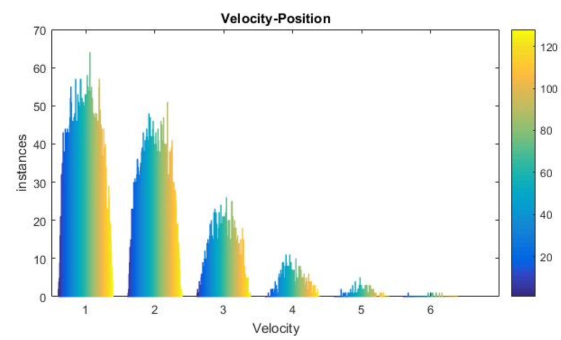


Figure 5 Velocity pattern (2) (left), decomposition of velocity(right)

Following plot is the histogram of the position. different color indicates space in the the column of the image matrix, where the blue is the left most of the image and the yellow is the right side. The x-axis is the velocity range with 1 to 6 (same scale with 1 = 1.6mm) The image implies that certain columns has most instances for one velocity. The significance of the difference might be calculated if necessary.



II single-slit experiment

The single-slit experiment is performed by placing the droplet in the far end of the plane and sees its behavior when go through the slit. Ideally, multiple observations should be recorded for one droplet to go through the slit for many times (>100). However in our experiment, the droplet cannot stay for a long time. Therefore, we used the data produced by several droplets with similar size, and add them together. Only droplets that go through the slit for more than 10 times are counted. The incidence angle is the angle when the droplet go through the slit, and the deviation angle is when its leaving the slit.

Since not many trials are useful in processing data, we try to see whether the incidence angle is significant in determine the pattern. Bellow we used two sets of dataset, one with incidence angle ranging from 0 to 90, and the other only consist the incidence angle from 75 to 90. Below is the path of every trail (with N = 114 for the left and N ~40 for the right). (Figure 6)

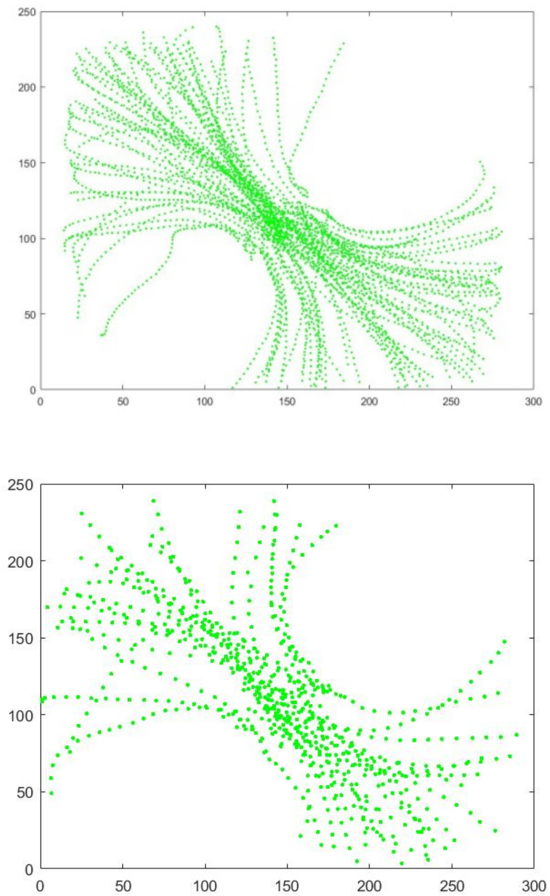


Figure 6 path for droplets with incidence angle(0-90)[left], path for droplets with incidence angle(75-90)[right]

We transform the image to the upright position, and superimposed the upper and botom part of the image toghther since they are symmetric. The a thin horizontal line on the image with most wide range of angles were chosen, and the image is rezied. It is clear that a pattern similar to diffraction is seen in the figure on the left. It analogs the electron beam project to a wall. (Figure 7)

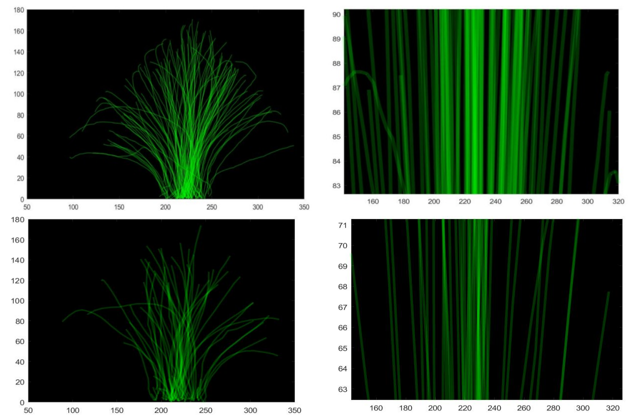


Figure 7 droplets with incidence angle (0-90)[upper left], corresponding diffraction [upper right]. Droplets with incidence angle(75-90)[lower right], corresponding diffraction[lower right]

Then we plot the intensity(the number of paths in a certain angle) versus the deviation angle. The histogram that has 50 bins are ploted below. The line is fitted by the equation $f[a] = A*\mathrm{Abs}[\mathrm{Sin}[\pi L\,\mathrm{Sin}[a]/\lambda]/(\pi L\,\mathrm{Sin}[a]/\lambda)]$, where lambda is the Faraday wavelength and calculated to be 0.005nm and L is 0.0014m. a is from -90 degree to 90 degree.

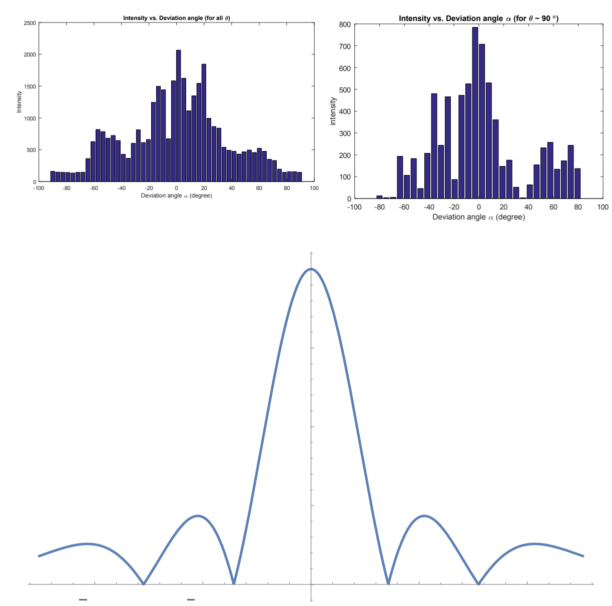


Figure 8 Intensity verses deviation angle (theta is all range for upper left and 75-90 for lower left) Upper right is the fitting of the equation

Discussion

Our projects show two quantum-like behaviors of the walking droplet. The data is not as good as expected, but still have some level of implications of the true results. In this section I will first discuss the problems encountered and how we fixed, as well as the possible reasons and errors in the experiment, and how to improve in the future.

The major problem we encountered during the experiment is getting the droplet to walk rather than stuck in one place. Throughout several check, we found that it is largely due to the unbalance of the system. We fixed the problem by centering the plate and level the plane. However, the slight unbalance problem could also affect the path for different memory states, as for the low memory states the path is not perfectly around the boundary, and it is much severe for the medium memory state, which results to a messy-look pattern. One reason that the diffraction pattern of the velocity in the high memory state is not obvious might also result from the unbalanced system. The other reason, hypothetically, can be the unstable amplitude the vibrator provides. The control for the amplitude is not precise, and turn the knob a little bit can change the memory state significantly. For the future research, the design of the experiment could be largely improved if a more stable and balanced vibrator is used.

As for single-slit experiment, the major problem is that the droplet coalesces into the fluid rather easy compared to the circular coral one. This might due to the particular structure of the single-slit and the different waveform produced around the slit. The results might be improved if only one droplet is used. Using different droplets that might have different sizes could affect the experimental result significantly. Also, the droplet does not always go through the middle line of the slit. As shown in figures, the droplet can walk through the place close to one slit, since the slit is 14mm apart. The data seems to be symmetric, but a more precise way to analyze the pattern would be centering all the paths as if the droplet always goes through the middle line. However, this is difficult to perform and needs more complicated programming techniques, which might be tried in the future.

Reference

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[3] Harris et al, *Wavelike statistics from pilot-wave dynamics in a circular corral,* PHYSICAL REVIEW E 88, 011001(R) (2013) , DOI: 10.1103/PhysRevE.88.011001