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MCEN 5151 Flow Visualization

12/6/2023

Team Third Report: Singing Bowl

I. Context & Purpose

Flow visualization is an observation technique that makes transparent fluid flow patterns more visible by using auxiliary methods such as optical methods or dye tracers. As a result, flow visualization is not only widely used in scientific analysis, but is also important in the artistic field. In the third team assignment, Team Snap Peas considered exploring a special physical phenomenon: the resonance created by the singing bowl. The singing bowl is an interesting instrument that resembles an inverted bell and can be sounded by simply hitting it. But an even more interesting way to play it is to use a kind of wooden mallet wrapped in suede and drag it along the rim of the bowl. Due to the stick-slip mechanism, the friction between the mallet and the bowl creates a continuous vibration, resulting in continuous beautiful harmonies. When the bowl is filled with water, this resonance can be visualized. Actually, this has a similar principle to what I did in the Team Second assignment, using sand on a vibrating board to show resonance. These two phenomena both form Chladni patterns, which are patterns formed by the standing waves of resonance. I decided to record a video using the slow motion mode of my camera to capture the tiny wave and the jumping water droplet. I'd like to thank my teammates, Abhishek Raut and Alexandr Vassilyev. I acknowledge their help during the assignment: Abhishek Raut helped a lot with the filming, and Alexandr Vassilyev surprised us with his talent for playing the singing bowl.

II. Flow Apparatus

Ernst Chladni was a great acoustician and physicist. In the late 18th and early 19th centuries, he researched the various modes of vibration of rigid surfaces and exhibited them to the public. Thus, the similar device used in the experiment was called the Chladni plate, and the pattern formed by the resonance was called the Chladni pattern. At that time, Chladni used a thin metal plate, sprinkled sand particles on it, then rubbed the edges of the plate with a violin bow, causing it to vibrate as if playing a violin. In resonance, the vibrations push the sand particles into a specific pattern[1]. Today, the principles of the Chladni pattern are used in many other fields, such as musical instrument manufacturing, electronic product calibration, and even quantum mechanics [1]. Chladni patterns can be made in a variety of ways. In the previous Team Second Assignment, the Team Snap Peas visualized the Chladni pattern using sand grains on a vibrating plate with an audio exciter, and in this assignment, the team used a bowl of water to show the Chladni pattern.

Figure 1. Overview of the Singing Bowl and playing methods

A singing bowl, mallet, ring pillow, and some water were used for this task. A five-inch diameter brass singing bowl was chosen for cost and portability. The bottom of the bowl is almost curved, so the bowl was placed over a ring cushion for stability. And the soft material of the cushion allows the resonance created when the bowl is played to be less affected by the solid surface of the table. Then the bowl was filled with water to about half its depth.

A wooden mallet wrapped in suede was an important tool for playing the singing bowl. As shown on the right side of Figure 1, vibrations can be created by dragging the mallet along the edge of the bowl. And the suede layer allows the mallet to glide more smoothly over the surface of the bowl. The principle behind this vibration is the stick-slip mechanism: the friction between two objects in contact is not uniform, resulting in a physical motion that is not smooth, but a mixture of subtle acceleration and stagnation, during which vibrations can easily be generated[2]. Then, these vibrations resonated inside the bowl, making sounds and stirring the water inside the bowl.

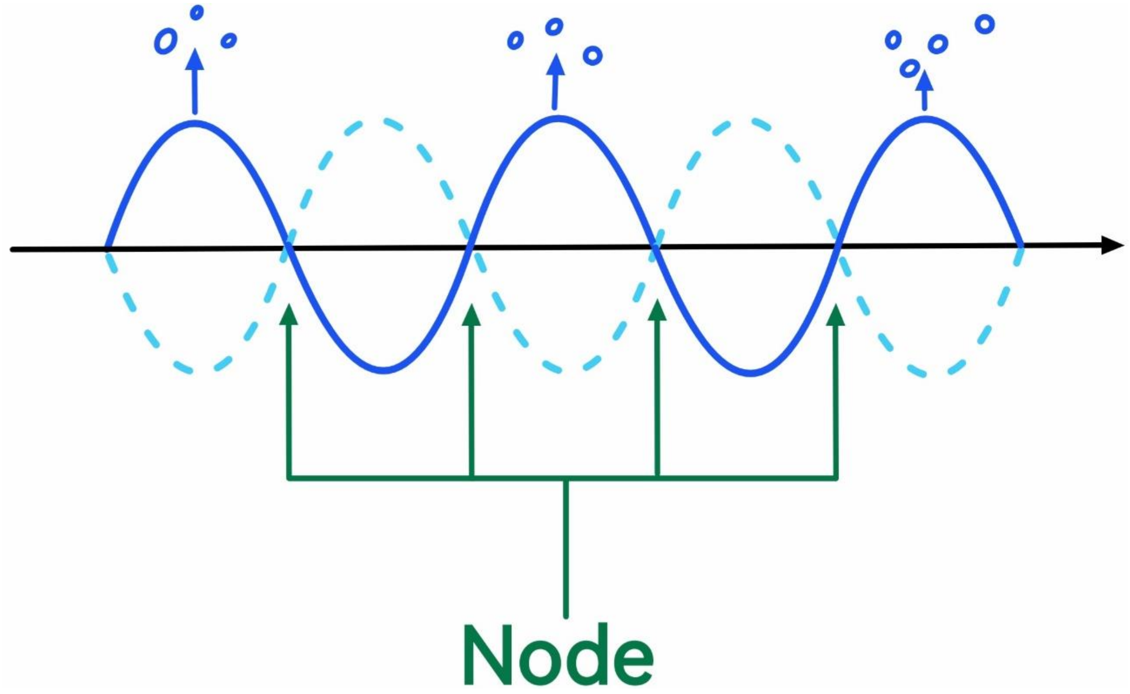

Figure 2. Principle of water wave

Figure 3. Water ripples

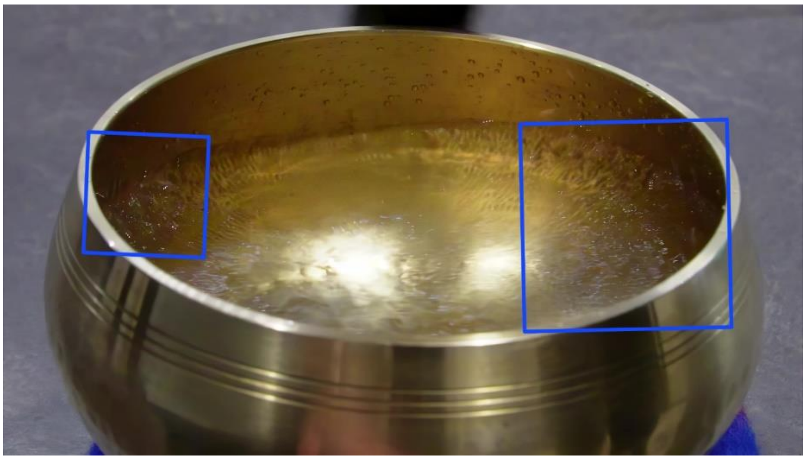

Figure 4. Jumping water droplet

After the vibrations were formed, the vibration waves were reflected when they reached the edges of the singing bowl, causing a change in the direction of the waves. In addition, the vibration waves were also transmitted to the water in the bowl and propagated along the surface of the water[3]. When two vibrating waves in opposite directions touch, they interfere and resonate, creating standing waves. In standing waves, there are some regions of minimum amplitude called "nodes". As shown in Figure 3, these standing waves form ripples on the surface of the water, consistent with the Chladni pattern. In addition, if the amplitude and frequency of the vibration wave were large enough, i.e. there was enough energy, it was possible for the water to be thrown out of the liquid surface as the wave trough turned into the wave crest. This created the scenario of jumping water droplets in the bowl as shown in Figure 4.

The computation and simulation of these standing waves and nodes is difficult and complex due to the free boundaries of the bowl and the fewer the boundary conditions. Also, water was used in this assignment to visualize vibrational waves and Chladni patterns. And water is not as conducive to recording waveforms and patterns as sand, which was used in the previous Team Second Assignment. Therefore, this assignment focused more on aesthetics than scientific research. However, singing bowls have a longer history, which has allowed people to develop enough experience to control the vibrations and sounds produced by singing bowls. For example, the angle, strength and speed at which the mallet is dragged, the size and shape of the bowl and the mallet, and the volume of water poured into the bowl are all factors that can change the properties of the vibration wave and the sound[4].

A shutter speed of 1/125 second was used in the video. Obviously, this time resolution is not suitable for water ripples and water droplets moving at high speed under the influence of vibrational waves. When the video was paused, the ripples and water droplets displayed a lot of blur. Although this has little effect on videos where ripples and droplets are observed in continuous motion, increasing the shutter speed is still recommended. The lighting conditions in this assignment were poor, which limited the shutter speed, but improvements can be made in future experiments. Considering the size of the water ripples and droplets, the spatial resolution of this video was high enough. It's not difficult to distinguish a single ripple or droplet that was about 20-50 pixels in size.

III. Visualization Technique & Photographic Technique

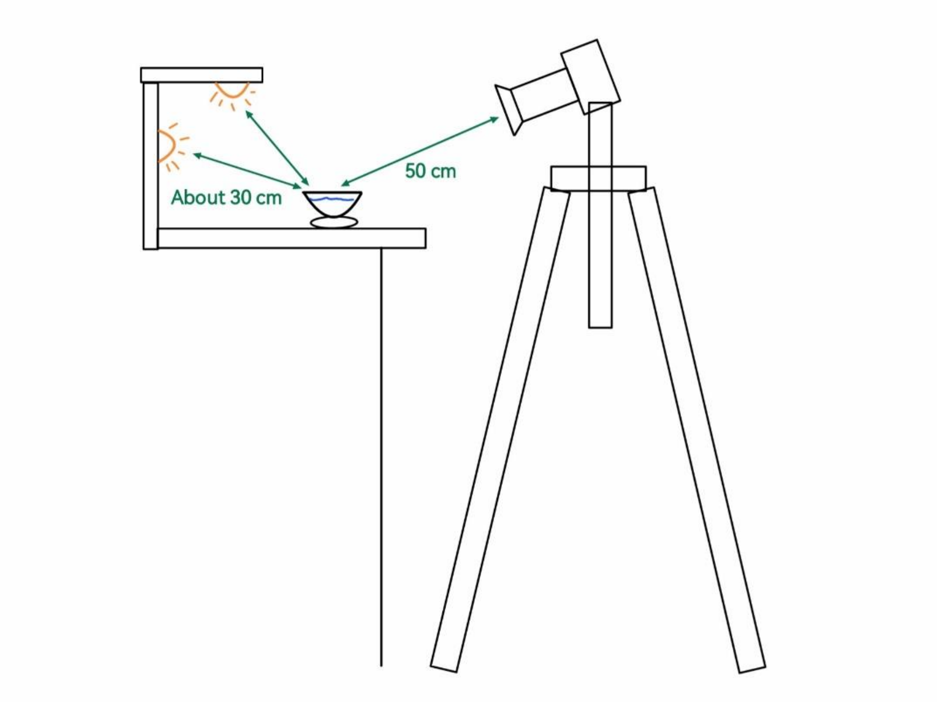

Figure 5. Filming scene

The lens was the Tamron 18-300mm F/3.5-6.3 lens, an all-in-one lens that covers a wide range of focal lengths and field of view from wide-angle to ultra-telephoto. The camera used was Sony's ZVE-10 mirrorless digital camera with 1920×1080 pixel slow-motion video recording capability. It can record the video at 120 frames per second and then play back the video at 24 frames per second, which is 5 times slow-motion video.

There were no special visualization techniques for this assignment, just using the water to show the vibrational waves of resonance. By adjusting the direction and angle of the light source, the reflection of the waves on the surface of the water was more easily captured by the camera. The filming scene is shown in Figure 5. The lens was about 50 cm from the singing bowl, and two common operating desk lighting tubes were about 30 cm from the sing bowl. The focal length of the lens was set to 100 mm, and due to the smaller APS-C size of the camera's sensor, its 35 mm equivalent focal length was 150 mm. The width of the field of view at this point is about 17 cm. This setup allows the field of view to be slightly wider than the singing bowl, thus reducing the work required for post-processing.

Due to poor light conditions, the lens was set to maximum aperture at the corresponding focal length, f/5.6. The shutter speed was set to 1/125 second, which was a compromise between noise and time resolution after many tests. The ISO was set to 2500 to minimize noise while maintaining the overall exposure.

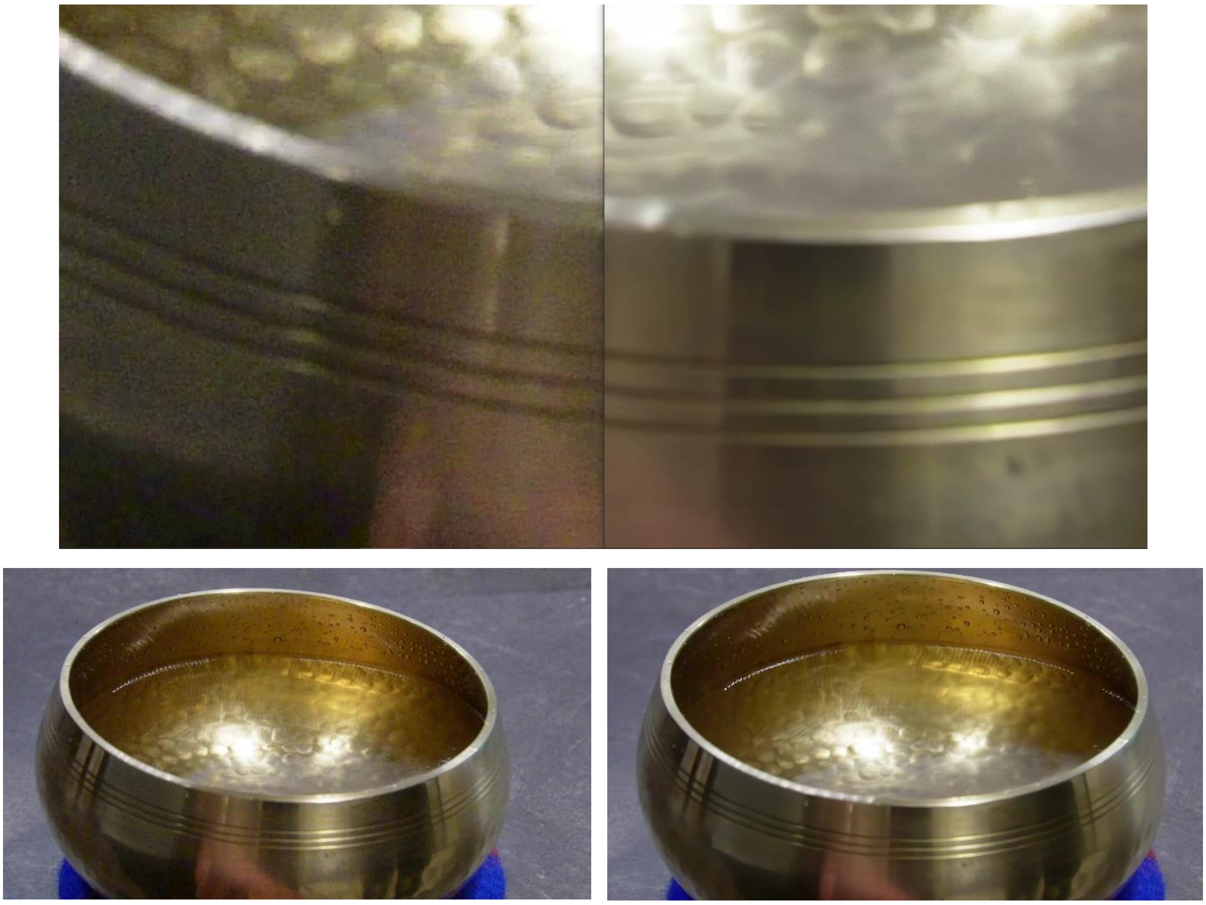

Figure 6. Comparison of video before (left) and after post-processing (right)

Due to camera limitations, only 1920×1080 pixel videos can be captured in slow motion mode and there is still a lot of visible noise appear in the origin video. First, I used Adobe

Premiere to make angle adjustments and some minor cropping, used some anti-shake rendering to reduce the shaking at the beginning of the video when adjusting the camera angle, and added titles and subtitles. Then I used the Topaz Video AI to enlarge the video and reduce noise. I was impressed with the performance of this software, which used AI analysis and processing to enlarge my video from 1920×1080 pixels to 3840×2160 pixels, which is the standard 4K format. It also eliminated most of the visible noise, as shown in the comparison image at the top of Figure 6. This software changes the color slightly when processing the final video, as shown in the comparison image at the bottom of Figure 6; this should be an added effect when the AI does the rendering, which has no negative impact. Overall, this is the first time I've used AI in video processing, and I think that AI technology is now capable of some very complex and critical video processing, and that it has a lot of potential for the future.

IV. Result

In this assignment, a resonance phenomenon of a singing bowl visualized by water was recorded. The resonance of singing bowls is difficult to calculate and simulate, but it's still easy to create cool phenomena like Chladni patterns and ripples on the water surface and jumping water droplets. These videos show the physics of singing bowl resonance in 5 times slower motion and capture the movement of the water in a special perspective. That's what makes them so appealing.

While filming the video, I struggled with whether to record in slow motion mode because of the limitations of the camera mentioned earlier, which would reduce the resolution of the video. Finally, I still use slow motion to capture the movement of the water more clearly. Then I learned how to use AI-assisted video post-processing, which resulted in a huge improvement in the quality of the video. I was glad to see that the audience enjoyed the slow-motion water movement.

In the future, I will probably try different factors that can change the properties of the vibration wave and the sound, such as the angle, strength and speed at which the mallet is pulled, the size and shape of the bowl and the mallet, and the volume of water poured into the bowl, etc. I believe that these more in-depth experiments helped me understand more about the science behind this physical phenomenon.

References

[1] "Ernst Chladni." Wikipedia, 19 Nov. 2023, en.wikipedia.org/wiki/Ernst_Chladni.

[2] "Stick–Slip Phenomenon." Wikipedia, 20 Nov. 2023, en.wikipedia.org/wiki/Stick%E2%80%93slip_phenomenon.

[3] "Using a Singing Bowl with Water." Shanti Bowl , 9 July 2016, www.shantibowl.com/blogs/blog/using-a-singing-bowl-to-charge-water.

[4] Renta, Evelina. "How to Use a Singing Bowl: Playing Guide for Beginners." wikiHow, 2 Nov. 2023, www.wikihow.com/Use-a-Singing-Bowl.

The background music for the video is *English Country Garden* by Aaron Kenny. The music was published by the author on YouTube Audio Library. YouTube Audio Library is a free music library that specializes in providing creators with royalty-free music. Therefore, my using this music for the video does not create a risk of copyright violations.