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Physics-based height map optimization conveying real-measured flow speed for virtual soap bubble rendering

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Abstract

In this paper, we propose a method to generate and optimize the height map that is suitable to render a soap bubble. The height map represents the flow speed of soap bubbles. To this end, we have analyzed the flow of the soap bubble surface through experiment, derived the moving speed value for each section. Some image filters have been used for optimization that reflects the parameters of the derived height map. In addition, in order to verify the results of the study, actual data measuring the surface flow speed of soap bubbles, the speed of the initial height map, and the optimized height map speed have been compared and tested. Through this study, we reach the issue that it is possible to express the variable flow speed of soap bubbles with the optimized height map, and it will help to express various fluids.

Keywords: *Soap bubble, Bubble rendering, Flow speed, Height map*

1. Introduction

Although there are many researches on terrain-related height maps [1], it has not been observed about studies on height maps simulated using actual measured values for soap bubbles. As photorealistic rendering becomes possible, several techniques for expressing it have been introduced. There are various ways to express the speed of each material through this technique. However, when the material is a fluid, since the flow speed is variable, it is difficult to render realistically. In order to solve these problems, this study proposes a method to express the flow speed of physically based soap bubbles using a height map. Previous researches propose a way to find detailed soap film movements for realistic soap bubble rendering. An experiment was performed to estimate the film flow and thickness that would change the soap film realistically [2]. Lucas-Kanade Optical Flow Algorithm Frame Tracking [5] was used to calculated the speed of soap film in five sections. To

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this end, we have cautiously investigated the flow of the soap bubble surface [2-4], which conveys the flow speed for each section using the optical flow algorithm. The image filtering has been used for optimization that reflects the parameters of the derived height map. In addition, in order to verify the results of the study, actual data measuring the surface flow of soap bubbles, the speed of the initial height map, and the optimized height map speed have been compared and tested. Through this study, we reach the issue that it is possible to express the variable flow speed of soap bubbles with the optimized height map, and it will help to express various fluids.

2. Initial height map production

Our first step is to simulate the speed of surface of a soap bubble, which has been reported in the previous study [2]. Through the frame tracking of Lucas-Kanade [5] Optical flow algorithm, a study was conducted to measure the water droplet flow speed based on the distance the soap film moved every frame. As shown in Figure 1, a study was conducted to determine the speed by dividing the fluid motion of the soap film into five sections to apply to the rendering of the soap bubbles. In order to express the flow of fluid based on the measured parameters, an initial height map was prepared and the brightness distribution of each section was checked. The brightness distribution was found to be a problem in that the brightness distributions of all pixels were aggregated in one section rather than one pixel. In order to secure this problem, we obtain the speed graph rather than the brightness distribution map using the initial height map, and then calibrate it to represent the droplet flow speed of the physically based actual speed study. From the initial height map, partial differential equations, (1) and (2) are used to acquire the x and y velocities respectively. The length of vector is computed using (3) as well.

$$\nabla f = g(x) = \frac{\partial f(x,y)}{\partial x} \quad (1)$$

$$\nabla f = g(x) = \frac{\partial f(x,y)}{\partial x} \quad (2)$$

$$L = \sqrt{g(x)^2 + g(y)^2} \quad (3)$$

Second, it is necessary to create a height map reflecting the actual speed. To this end, an initial height map was created and an image filtering process was performed to optimize it. The speed was analyzed by dividing the initially generated height map image into 5 sections. The initial height map is loaded using Matplot image library in Python, and then all values of each pixel are loaded [6]. Since the size of the image is 1,024 by 1,024, 1,048,576 pixels are produced. Since the speed graph will be extracted for each section, it is divided into 205, 205, 204, 205, and 205 based on the vertical as shown in the right image in Figure 1, and proceeds in a total of five sections from section one to section five.

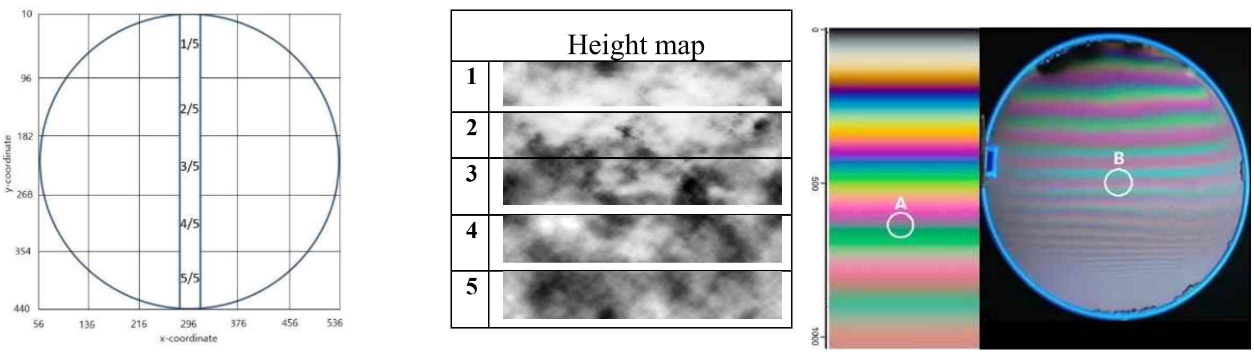
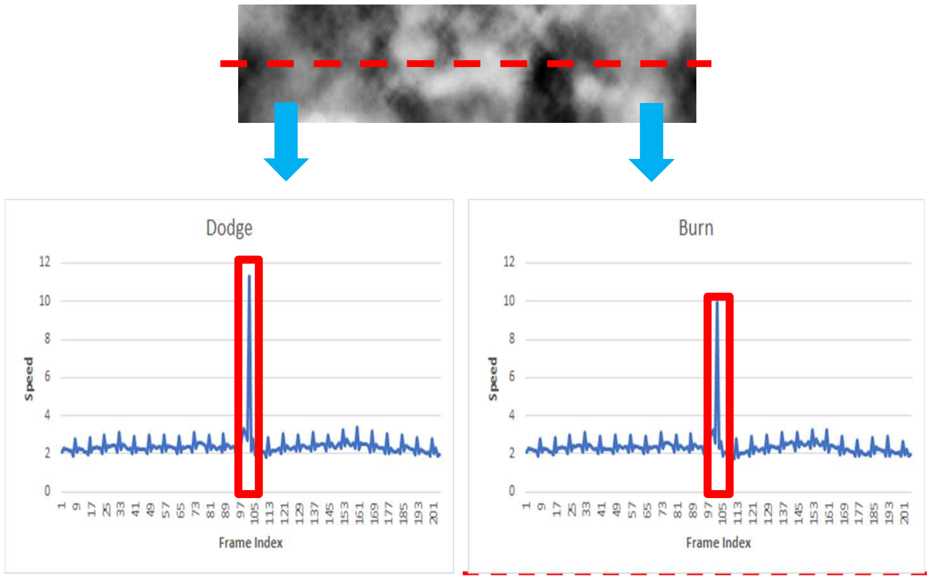


Figure 1. Five sections (left), real soap movie (center), and the initial height map (right)

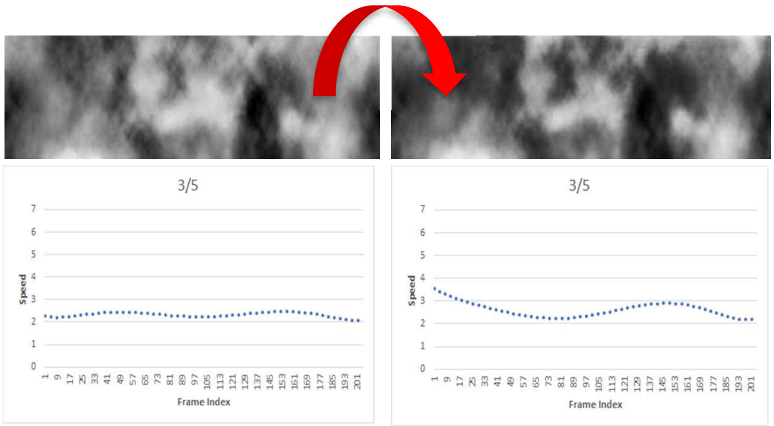
After extracting the image array of each section, it was loaded and saved to enable image processing. In order to obtain the height map speed for each section, image filtering using partial differential equations was used [7]. In the image, *U* and V parameters represent *x* and *y* speeds. After finally displaying the averaged values on the x-axis as a curved line graph with the final values, they were converted to a polynomial equation graph to obtain a height map speed graph for each section.

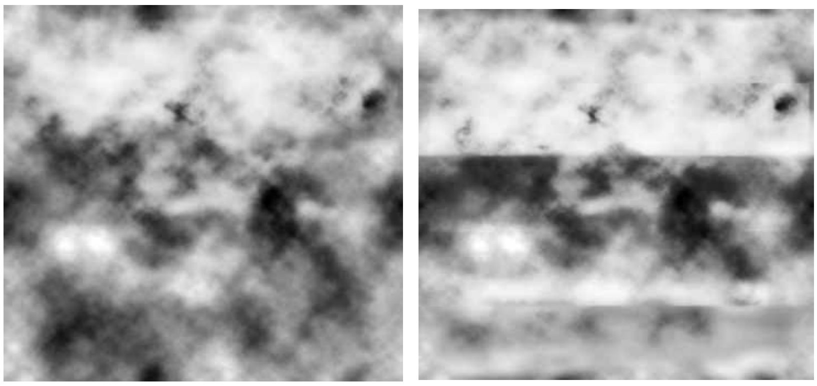


3. Height map optimization

In order to optimize the height map suitable for the speed of each section, it is necessary to correct the height map generated initially. For example, Let's account for the process of correction using the image of section three. After dividing the image into two parts using the dodge filter, the dodge function that brightens the contrast across the lower part and the burn function that darkens the contrast each gave an effect once. Figure 2 shows two filter effects.

In Figure 3, we can differentiate the initial height map from speed graph in section three and the height map and speed graph after image correction. It can be found that the speed changed from the center of the corrected speed graph is observed similar to the measured speed. The speed decreases at the beginning, and then gradually increases after the middle and decreases as you forward to the latter. In the step of optimizing the initial height map to actual data, the height map has been optimized to be similar to the rate of change of the actual measured speed. We observe the same as the actual measured rate of change in the initial height map optimization stage. Figure 4 shows the initial height map and the corrected height map after optimization.

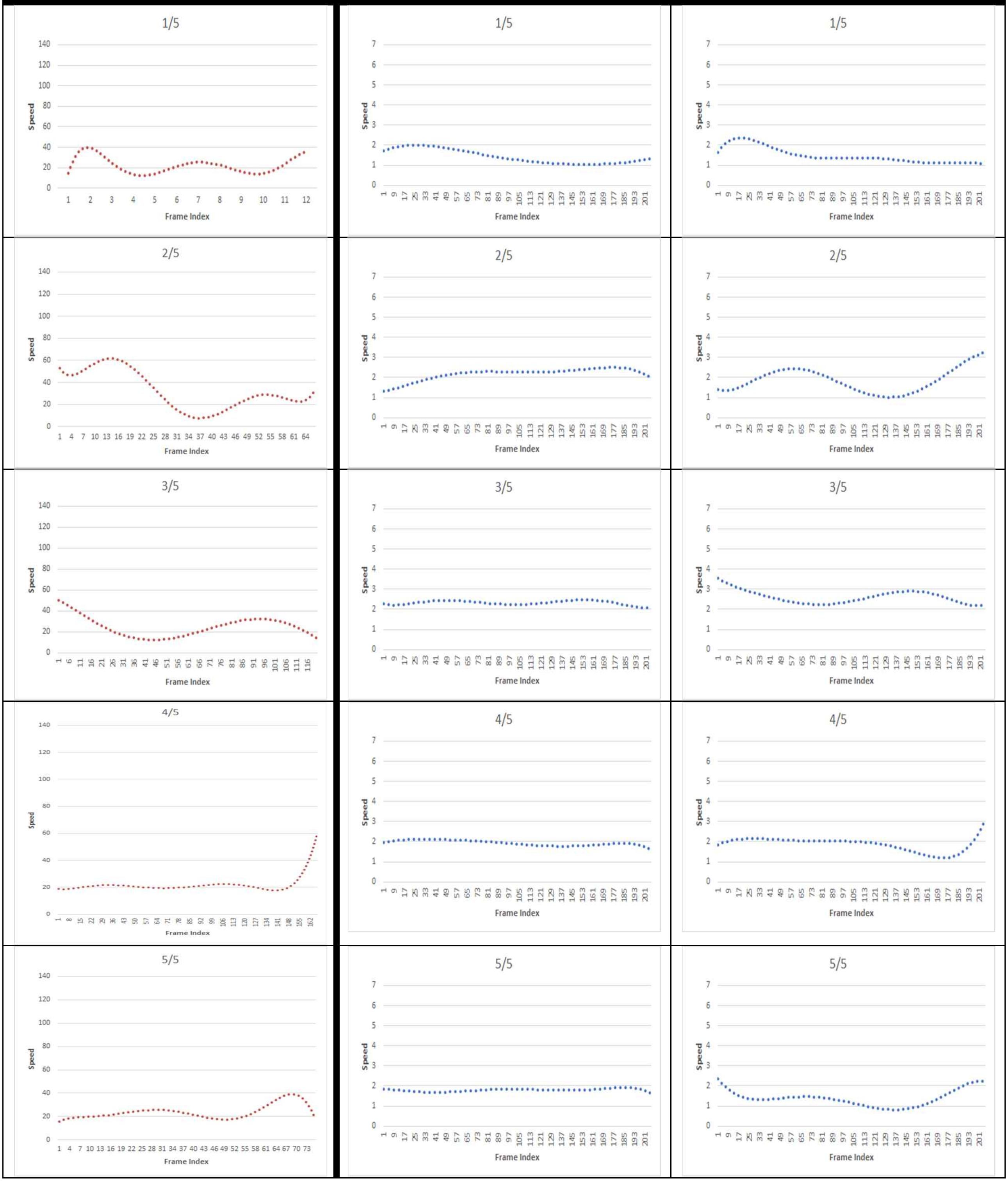




3. Experimental Results

It is necessary to verify that the corrected height map reflects the actually measured speed. The speed graph has been extracted and expressed for five sections to check whether the speed graph of the measured speed graph and the corrected height map match. In order to visualize the speed, the speed is averaged on the horizontal axis, which is the x-axis of each section. Table 1-(1) is a graph showing the flow values of soap bubbles from experiment [3] through the actual optical flow algorithm. According to Table 1-(1), (2) Before correcting the height map speed graph, we can observe the change of the graph according to the contrast. Looking at the speed graph of the initial height map and the speed graph (3) of the height map after correction, it can be found that the speed graph after correction is very similar to the actual speed graph (1) using optical flow.

(1) Optical flow speed	(2) Initial height map speed graph	(3) Corrected height map speed graph



In the right image of Figure 5, you find the result of rendering using the final corrected height map. The rendering result on the left in Figure 5 shows using the height map not optimized [3]. By comparison, the rendered soap bubble on the left has an exaggerated layer of oil. Also, the problem is that soap bubbles remain on the border. In Figure 5 (center), the image on the right, circles are shown so that continuous flow can be seen at a glance if we closely take a look. Other background scenes are posted with soap bubble renderings in Figure 5 (right) as well.

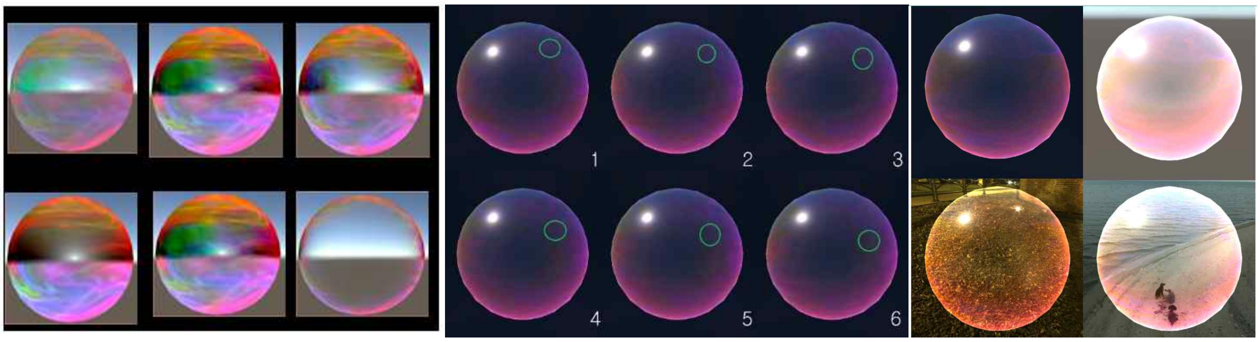


Figure 5: Soap bubble rendering results without height map (left) [3], with corrected height map (center and right)

4. Conclusion

In this study, we conducted a study to verify and correct the height map used to represent the flow similar to the measured data for the real rendering of soap bubbles. An initial height map was created by estimating the velocity graph based on the actual measurement data [2] obtained from the optical flow algorithm of Lucas-Kanade [5]. In order to solve the problem, we use Python image package to compute the partial differential filters in the x-axis direction and the y-axis direction for each interval. The backward differential formula, which is a differential equation, is used to finally obtain the velocity graph. Finally, we carried out to create an optimized height map that was corrected by a method of adjusting contrast using image filtering.

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