Sloshing Surface Monitoring Using Image Processing

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Abstract

Liquid sloshing in tanks during suddenly braking or severe maneuvering of tanker trucks can cause many problems including cracks in liquid tanks and their supporting frames, uncontrollable steering systems, etc. The Computational Fluid Dynamics (CFD) can perform to study these problems and to develop the superior tank. However, these simulations must be validated to ensure their accuracies with laboratory experiments. During sloshing of water, variations of pressure developed on the wall and the surface wave and also the motions of water are the fundamental data recorded in the experiments. This paper proposes the image processing methods to digitize the motion of the surface wave of water in the movable tank. Particularly, all image processing algorithms were applied to create the "SloshDetector" software. This software utilized video files recorded by a webcam to create the series of digitized images of the sloshing surface for validating with the data obtained from CFD models.

***Keywords**:* Free Surface, Sloshing, Edge Detection, CFD, Image Processing.

1. Introduction

Many tanker truck's accidents occur due to the severe moving of liquid contained inside the tank. Understandings of sloshing behaviors can prevent these accidents. The study of the liquid sloshing can perform with laboratory experiments and computer simulations using the Computational Fluid Dynamics (CFD) or the Finite Element Analysis (FEA) methods [1,2]. The motion of water contained inside a clear tank is a fundamental data recoded in experiments which can obtained from a CCD video camera. Usually, the surface wave of the moving water will be compared with the computer simulation's results using an image mapping. This method neither digitizes the free surface nor calculates deviation between free surface of experiment and software simulation.

Edge Detection is a part of image segmentation. As the image is processed, the edge in an image is extracted [3,4]. The Edge Detection methods can be used to capture the surface wave of the moving water inside the tank. Because of noise contained in data, the surface wave is implicit. The other methods comprising of grayscale and filter methods must be used in order to detect the explicit surface wave. This image process can accurately extract the surface wave of the moving water which can be used to compare with the computer simulation's results.

2. Edge detected algorithm

Edge is discontinuity in a digital image. The first-order digital derivative is typically used for the detection of edge in an image. Suppose that the filter *f(x)* supported in [-*W*,+*W*] is used as the detector. A single step edge *G(x)* corrupted by Gaussian white noise *n(x)* and an edge is centered at $x = 0$. Canny [5] generalized three criteria to evaluate an edge detector:

1. Good detection. It is signal-to-noise ratio (SNR) should be as high as possible. The criterion is

$$SNR = \frac{\left| \int_{-W}^{+W} G(-x) f(x) dx \right|}{n_0 \sqrt{\int_{-W}^{+W} f^2(x) dx}} . \quad (1)$$

2. Good location. The detected edge should be as close to location $x = 0$ as possible. Thus, the localization (*L*) criterion is defined as

$$L = \frac{\left| \int_{-W}^{+W} G'(-x) f'(x) dx \right|}{n_0 \sqrt{\int_{-W}^{+W} f'^2(x) dx}} . \quad (2)$$

3. Only one response to a signal edge. The mean distance between two noise maxima and expected $x_{max}(f)$ to be as big as possible. Canny defined by

$$x_{\max}(f) = 2\pi \left(\frac{\int_{-\infty}^{+\infty} f'^2(x) dx}{\int_{-\infty}^{+\infty} f''^2(x) dx} \right)^{1/2} . \quad (3)$$

With Canny's mathematical formulation of these criteria, the *C* language implementation of the algorithm has been written in the "SloshDetector" software for this research. Other *C* language codes comprise of grayscale, filter and exported edge pixels are also written in the software. The SloshDetector software has ability to detect the surface wave's coordinates and to export coordinate data of the detected surface wave during the water sloshing.

3. Experimental Setting

The experimental setup has been developed to investigate the surface wave and displacement of liquid (water) as shown in Fig. 1. The clear acrylic rectangular tank dimension is 300x240x50 mm (width x height x depth) which is moved by means of the servo motor and the ball screw. The velocity and position of the tank are controlled by voltage supplied to the servo motor. The input voltage controls the time function of velocity and position for this experiment as shown by graph in Fig. 2.

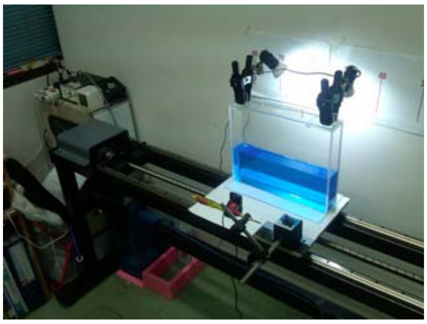


Fig. 1 Apparatus of experimental device for sloshing.

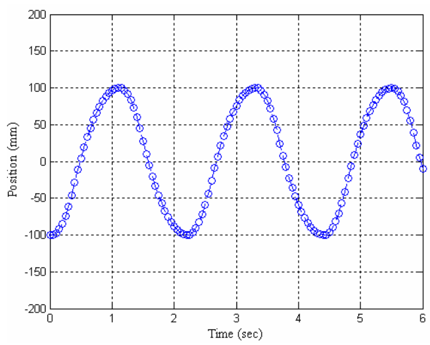


Fig. 2 The input signal to control the position of the rectangular tank.

The image capture process was carried out using a Logitech webcam, model "Quickcam Pro for Notebooks" which moved with the tank and connected to a computer via a USB port.

4. Results and Discussion

The series of the surface wave images are extracted by the SloshDetector software. All images are then converted from the multi-color pictures to the gray color images using Grayscale toolbar on the software menu (Fig. 3). This method is used to reduce the variable color from three to one color mode (RGB to Gray). The sequential times of the gray color images corresponding to the frame rate of the video recorded file for $0 \leq t \leq 1.79$ sec are extracted as shown in Fig. 4.

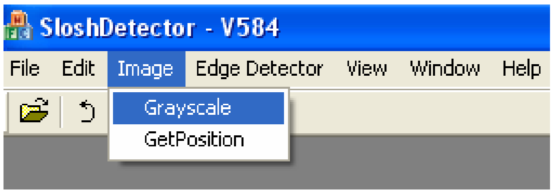
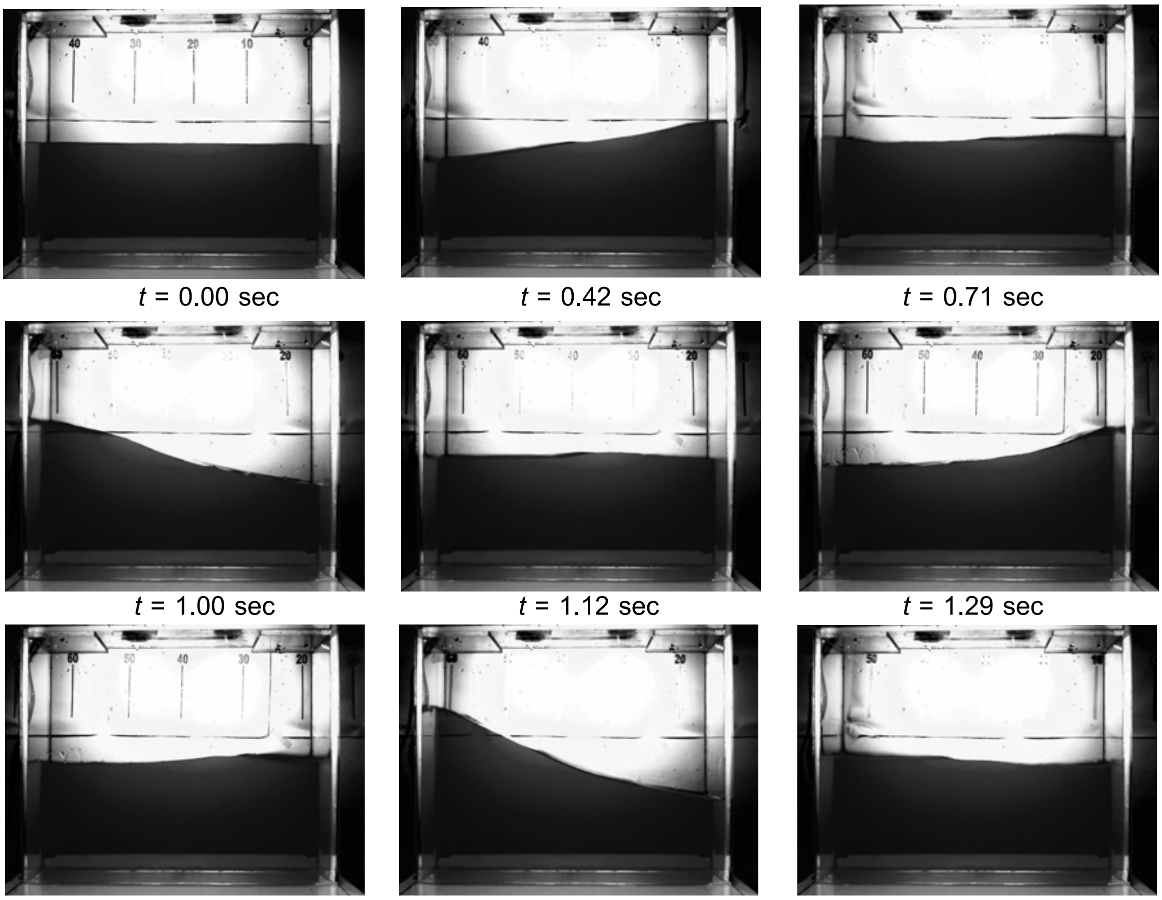


Fig. 3 Grayscale toolbar of the SloshDetector software menu.

The Canny's mathematical formulations implemented into the SloshDetector software can be used through the "Canny" toolbar which is a drop down menu of the Edge Detector menu as shown in Fig 5.

The surface wave will be found from the gray images after using the Canny toolbar. The sequential images of surface wave are shown in Fig. 6. After the edge detection method is



t = 0.00 sec, t = 0.42 sec, t = 0.71 sec

t = 1.00 sec, t = 1.12 sec, t = 1.29 sec

t = 1.37 sec, t = 1.54 sec, t = 1.79 sec

Fig. 4 Sequential gray images of the surface wave using Grayscale toolbar in the SloshDetector software.

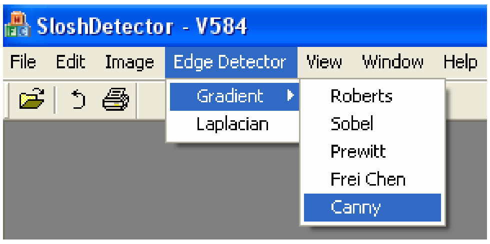


Fig. 5 Canny toolbar in the Gradient group of the SloshDetector software menu.

performed all of the sequential images have two colors (black and white color). In the images, the detected surface wave is white pixels. These pixels superimposed on the surface wave can be proved by overlapping the detected surface wave's images onto the original images. The detected surface wave fitting accurately to the original image of the surface wave is shown in Fig. 7.

The *C* language code was written to obtain the rectangular coordinates of the white pixels. The coordinate data can then be exported to the text files using the "GetPosition" toolbar as shown in Fig. 8. The text files are the coordinated of the surface wave in the pixel unit (image size). Consequently, the unit of the experiment results has to convert from the pixel unit to the measurement unit (mm).

Because the images have the original size of 960x720 pixels (width x height) and the height of the tank is 692 pixels, the constant factor to multiply to the pixel coordinates is 0.35.

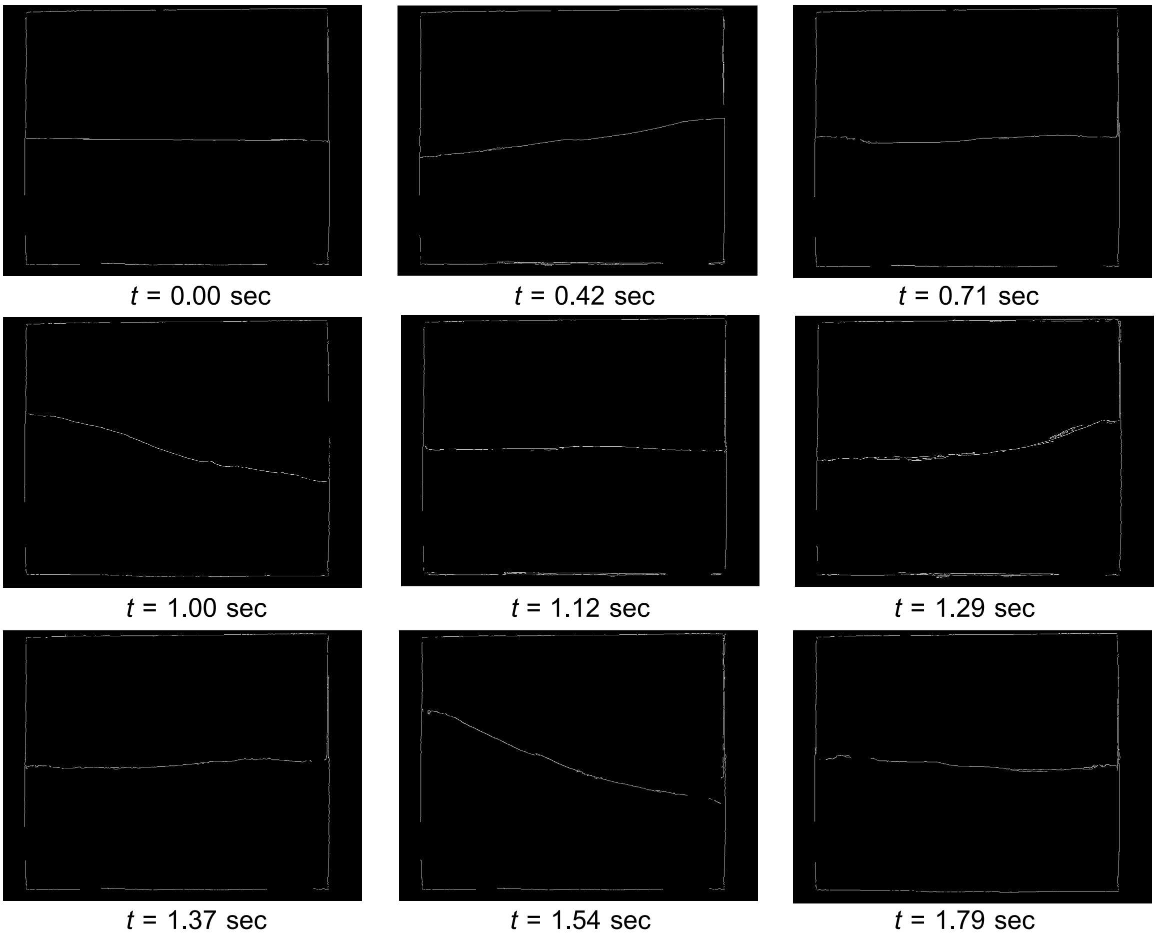


Fig. 6 Sequential images of detected surface wave using the Canny toolbar in the SloshDetector.

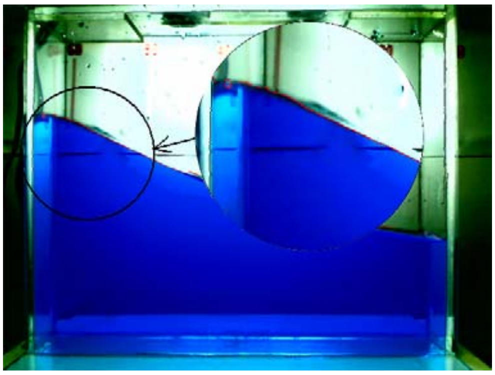


Fig. 7 The detected surface wave overlapping on the original image at t = 1.54 sec.

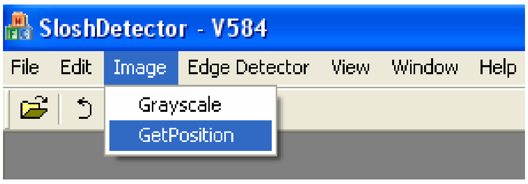


Fig. 8 GetPosition toolbar of the SloshDetector software menu.

The surface wave of the moving water can be converted the data consisting of *x-y* coordinates of points on the surface wave at the specified time of the tank motion. After this data is imported to the Microsoft Excel program to create the *x-y* graph, the *x*-axis is the width and *y*-axis is the height of the graph. Fig. 9 shows the sequential plots (*x-y* coordinates) of the surface wave for t = 0.00 sec to t = 1.79 sec.

The sequences of the surface wave can express the maximum height of the sloshing water inside the rectangular tank which moves from the right to the left. The amplitude of the top wave depends on the time variation of the tank moving. The behaviors of the surface wave at the left side wall in this experiment resembles to a sine wave. Fig. 10 shows the height of the sloshing surface varied with time at the left side wall of tank for $0 \leq t \leq 4.00$ sec.

5. Conclusion

Coordinate data of the surface wave can be determined using image processing. This process comprises with the conversion of the RGB color images to gray color image, noise filtering method and the edge detection method. We found that the Canny method obtained the most accurate method for detecting the surface wave

The processes above were implemented using *C* language to create the "SloshDetector" software. This software can perform to detect the *x-y* coordinates of the surface wave of water in the moving tank at the specified time. The coordinate data is the fundamental data for studying of sloshing behaviors of the partially filled liquid containers. Particularly, the experiment results which obtain from our image processing can use to compare with the CFD results especially in the multiphase flow analysis.

6. Acknowledgement

This research was fund by the Thai Research Fund (TRF) under the IRPUS Project no. I52A07008 and Heil Asia Ltd.

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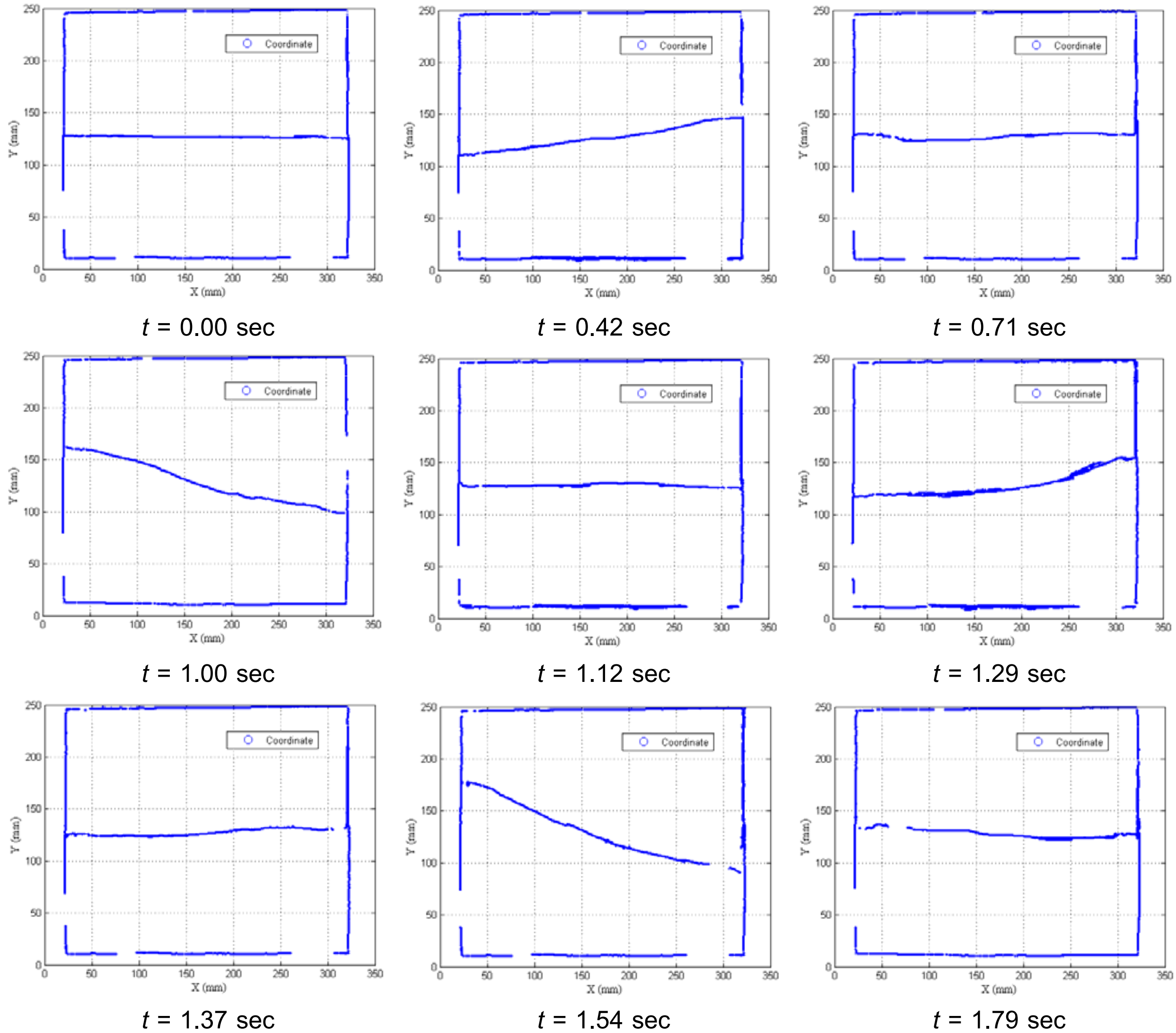

Fig. 9 The sequential plots of the surface wave for time = 0.00 sec to time = 1.79 sec using the SloshDetector software.

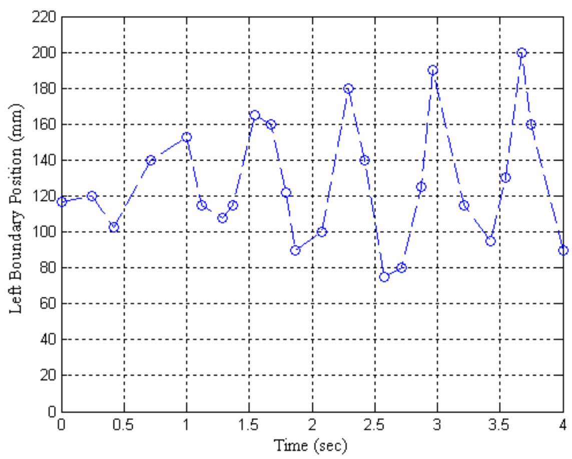

Fig. 10 The height of the surface wave at the left wall of tank vs. time.

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