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Research paper

Study of fluid edge detection and tracking method in glass flume based on image processing technology

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ABSTRACT

Research on changes in the fluid edge of a wave flume is important for experimental hydrodynamics. However, disturbances often occur because of the presence of sensors. To solve this problem, a new grey-scale image processing method for fluid edge analysis is presented here. By fusing methods combining image gradients and image segmentation with shifting-window technology and with concepts derived from experimental fluid mechanics, the proposed method can overcome many of the inherent challenges of fluid-edge measurement. First, the geodesic distance is modified to obtain a class curve. Second, an edge position is determined by the inflection point of the class curve related to the gradient peak distribution. Next, the position of the interrogation window is relocated with reference to neighbors or to previous results, and the current edge position can be calculated according to the predicted value. During the computation, the interrogation window can change its position adaptively with fluid motion, ensuring that the amount of data to be analyzed always remains stable. A model combining the class curve and gradient curve can improve the validity of edge identification. Finally, the performance of the proposed method has been evaluated using images in a glass flume. The results show that the proposed method for studying the fluid edge is effective and robust.

1. Introduction

With the development of image sensors and image processing technology, measurement methods based on digital image processing have received more and more attention and have been widely used in many engineering studies [1–4]. In the case of fluid research, the measurement mechanism of the image processing system is contactless and only a few sensors are required. Because this measurement technique not only can supply experimental data with high precision, but also can resolve the disturbing problems caused by sensors, applications combining ocean engineering and image technology are becoming more widespread [5–8]. The purpose of this research has been to design an image edge detection and tracking method that can effectively extract the level lines of water or another fluid in a wave flume in a laboratory.

In image processing architectures, edge information is very important for research into object structures. Image edge detection is the process of identifying and locating sharp discontinuities, which appear as abrupt changes in pixel intensity. Many ways to perform edge detection have been proposed by researchers such as Roberts, Sobel, Prewitt, Krisch, Laplacian of Gaussian (LoG), Canny and others [9]. Most of these methods can be grouped into two categories: gradient-based edge detection and Laplacian-based edge detection [10].

Over the years, many edge detection methods have been used for water level measurement. Brady et al. (2004) used binary images to analyze water level in a flume; the images were extracted from a single green channel of a color camera [11]. Yu and Hahn et al. (2010) reduced the amount of data in various images to obtain a horizontal edge image. The water boundary points of the water level were detected from the Y-axis profile of the horizontal edge image [12]. Lin et al. (2013) used a histogram equalization method to preprocess images and used the Otsu threshold method to analyze the level in a water gauge [13]. Kim et al. (2014) developed an image water level gauge system in which the water level was measured by correlation analysis of different images together with a feature recognition algorithm [14]. Viriyakijja et al. (2015) used the Canny algorithm to extract a water level line and used this method to analyze waves in a flume [15]. All these studies used image-based approaches to analyze the fluid surface and achieved

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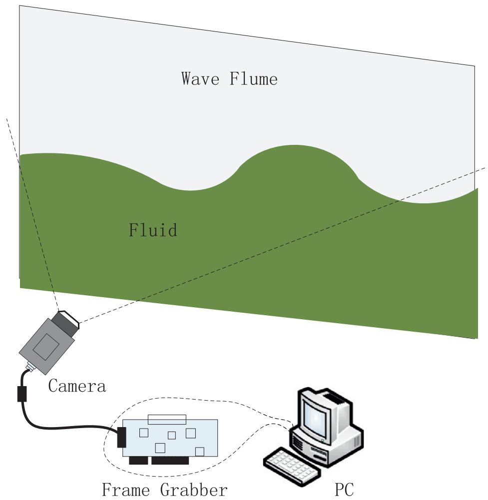

Fig. 1. Edge measurement system structure.

Fig. 2. Sediment flushing experiment.

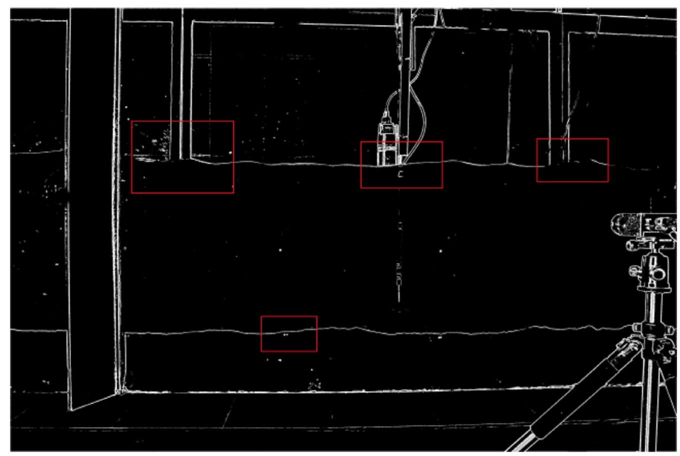

Fig. 3. Edge detection results from Fig. 2 based on Canny and Otsu.

their goals. However, in the case of edge extraction methods, each of which has its own advantages and drawbacks and may be better suited to particular applications, the performance of image-based water level measurement is heavily limited by various factors, including image resolution, lighting effects, lens distortion, perspective, the water meniscus, and others [16]. These potential sources of uncertainty that affect image-based water level measurements will also have an impact when doing experiments in a glass flume in the laboratory.

Inspired by geodesic segmentation methods, a new method for edge detection and tracking with a floating interrogation window for fluid in a glass flume is proposed here. This paper examines the distribution properties of similar distances within a small region of a gray-scale image and forms class curves according to these properties. Furthermore, to obtain the exact position of the fluid edge, the class curve is combined with the gradient curve within an interrogation window, and the fluid motion is tracked by small movements of the interrogation window. The proposed method is shown to provide the exact edge position of the fluid by using a fusion of clustering and gradient methods and by combining local and global features. In addition to this benefit, the new fluid edge detection and tracking method is flexible and easy to use, whether for single- or multi-position analysis.

2. *Characteristics of a fluid image in a wave flume*

As shown in Fig. 1, the measurement system used in this research consists mainly of one camera and its accessories in addition to the flume and the target fluid. When capturing images, the camera is placed outside of the flume. The subject of this paper is a method for extracting the fluid edge near the glass wall between the camera and the fluid. The next paragraph describes the feature analysis of the fluid image.

Fig. 2 is one of the images from a sediment flushing experiment. The purpose of the analysis is to obtain the sediment edge and water level synchronously, which is difficult to do. Fig. 2 clearly shows that there are other objects in the image, such as flume backgrounds and sensors (such as ADV), besides sediment and water. Hence, extracting the target edges requires an evaluation of the properties of object edges.

The Canny operator is a popular edge detection algorithm which uses the Gaussian and the derivative of Gaussian operators to detect gradients. The Canny operator [17] was first used to detect edges in Fig. 2. Then the Otsu method [18] was used to obtain a binary image with an adaptive threshold, which is shown in Fig. 3. From the processing results, it is clear that the obvious edges of water and sediment have been detected successfully. However, it is difficult to extract whole-edge information related to water or sediment in Fig. 2 because of edge discontinuities and interference caused by other objects (problem regions have been identified by red rectangles in Fig. 3). The problem can be solved by adopting a suitable threshold for binary images and using an edge tracking method to select edge points, but the computation is expensive. Moreover, performing the analysis at every pixel position is not necessary. This approach will degrade edge extraction efficiency, especially when dealing with image sequences. Furthermore, the level of the water changes faster than that of sediment. Hence, it may be better to divide the edge processing procedure into two independent parts: one for water, the other for sediment.

3. Fluid edge detection method within an interrogation window

This section first examines the gradient distribution characteristics using an interrogation window near the water surface. The gradient values of pixel position (2565, 1277) in Fig. 2 along the vertical direction are shown in Fig. 4.

The multi-peak feature, which is caused by image noise and particles produced by sediment flushing in water, is obvious in Fig. 4. The curve shown in Fig. 4 is called the *gradient curve* and the set of peak positions shown in Fig. 4 is defined as *GradientMaxSet*:

$$GradientMaxSet = \{gp_1, gp_2, \cdots, gp_i, \cdots, gp_{mg}\},$$

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