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Application of Hough Transform for the Identification of Secondary Flow Patterns

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Abstract- **This paper reports the application of Hough transform image processing technique to identify the existence of secondary flow patterns in a curved channel. When a fluid is forced through a passage with curvature, secondary flow appearing in spiral motion will superimpose on the main flow. Such phenomena are commonly found in many heat exchange equipment. While secondary flow promotes mixing of the fluids, thereby improving the heat exchange efficiency, limited attempts were made to improve the heat exchange process through the control of the secondary flow. In addition to the highly complex nature of the secondary heat transfer process, it is difficult to quantify or measure the extent of the secondary flow. Hence, much research and investigations have concentrated on the study of the exact mechanism and characteristics of the secondary flow. In this paper, a novel approach using an image processing technique based on the Hough Transform is used to locate and extent of the secondary vortices. Hough transform, is used to capture the secondary flow system pattern and then it is used to reconstruct the boundary of the secondary flow patterns.**

Keyword – **Object Reconstruction, Hough Transform, Secondary Flow Pattern.**

I. Introduction

This paper describes a novel approach based on the Hough Transform image processing technique for the identification of secondary vortices in a curved channel.

When a fluid is forced through a passage with curvature, centrifugal forces acting on the fluid will generate a pair of counter-rotating vortices. When the flow exceeds a certain condition, additional secondary vortices will appear at the outer concave wall along the flow passage. This phenomenon has been identified in the field of fluid dynamic as Dean's hydrodynamic instability. The secondary vortices are known as the Dean's Vortices [1]. This secondary flow appearing in spiral motion will superimpose on the main flow and they tend to increase turbulent interaction among the fluid. This has a significant effect on the heat exchange characteristics [2]. Such phenomena are commonly found in radiators, compressors, centrifugal pumps, turbine blades and many heat exchange equipment. These effects have been taken into consideration in the design of heat exchanger in order to improve the efficiency in waste heat recovery [3,4]

While secondary flow promotes the mixing of fluids, limited attempts have been made to improve the heat exchange process through the control of the secondary flow. This is mainly due to the fact that many aspects and nature of the secondary heat transfer are highly complex. Hence, much research and investigations have concentrated on the examination and study of the exact mechanism and characteristics of the secondary flow.

In the past, studies have been conducted in the use of external heating to enhance the heat transfer in a curved rectangular channel [5] and the prediction of the secondary flow characteristics using numerical analysis [6]. While the predicted secondary flow patterns are observed to be similar to the practical flow patterns, no attempt has been made to quantify and measure the actual flow patterns.

In this paper, pattern recognition technique is used to identify and reconstruct the actual secondary vortices from the captured images. If the extent of secondary flow is known, it is possible to provide feedback information for the control of the main flow, thereby improving the heat exchange performance. The pattern recognition technique can then be applied to predict the dynamic behaviour of the system.

This paper reports the investigation of using different Hough transform techniques to capture and process the secondary flow system patterns. The paper also extends the Hough transform technique for the reconstruction of the boundary of the patterns thereby providing quantitative information on the secondary vortices.

II. Secondary Flow Recognition

An example of a image of secondary flow is given below.

Figure 1: A typical secondary flow pattern

The procedure in an image processing and recognition system normally comprises the following stages: image capturing, noise filtering, edge detection, features extraction and object identification. In this study, the images have been captured

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with a high-speed and high resolution camera. After the initial stages of image capture and processing, the first attempt to identify secondary flow is the application of edge detection. A template matching technique is then used for feature extraction and recognition. However, it has been observed that the patterns captured tend to have ill-defined and non-continuous edges. In addition, irrelevant patterns are often captured which can be considered as *noise*. Furthermore, it is found that most of the secondary flow patterns exist in a closed circular loop. However, they are not necessarily expressible by a linear mathematical expression. This is a major weakness in Hough transform techniques that rely on using model references for recovering the pattern.

In order to overcome these problems, it is clear that an algorithm is required such that it satisfies the following criteria:

- The algorithm must be able to connect the weak and the non-continuous edges.
- The algorithm should be robust to noise. It should also be capable to filter off any irrelevant patterns.
- The algorithm must be able to reconstruct shapes that correlate with the expected flow patterns.

With these characteristics in mind, the following sections describe the development and investigation of such algorithm.

III. HOUGH TRANSFORM

A. Background

Hough transform is a technique used in converting image space into a parametric space. It is a well-established technique in computer vision applications. It has been used to find line segments, shapes and other features of the image. The technique is well recognised for its ability in detecting pre-defined image features with noise and is able to withstand certain degree of occlusion and boundary defects. However, there are two major drawbacks from the Hough transform. These drawbacks are the requirements for a large amount of storage and high cost in computation [7].

To tackle these problems, many improvements have been suggested. However, all the improvements are made with the cost of making certain assumptions or by sacrificing the degree of flexibility in the algorithm.

B. Use of Hough Transform for Processing Secondary Flow Patterns.

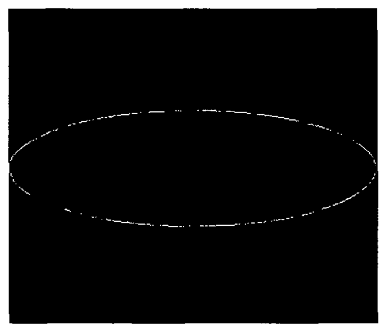
As discussed in the previous section, weak and broken edges together with non-related patterns are viewed as the major problems in processing secondary flow patterns. The following paragraphs give a description on how different varieties of Hough transform techniques are used in processing the secondary flow pattern images [12].

One frequently adopted technique in recognising shaped is the standard Hough transform (SHT) method [8]. The method is robust to noise and is able to withstand certain degree of boundary defects. Unfortunately in this application, the technique suffers two shortfalls. Firstly, it requires tremendous number of different templates and the time to reconstruct all the different shapes that may exist in the secondary flow system. Secondly, the reference point for the template and the actual object are required to be consistent for the matching process to proceed successfully. Depending on the characteristics of the image feature and the conditions applied, the steps involved in allocating the same reference point may be very complicated.

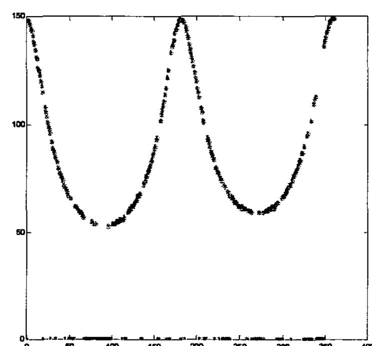
C. Proposed Methods

(a) Image Space to Hough Space

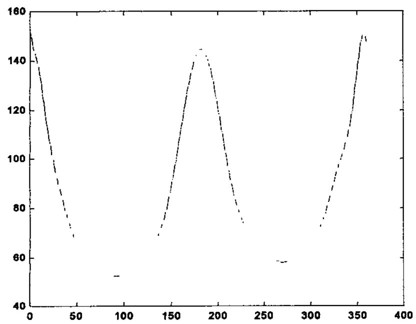
In a paper written by Wright et al. [9], they have suggested that a reference point inside a closed loop may be assumed. By converting the close loop from image space into the parametric (Hough) space, the closed loop can be mathematically described by a polynomial expression. This implies that the broken boundary of a close loop in the image space can simply be re-connected by estimating the curve in the parametric space and transforming them back to the image space. Consider the example in Figure 2 below, an ellipse with broken boundary is mapped to the parametric space. The mapping is then represented by a polynomial expression as shown in Figure 2(c). Figure 2(d) shows the reconstructed ellipse from the polynomial function. It can be seen that the reconstructed ellipse is slightly distorted. This can be improved by altering the polynomial expression of the estimated function [10].



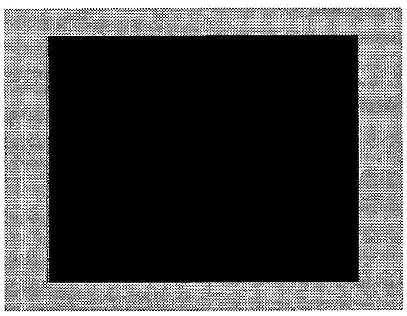
(a) An ellipse with broken boundary



(b) Mapping of the ellipse to the parametric space with the reference point located at the centre of the ellipse



(c) Ellipse represented by a polynomial function in the parametric space.

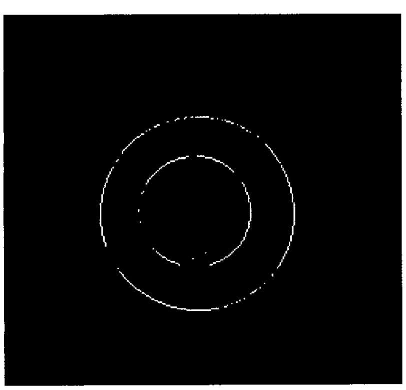


(d) The reconstruction of ellipse from the parametric space

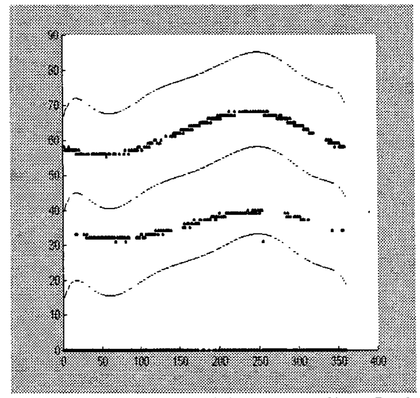
Figure 2: Mapping from image space to parametric space:

(b) Multiple Layers Of Circular Loops

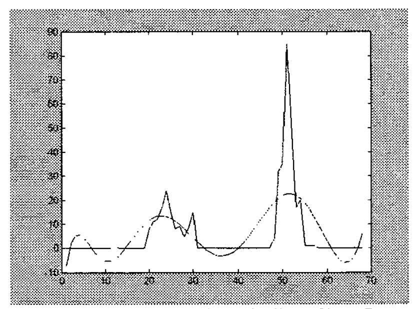
Instead of a single circular objet, it was observed that the secondary flow patterns exist as multiple layers of circular loops. The proposed approach was therefore extended to reconstruct multiple layers of circular loops. This involves the use of a filter function to isolate each layer of circular loop in the parametric space. Using the filter function, each circular loop is then isolated by a window. This step is necessary to provide a more accurate estimation on each curve in the parametric space [11]. Figure 3 demonstrates the multiple circular loops reconstruction process.



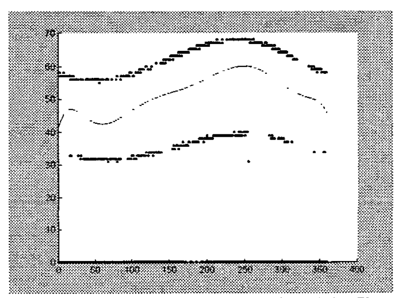
(a) Multiple closed-loops with broken boundaries.



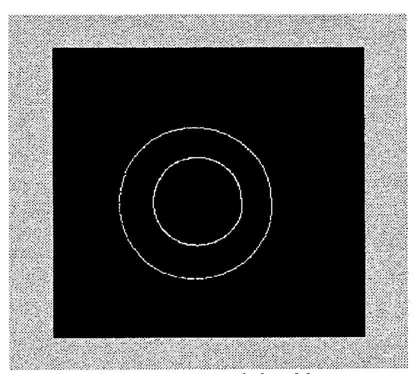
(b) Parametric representation and the average of best-fitted curve.



(c) Correlation result from the line of best fit



(d) Isolating the curves with correlation result and the filter function



(e) The reconstructed closed-loops

Figure 3: Re-construction process for multiple closed loops.

The steps used in reconstructing multiple layers of circular loops are listed below:

Step 1. Use Hough transform to transform features from image space into parametric space.

Step 2. Create a filter function to isolate each curve in the parametric space. This function is generated by applying the average curve with the best fit method.

Step 3. Correlate the parametric space with the filter function to find the boundary for each window. The steps involved are as follows:

a. Scan through the parametric space with the filter function.
b. Record the number of correlated points as the filter function scan through the parametric space.
c. Locate the local minimum points generated from the correlation result.
d. Divide the parametric space in a number of windows. Each window is located between the local minimums found in the correlation result.

Step 4. With each window:

a. Create the approximate function of the window by applying the average curve with the best fit method.
b. Scan through the window with the approximate function.
c. Record the number of correlated point as the approximate function scan through the window.
d. Apply a threshold value on the correlation result such that only result passes the threshold value can be used for further processing. Size of the widow is normally used for determining the value of the threshold. (NOTE: This is also used as a mechanism for filtering the unrelated pattern.)

Step 5. Transforming the curve located in each window back to the image space.

IV. CASE STUDY

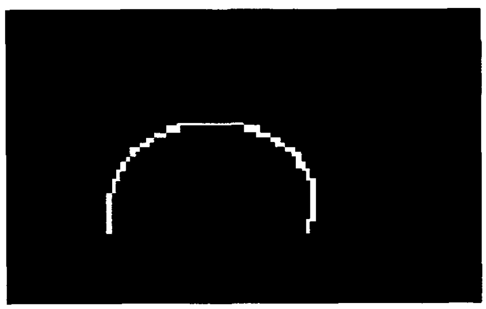
A case study is presented to illustrate the application of the proposed technique to real image data for the reconstruction of the flow patterns. Two typical images captured in a heated flow channel are presented. The first image with a vertex is shown in Figure 4. The other image in Figure 5 contains an undetermined pattern.

From Figure 4, it can be seen that a semi-ellipse can now be used to describe the shape of the vertex. By following the algorithm proposed in Section III(c), the reconstruction results can be seen in Figure 4 (b). Again, the image is only partially reconstructed, but it is enough to show that a vertex has been detected.

The best-fit approximation is expressed by a polynomial function. By restricting the function characteristic, the polynomial power, it is possible to restrict the reconstruction algorithm to only limited number of shapes. As for this application, the polynomial power of 7 is more than adequate to describe the full circular and ellipse shape. Thus, along the algorithm proposed in the previous section, it is possible to filter the unrelated pattern as shown in Figure 5.

(a) A typical secondary flow pattern with a vertex in a heated channel.

(b) Edge feature detected by using Sobel Edge Detector.

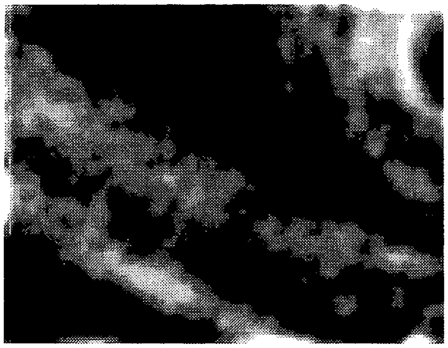


(c) The reconstructed vertex shape

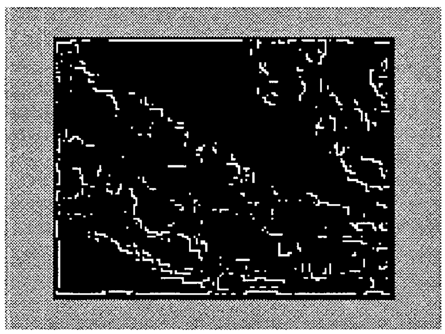
Figure 4: Processing of a typical image of secondary flow patterns

V. DISCUSSION

The proposed technique in this paper provides several advantages. Firstly, the technique is very simple and it is remarkably easy to implement. Secondly, unlike the reference model approach, a reference point can be placed anywhere in the image. However, polynomial function can only be used to describe the parametric space mapping of a close circular loop if the reference point is inside the loop. It is however possible that the reference point may not be limited to the inside of the close loop if other types of function are used for representing the secondary flow system's features. Thirdly, as shown in the case study, with an accurate best-fit curve function, this technique has the potential of recovering any given shapes



(a) A secondary flow Image with an unrecognizable image of vertex



(b) Edge feature detected by using Sobel Edge Detector

Figure 5: A typical flow pattern without Dean's Vortices

It is recognised that the proposed technique in this paper is in an initial stage of development. It is noted that the proposed method does suffer from several shortfalls. Firstly, depending on the complexity of the shape, the technique may not accurately recover the boundary of the original shape. However, in the problem of secondary flow pattern recognition, it is not required to accurately recover the boundary of the pattern as the objective of the process is only to determine the number of close-loop forms in a given area of an image. Secondly, the best-fit approach is only capable to reconstruct the related pattern provided that if the window consists only the desired pattern. It is not robust with the existence of noise or other unrelated objects. As stated in the problem definition, filtering unwanted pattern is very important for recognition of the secondary flow patterns. One approach that has been studied closely is the use of windowing technique to segment the image into a number of smaller windows. Thirdly, the reference point for the Hough Transform is currently determined manually. Automatic reference point selection and adaptive windowing techniques are the next stage in the development.

VI. CONCLUSION

The development and application of Hough transform image processing technique for the identification of secondary flow patterns in a curved channel are proposed in this paper. Secondary flow are commonly found in many heat exchange process. This is due to the interaction which occurs when a fluid is forced through a passage with curvature. The secondary flow will appear in spiral motion superimposing on the main flow. While secondary flow promotes mixing of the fluids, thereby improving the heat exchange efficiency, limited attempts were made to improve the heat exchange process through the control of the secondary flow. In this paper, a novel approach using an image processing technique based on the Hough Transform is used to locate and extent of the secondary vortices. The process reconstructs the object through stages of filtering, edge detection and reconstructure of the object's boundary. It was found the process is successful in reconstructing and recognizing the flow pattern. However, the procedure at this stage relies on the human intervention to determine window size and parameters for the filtering process. Further studies will be conducted to determine the parameters automatically and adaptively.

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