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A PTV Method Based on SIFT Feature Points Matching for Velocimetry Measurement

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Abstract

Due to the scale invariant feature transform (SIFT) feature points' advantages for the invariant to image scale, brightness, rotation, occlusion and noise so on, in this paper, a PTV method on SIFT feature points matching for velocity measurement of oil-water two-phase flow based is proposed. For the oil-water two-phase flow with large droplet diameter, oil droplets overlap, ununiformed lighting, and the centroid position of oil droplets can't be obtained only by using traditional PTV methods through morphological processing. However, the algorithm in this paper can directly achieve the average velocity of the flow field according to the positions of correctly matched SIFT feature points, and there is no need to extract the centroid coordinates of each oil droplet. The experimental results show that the proposed algorithm can be used in the average velocity measurement of oil-water two-phase flow, moreover, the measuring accuracy can reach 95% when the matching feature points are sufficient.

Key words: PARTICLE TRACKING VELOCIMETRY(PTV), INVARIANT FEATURE TRANSFORM(SIFT), FEATURE POINTS MATCHING, OIL-WATER TWO-PHASE FLOW, VELOCIMETRY MEASUREMENT.

1. Introduction

The flow characteristic parameters of oil-water two-phase flow have been an important factor influencing oil extraction and production logging, and studying on flow regularity is not only the foundation of the research of oil-gas-water three-phase flow, but also is the key to improve the multiphase flow measurement technique. Especially the accuracy and reliability of the velocimetry measurement restrict the development of the PIV measurement technology of multi-phase flow.

At present the PIV velocity measuring technology of two-phase flow has got a great development, but most method concentrate on the gas-liquid, gas-solid and liquid-solid two-phase flow [1-3], and the research and development of PIV technology of oil-water two-phase have been lagged behind. Due to that the flow regime of oil-water two phase flow in horizontal is complicated, the phenomena such as the uneven distribution of oil droplet size, Oil droplet velocity gradient, droplet overlap and rotation often exist, and the velocity parameter measurement technology of oil-water two-phase flow is still relatively backward [4], about which many researches about it has been done by a few scholars. Elseth et al [5] measured velocity field of oil-water stratified flow by a laser Doppler displacement meter. Zhang H B et al [6] simulated velocity field of oil-water stratified flow of horizontal well. Wang L h and Xu M et al [7,8] measured velocity field of stratified flow and dispersed flow of oil-water two-phase flow in horizontal pipeline respectively on the PIV experiments platform by self-developed. Zhai et al [9] measured the cross-correlation velocity of oil-water two-phase flow in horizontal pipeline by a parallel line capacitance detector PIV technology as a transient velocity measurement method of unperturbed audience has been widely applied to various aspects of velocim-

etry measurement. According to the concentration size of tracer particles, Adrian [10] divided the PIV technology into particle tracking velocimetry (PTV), particle image velocimetry (PIV) and laser speckle velocimetry (LSV). When the particle concentration is extremely low, particle displacement by identifying and tracking the movement of individual particles can be obtained, thus obtained particle velocity, the velocity measurement method of this model is called particle tracking PTV technology. Traditional PTV [11-13] particle tracking method is largely dependent on image segmentation techniques, it will be appear a phenomenon that the particle diameter is larger or exist in the sheltered and rotation of the particle, and the method is no longer applicable.

Due to that the SIFT operator [14] has the characteristics of remain invariance to scale, rotation, occlusion, brightness and so on, therefore, according to the characteristic of SIFT feature points matching, a new PTV algorithm based on Scale Invariant Feature Transform (SIFT) feature points matching is proposed. The velocity field of oil-water two phase flow with low-concentration of oil droplets is measured by this algorithm, and experimental results show the effectiveness of this algorithm.

2. The PTV Algorithm Based on SIFT Feature Points Matching

When the tracer particle concentration of measuring flow field is very low, the particles following the fluid flow is similar to the motion of a single particle, then the PTV method of particle trajectory tracking should be used to implement velocity measurement of the particles. Currently, there is a major implementation PTV technology [15]: four-frame image particle tracking algorithm, the nearest neighbor and matching probability algorithm, these algorithms have been widely applied in two-phase flow study under gas-solid, solid-liquid and so on , but its appli-

cation in oil-water two-phase flow is still relatively small. Therefore, this paper proposes a PTV method that can be used for oil-water two-phase flow velocity measurement of low oil droplets concentration, and the method achieved by SIFT feature point matching.

SIFT algorithm is a local feature extraction approach based on scale-space. The algorithm not only has the invariant feature to image translation, rotation, illumination and so on, but also it can maintains better matching effect for the target of the movement, occlusion, noise and other factors[16]. The major steps of image matching based on SIFT feature points are as follows.

2.1 Constructed scale space

To simulate multi-scale features of the image data, it needs to construct scale space. Due to the Gaussian convolution, kernels is the only can realize linear nuclear of scale transform, so it often used Gaussian functions convolve with image [17]. For example, a scale space $L(x, y, \sigma)$ of two-dimensional image $I(x, y)$ may be represented as Eq (1):

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y) \quad (1)$$

Where $G(x, y, \sigma)$ is a two-dimensional Gaussian function of scale variable, the expression as shown Eq (2):

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

In order to detect feature points of stable and effective effectively in the scale spatial structure, and improve computational efficiency, Difference of Gaussian scale-space DOG is used in SIFT algorithm as shown in Eq (3):

$$\begin{aligned} D(x, y, \sigma) &= (G(x, y, k\sigma) - G(x, y, \sigma)) * I(x, y) \\ &= L(x, y, k\sigma) - L(x, y, \sigma) \end{aligned} \quad (3)$$

Where k is a constant scale factor, σ is a scale space factor; the smoothness of the image was determined by the value of σ ; If the σ is greater, the profile characteristics of two-dimensional image correspond it; If the σ is smaller, the detail feature of two-dimensional image correspond it.

2.2 Detection extremum of scale space

Extreme point is a feature point of scale invariance, and it needs to find extreme points in the pyramids after the complete construction of DOG scale space.

The method to detect extreme point is that for any one pixel, its image domain and adjacent 26 pixels within scale domain to compare, so that the sampling points are extreme points in the image space and scale space. The detected extreme points are considered to be potential feature points of the image.

2.3 Precise positioning extreme points, discard the unstable feature points

In order to locate the positions of detected feature points precisely, it can be achieved by surface fitting method. First, get fitting function of feature points:

$$D(X) = D + \frac{\partial D^T}{\partial X} X + \frac{1}{2} X^T \frac{\partial^2 D}{\partial X^2} X \quad (4)$$

Derivative the above formula, and the extreme points can be obtained:

$$X = -\frac{\partial^2 D^{-1}}{\partial X^2} \frac{\partial D}{\partial X} \quad (5)$$

And the corresponding extremes are:

$$D(X) = D + \frac{1}{2} \frac{\partial D^T}{\partial X} X \quad (6)$$

To obtain the local optimal point by revise X constantly and discard instability, ineffective feature points of $|D(X)| < 0.03$. Meanwhile, discard lower contrast points and unstable edge response points based on Hessian matrix, so as to obtain the effective feature points of the image.

2.4 Generate the feature descriptors

In order to make the key point do not change with a variety of changes of the illumination and the perspective, so it needs to establish a descriptor for each critical point, and the descriptor should have a high uniqueness, so as to improve the matching probability of feature points. To ensure rotation invariance, first, it should make coordinate axis direction of rotation to the primary key. To enhance the robustness of the SIFT algorithm, with the description of each feature point by using $4 \times 4(16)$ seeds, each seed point with eight directions vector information, for such a feature point can generated 128 datas; finally, to form a 128-dimensional feature descriptors. At this point, the SIFT feature descriptor has been removed influence of scale, rotation, illumination and noise and other factors.

2.5 Feature matching

Use the extracted SIFT feature points for image matching. The basic principle is to be similarity measured for SIFT feature points of two images which will be matched, and calculate the closest match of each feature point with the first image which in match characteristics point of the image. In this paper, we uses the slope distance as a measure similarity measurement of the feature points matching effect. First, the slope distance with U_{ab} between the feature vector (a_1, a_2, a_3, \dots) and (b_1, b_2, b_3, \dots) is calculated, the following expression:

$$U_{ab} = \arccos \left(\sum_{i=1}^n (a_i + b_i) \right) \quad (7)$$

With $i \in (1, 2, \dots, n)$, n is a feature vector dimension. In order to improve the matching precision and exclude the feature point of no matching relation produced by the factors such as image occlusion and busy background, and eliminate erroneous matching feature points by the threshold method, the following expression:

$$U_{\min}/U_i < R, \quad 0 < R \leq 1 \quad (8)$$

Where U_{\min} and U_i are the closest distance and times near distance respectively, when the ratio is less than the threshold value with R , they correctly match, otherwise for the mismatch, in this article the threshold R value is set to 0.65.

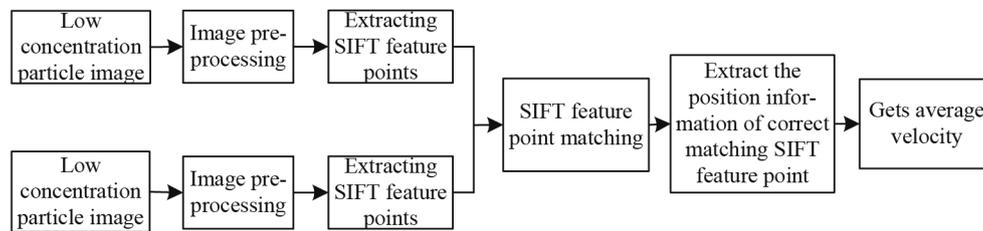


Figure 1. The flow chart of PTV method based on SIFT feature points matching

Implementation process can be described as follows: First, the images of low concentration particles were pre-processed, extract the area to be measured and eliminate noise and other interference of the image. Secondly, the SIFT feature points or feature point set from two images were extracted respectively by constructing scale space, detecting scale space extrema, accurate positioning feature points and generating feature descriptors and other steps. Once again, the SIFT feature points of two images were matched by using the slope distance as a measure similarity measurement of the feature points matching effect; the unstable and invalid matching points were eliminated by using the threshold methods of the closest distance and times near the closest distance and the location information of correctly matching SIFT feature points was extracted; the particle movement displacement was obtained according to the location information, and further the velocity value can be obtained. Finally, for the correctly number of matching feature points is not necessarily unique, there may be obtained a plurality of velocity values; In order to obtain a more accurate velocity value, the averaged estimate was required for such matching results and the final velocity value was obtained.

The main advantage of this algorithm is that, for

For a very low particle concentration in the flow field, PTV method is usually used to measure the flow velocity. In oil-water two-phase flow, the diameter of oil droplet is generally larger, and exist in the phenomenon as oil droplets overlap and uneven brightness. It often can't get integrated oil droplets information by the traditional image segmentation technology, and it is difficult to extract the information such as the location and centroid of oil droplets. Therefore, in order to extract more unique droplets information, in this paper to achieve the velocity measurement of low oil droplet concentration of oil-water two phase flow by SIFT feature point matching method, and so it is called the PTV method based on SIFT feature points matching. In this paper, the flow diagram of PTV algorithm based on SIFT feature points matching, as shown in figure 1.

the existence of overlapping and rotating particle, the particle diameter is large, and the flow field uneven illumination has strong applicability, so the algorithm is relatively simple to implement.

3. The Experimental Apparatus and Process

Figure 2 shows a system diagram of PIV velocity measurement, this apparatus including: a dual resonance pulsed Nd, YAG laser, CCD camera, synchronizer and computer. Laser is an adjustable semiconductor lasers which the wavelength is 532nm (green) and the maximum output power is 2 watt. CCD camera with a resolution of 1280 pixels \times 392 pixels, the acquisition rate is 10 frame / s, the laser beam into a sheet of light, the chip optical thickness is less than 1mm in the CCD collection area, the CCD cameras ratio scale is 30 pixel / m.

The fluid is a mixture of oil and water in the experiment. When oil-water mixture with different flow rates and different moisture content through the horizontal pipe, the flow field region of interested light sheet was formed by the laser irradiation, by shooting the fluid for the CCD camera under the effect of the synchronous controller, and to set the synchronization parameters, stored and processed image data by a computer, ultimately, using the algorithm of this paper realized the analysis of video images of oil-water

two-phase flow in MATLAB software platform, thus to obtain the mean flow velocity of the fluid.

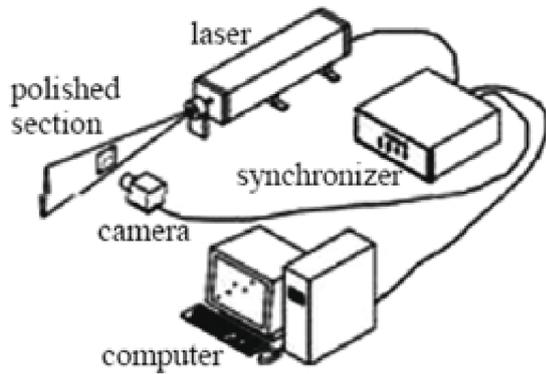


Figure 2. PIV method velocity measurement system

4. Experimental Results and Analysis

In this paper, oil-water two-phase flow video is made based on a total flow rate with 5m³/d, water content with 80% in horizontal pipe as experimental subject, the average velocity of the fluid is 0.20m/s. the PIV velocity measurement system with Figure 2 was used to collecting the movement of oil-water two-phase flow in horizontal pipe, and the PTV method Based on SIFT feature point matching was used to analysis and processing the collected fluid image.

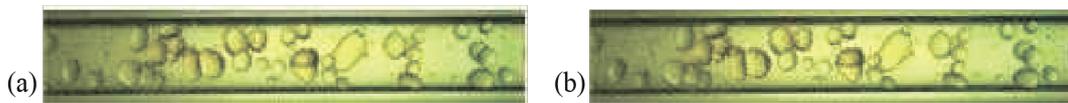


Figure 3. Original images of oil-water two-phase flow in horizontal pipe with 5m³/d-80% condition (a) The 853th frame original image (b) The 854th frame original image

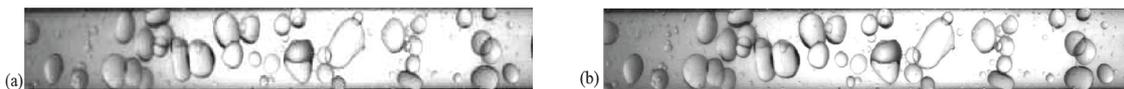


Figure 4. Preprocessed images of oil-water two-phase flow in horizontal pipe with 5m³/d-80% condition (a) The 853th frame preprocessed image (b) The 854th frame preprocessed image

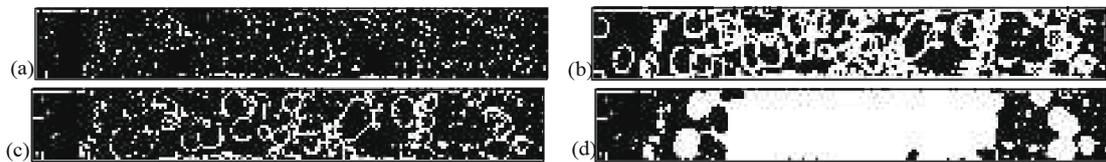


Figure 5. Morphological method to get the centroid (a) Canny edge detection (b) Expansion image (c) Corrosion image (d) Filled image

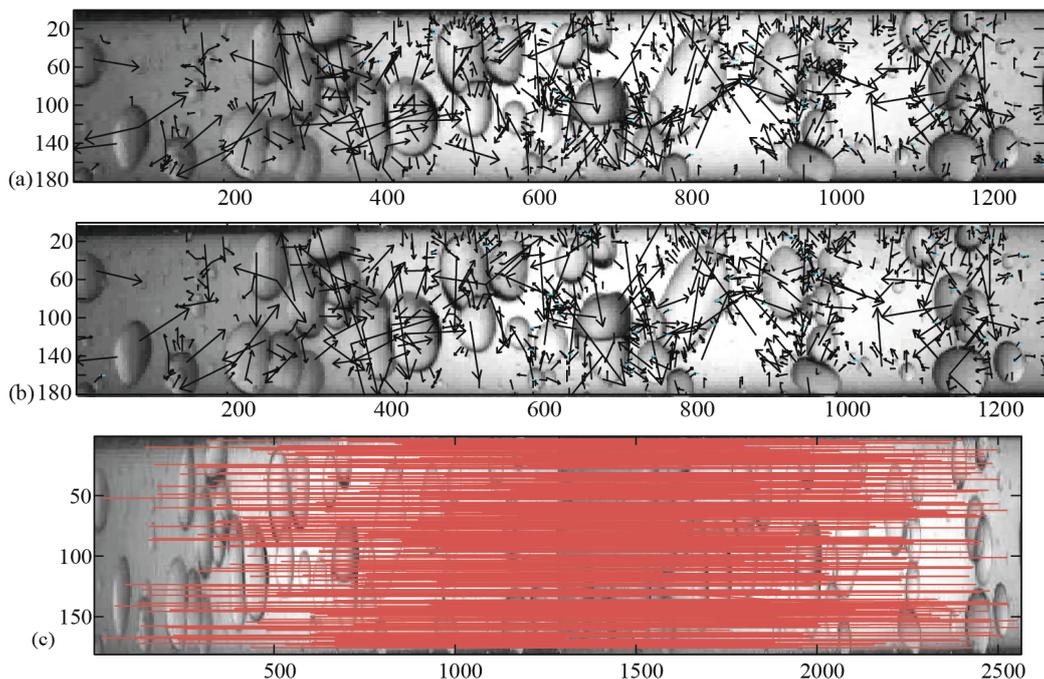


Figure 6. The results of the SIFT-PTV method (a) the 853th frame image by employ SIFT to

extract feature points (b) the 854th frame image by employ SIFT to extract feature points (c) the image by SIFT feature point matching

Figure 3 and Figure 4 show that, the measured flow field evident droplet size uneven distribution, droplet size is large, uneven luminance and occlusion. When it is measured by using conventional PTV method, the droplets centroid was obtained by using morphological. Figure 5 shows a series of images were obtained by morphological operations. Analysis shows that it cannot get a great effect by using traditional PTV morphological methods in this condition, and it occur to severe adhesions and even connected into one among the filler image particles, it is unable to obtain the centroid coordinates of droplet particles.

Figure 6 (a) and (b) are extracted to SIFT feature points images from the two images, and that in this paper the PTV method based on SIFT feature points matching was used to measure respectively. From figure 6 (a) the extracted SIFT feature points is 846, and Figure 6 (b) SIFT feature points extraction to 853. Figure 6 (c) shows a match of two images SIFT feature points, the red line represents the connection to correctly match the two feature points, two images have 452 SIFT feature points to achieve a proper match. The location information of the first 20 feature points is correct matching, as shown in Table 1.

Table 1. The coordinate positions of the previous 20 correct matching feature points in the 5m³/d-80% condition by using SIFT-PTV method

	the coordinate positions of the previous 20 correct matching feature points				
the 853th frame image	(893.98,119.06)	(615.67,55.90)	(361.69,128.06)	(361.69,128.06)	(735.89,46.40)
	(735.89,46.40)	(1150.24,86.5)	(976.46,60.41)	(820.46,144.77)	(212.84,144.77)
	(212.84,144.77)	(86.53,123.35)	(934.18,119.94)	(437.37,116.95)	(434.37,116.95)
	(287.26,82.17)	(878.81, 76.38)	(878.81,76.38)	(540.83, 65.35)	(821.47, 57.14)
the 854th frame image	(892.32,118.30)	(614.4,57.52)	(361.04,127.68)	(361.04,127.68)	(735.01,46.79)
	(735.01,46.79)	(1149.44,86.92)	(975.74,60.18)	(821.24,144.01)	(212.24,145.6)
	(212.24,145.6)	(85.57,124.4)	(932.93,120.04)	(433.59,117.33)	(433.59,117.33)
	(286.69, 82.16)	(878.09,75.91)	(878.09,75.91)	(539.40,65.72)	(820.1,58.07)

The coordinate position data is processed for SIFT feature points of correctly matching, the displacement information can be obtained on the oil droplets x, y direction, and further it the average velocity of oil droplets can be obtained in which the size is 0.19m/s, measurement error is 0.01m/s, compared with 0.20m/s of the actual fluid velocity, i.e., the measurement accuracy is 95%.

To further verify the effectiveness of the algorithm, the intercept part of flow field was simulated in pretreatment images from in figure 4, Figure 7 shows the next part of the interception to the flow-field image, the actual average velocity is also 0.20m / s.

Figure 7 shows a simulation image in low particle concentration, and the particle diameter vary in size and vary greatly, as well as it has some occlusion phenomena among the particles. It needs to filled binary image by using conventional PTV speed, as shown in Figure 8. Apparently, the filled effect is not good, and it has adhesion among the particles, even connected into a big particle, which seriously affect the particle centroid determination, so the measurement precision is affected significantly when PTV method was using in measuring.

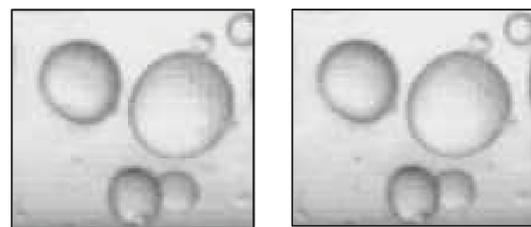


Figure 7. Two consecutive frame particle images

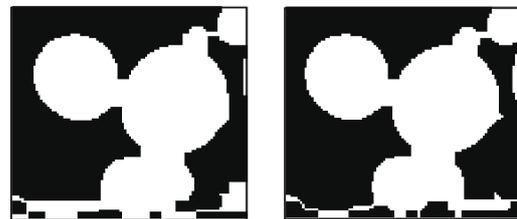


Figure 8. Filled images

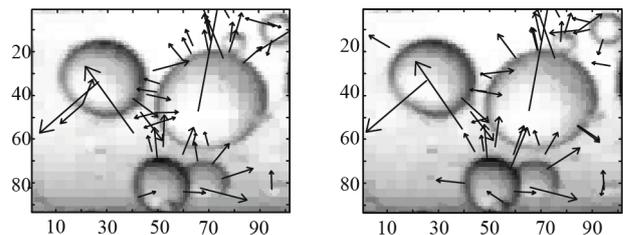


Figure 9. The SIFT feature point extraction image of part flow field

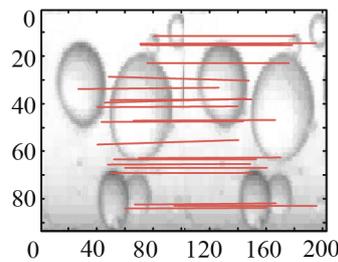


Figure 10. Results of SIFT feature point matching

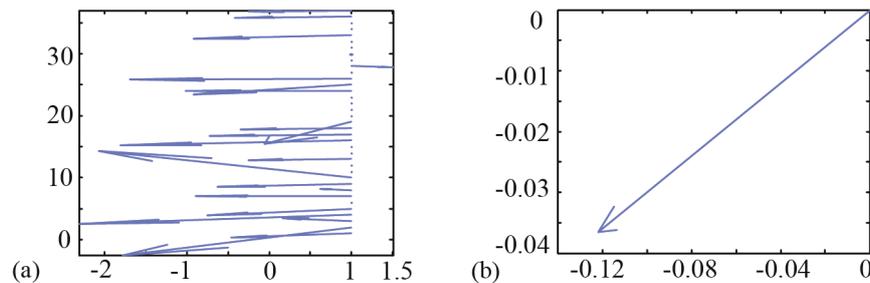


Figure 11. Velocity vector obtained by SIFT-PTV method (a) Velocity vector component diagram(m/s) (b) Mean velocity vector(m/s)

Figure 10 shows a feature point matching results map for two images, the red connection line represents correctly matched feature point pairs. Figure 9 extracts image feature points comparison, the true feature points match up to almost half, the amount of data with relative to the individual centroid position information, the more feature points. The position information of the correct match feature points, as shown in Table 2. Figure 11 shows a correct matching feature points calculated velocity vector, Figure 11(a) shows all the feature points of correct matching cor-

responding to the velocity vector, Figure 11(b) shows the velocity vector after the average estimate, and the units are m/s.

Processing the data in the table 2 and the size of average velocity can be obtained with 5.24 pixel/s, then the size of an average velocity can be obtained about 0.17 m/s by using ratio scale to unit conversion, measurement error is 0.03 m/s, compared with 0.20 m/s of the actual fluid velocity, i.e., the measurement accuracy is 85%.

Table 2. The correct matching feature points positions by using SIFT-PTV method

	the coordinate positions of correctly matching feature points				
the first frame image feature points	(65.89,47.26)	(40.41,57.08)	(75.66,22.82)	(26.59,33.83)	(66.62,82.37)
	(49.82,69.23)	(52.14,63.40)	(43.10,47.64)	(48.02,28.56)	(59.80,67.06)
	(40.22,41.41)	(70.74,14.76)	(60.03,84.03)	(45.60,39.41)	(78.40,15.32)
	(70.82,15.34)	(80.33,11.57)	(94.53,83.10)	(47.70,65.54)	(49.45,38.51)
	(94.70,14.70)	(69.77,62.81)			
the second frame image feature points	(65.28,46.99)	(39.25,55.22)	(75.31,23.04)	(25.21,33.21)	(65.89,81.94)
	(49.03,69.27)	(51.98,63.50)	(42.42,47.43)	(46.74,30.37)	(59.28,67.00)
	(39.05,41.11)	(70.02,14.67)	(59.47,83.95)	(45.16,37.94)	(77.56,15.33)
	(70.02,14.67)	(79.21,11.50)	(94.74,83.01)	(47.77,65.45)	(48.65,38.28)
	(94.11,14.63)	(69.25,62.73)			

The above two cases experimental results show that in this paper the proposed PTV algorithm based on SIFT feature point matching achieve an average velocity measurement of oil-water two-phase flow at low concentrations of oil droplets, and measurement accuracy can be up long enough 95% in matching feature points enough, and it has a strong applicability

that oil droplets larger diameter, overlapping droplets, droplet size and brightness distribution unevenness etc.

5. Conclusions

The innovation in this paper is that based on SIFT feature points on the scale, light, rotation, occlusion invariance, the SIFT feature point matching is applied

to the low concentration of velocity measurements in oil-water two phase flow field. Using this method in uneven illumination and particle diameter oversize of the flow field or the presence of particles occlusion cases, the measured fluid image is extracted SIFT feature points and processed matching, it can obtained more accurate flow velocity of oil-water two-phase flow, and thus provide an accurate basis for the exploitation of crude oil and gas fields.

Therefore, the introduction of SIFT feature points matching on the uneven illumination, and particles diameter oversize or the presence of particles occlusion particle of fluid velocity measurement have a good application prospect.

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