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A PTV Method Based on SIFT Feature Points Matching for Velocimetry Measurement of Oil-water Two-phase Flow in Horizontal Pipelines

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Abstract

Due to the advantages of scale invariant feature transform (SIFT) feature points on the invariant to image scale, brightness, rotation, occlusion, noise and so on, this paper proposes a Particle Tracking Velocimetry (PTV) method, based on SIFT feature points matching for velocity measurement of oil-water two-phase flow in horizontal pipelines. The oil-water two-phase flow with large droplet diameter, oil droplets overlap, ununiform lighting, and the centroid position of oil droplets can't be obtained only by using traditional PTV methods through morphological processing. However, in this paper, the algorithm 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 not only can be used in the average velocity measurement of oil-water two-phase flow in horizontal pipelines, but also can reach 95% in the measuring accuracy when the matching feature points are enough sufficient.

Keywords: *Oil-Water Flow, Particle Tracking Velocimetry (PTV), Scale Invariant Feature Transform (SIFT), Feature Points Matching, Two-Phase Flow, Velocimetry Measurement*

1. Introduction

The flow characteristic parameters of oil-water two-phase flow have become an important factor on oil extracting and production logging, and studies on flow regularity are not only the foundation of the research of oil-gas-water three-phase flow, but also the key to improve the multiphase flow measurement technique. Especially the accuracy and reliability of the velocimetry measurement restrain the development of the PIV measurement technology of multi-phase flow. At present, the PIV velocity measuring technology of two-phase flow method has got great progress, but most of methods concentrate on the gas-liquid, gas-solid and liquid-solid two-phase flow method [1-3], but the research and development of PIV technology of oil-water two-phase has been lagged behind.

Due to the complication of the flow regime of oil-water two phase flow in horizontal pipelines, the phenomena such as the uneven distribution of oil droplet size, oil droplet velocity gradient, droplet overlap and rotation often occur, and the velocity parameter measurement technology of oil-water two-phase flow method about which only a few

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scholars have made study is still relatively backward [4]. Elseth *et. al.*, [5] have measured velocity field of oil-water stratified flow method by using a laser Doppler displacement meter. Zhang H B *et. al.*, [6] have simulated velocity field of oil-water stratified flow method of horizontal well. Wang L h and Xu M *et. al.*, [7-8] have measured separately velocity field of stratified flow method and dispersed flow of oil-water two-phase flow method in horizontal pipeline respectively on the PIV experiments platform developed by themselves. Zhai *et. al.*, [9] have measured the cross-correlation velocity of oil-water two-phase flow in horizontal pipeline by using a parallel line capacitance detector. The PIV technology which is a transient velocity measurement method of unperturbed audience has been widely applied to various aspects of velocimetry measurement. According to the concentration size of tracer particles, Adrian [10] have divided the PIV technology into three including 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, which will be appear phenomenon that the particle diameter is larger or exist in the sheltered and rotation of the particle, leading to the method 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. Using the method of low-concentration of oil droplets of oil-water two phase flow velocity which is measured, the 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 situation, at this time the PTV method of particle trajectory tracking should be used to implement velocity measurement of the particles. Currently, there are major implementation PTV technologies [15]: four-frame image particle tracking algorithm, the nearest neighbor and matching probability algorithm, which have been widely applied in two-phase flow study under gas-solid, solid-liquid and so on, but its application in oil-water two-phase flow is still relatively small. Therefore, this paper proposes that a PTV method which achieved by SIFT feature point matching can be used for oil-water two-phase flow velocity measurement of low oil droplets concentration.

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 can maintain 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:

1) Constructed Scale Space

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

$$L(x,y,\sigma) = G(x,y,\sigma) * I(x,y) \tag{1}$$

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

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

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

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

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, which corresponds the profile characteristics of two-dimensional image; If the σ is smaller, which corresponds the detail feature of two-dimensional image.

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 constructing the DOG scale space.

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

3) Precise positioning extreme points, discard the unstable feature points

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

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

We derivative the above formula, then the extreme points can be obtained:

$$X=-\frac{\partial^2 D^{-1}}{\partial X^2}\frac{\partial D}{\partial X} \tag{5}$$

And the corresponding extremes are:

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

We obtain the local optimal point by constantly revise X and discarding unstable, ineffective feature points of $|D(X)|<0.03$. Meanwhile, we discard lower contrast points and unstable edge response points in the initial feature points by using Hessian matrix, so as to obtain the effective feature points of the image.

4) Generate the Feature Descriptors

In order to keep the key point not changing with a variety of changes of the illumination and the perspective, it needs to establish a descriptor for each critical point. However, 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 4×4(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.

5) Feature matching

By using 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 each feature point with first image which match the closest match characteristics point of the image. In this paper, we use 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 $(a_1, a_2, a_3, \ldots)$ and $(b_1, b_2, b_3, \ldots)$ is calculated, the following is the expression:

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

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

$$U_{\min} / U_l < R, \quad 0 < R \le 1 \tag{8}$$

where $U_{\min}$ and U_l are the closest distance and the second closest 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.

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 there are phenomenon which exist 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 we use SIFT feature point matching method which is called the PTV method based on SIFT feature points matching to achieve the velocity measurement of low oil droplet concentration of oil-water two phase flow. In this paper, the flow diagram of PTV algorithm based on SIFT feature points matching shows in Figure 1.

Implementation process can be described as follows: First, we should pre-processed the images of low concentration particles, extract the area to be measured and eliminating 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. Thirdly, 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 the second closest distance then the location information of correctly matching SIFT feature points was extracted; the particle movement displacement was obtained according to the location information, and the velocity value can further 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.

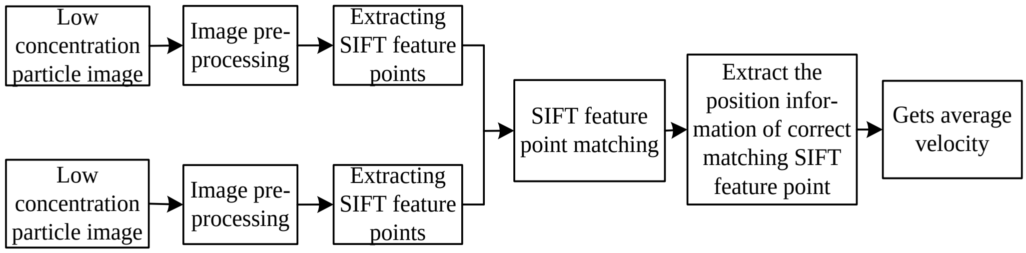

Figure 1. The Flow Chart of PTV Method based on SIFT Feature Points Matching

The main advantage of this algorithm is that has strong applicability for the condition which overlapping and rotating particle exist, the particle diameter is large, and the flow field is uneven illumination, therefore 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 mainly includes: a dual resonance pulsed Nd, YAG laser, CCD camera, synchronizer and computer. Laser is an adjustable semiconductor which the wavelength is 532nm (green) and the maximum output power is 2 watt. This is CCD camera which a resolution is 1280 pixels × 392 pixels, the acquisition rate is 10 frame/s, the laser beam is a sheet of light which thickness is less than 1mm in the CCD collection area, the CCD cameras ratio scale is 30pixel / m.

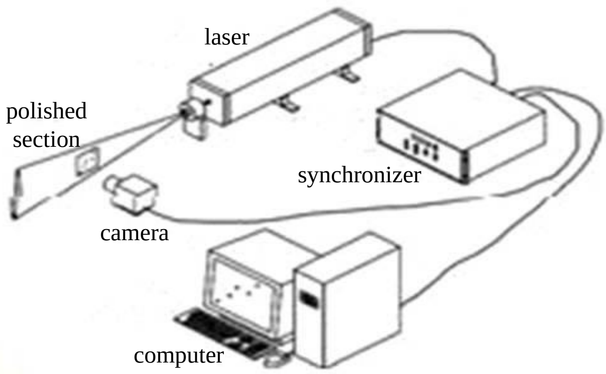

Figure 2. PIV Method Velocity Measurement System

The fluid is a mixture of oil and water in the experiment. When oil-water mixture with different flow rates and different moisture content flows the horizontal pipeline, the flow field region of interested light sheet was formed by the laser irradiation. CCD camera shoots the fluid under the effect of the synchronous controller, and using a computer set the synchronization parameters, store and process image data. Ultimately, using the algorithm of this paper realize the analysis of video images of oil-water two-phase flow in MATLAB software platform, thus obtaining the mean flow velocity of the fluid.

4. Experimental Results and Analysis

In this paper, oil-water two-phase flow video is made by a total flow rate with $5m^3/d$, water content with 80% in horizontal pipeline as experimental subject, the average velocity of the fluid is 0.20m/s. The PIV velocity measurement system with Figure 2 is used to collecting the movement of oil-water two-phase flow in horizontal pipeline, and the PTV method based on SIFT feature point matching is used to analysis and process the collected fluid image.

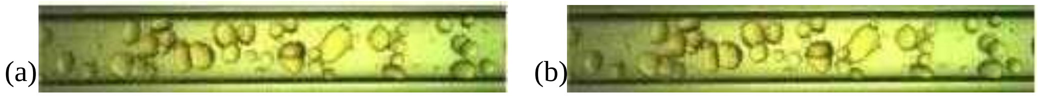

Figure 3. Original Images of Oil-Water Two-Phase flow in Horizontal Pipe with $5m^3/d$-80% Condition; (a) The 853th Frame Original Image; (b) The 854th Frame Original Image

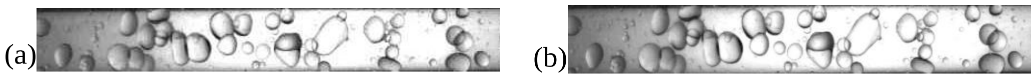

Figure 4. Preprocessed Images of Oil-Water Two-Phase Flow in Horizontal Pipe with $5m^3/d$-80% Condition; (a) The 853th Frame Preprocessed Image; (b) The 854th Frame Preprocessed Image

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

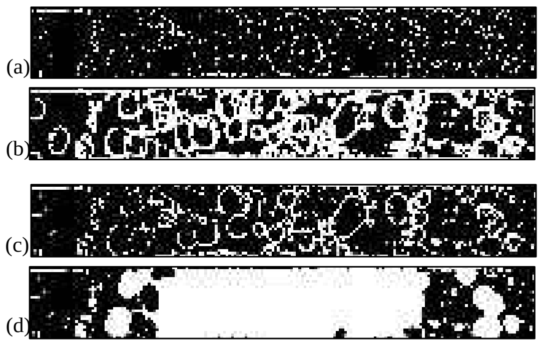

Figure 5. Morphological Method to get the Centroid; (a) Canny Edge Detection; (b) Expansion Image; (c)Corrosion Image; (d) Filled Image

Figure 6 (a) and (b) are extracted to SIFT feature points images from the two images, which 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, and 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 correctly matching is showed in Table 1.

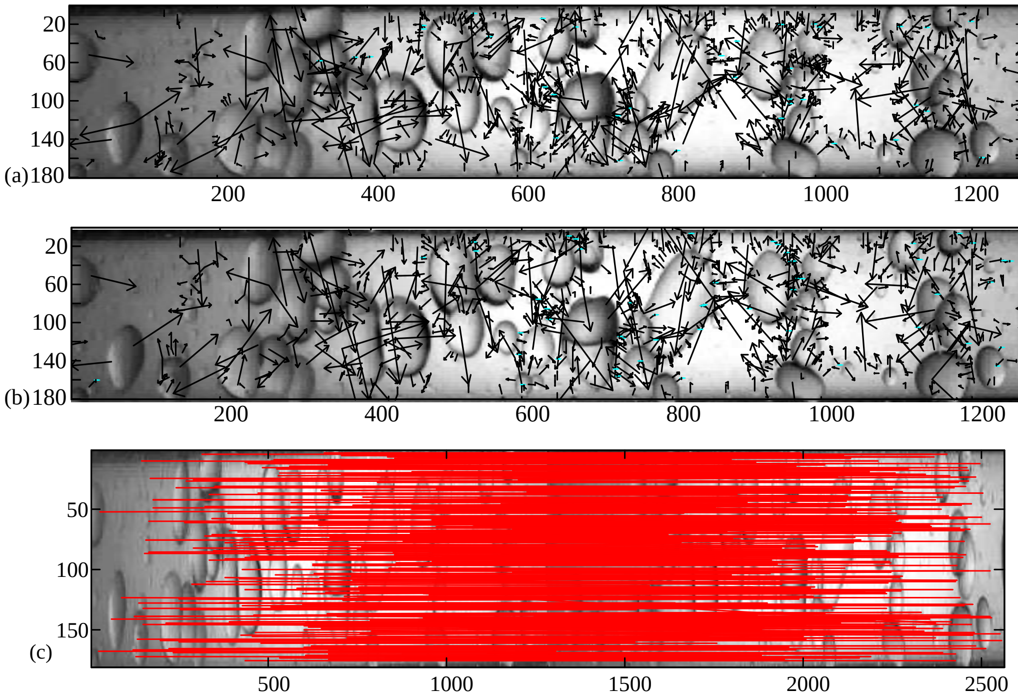

Figure 6. The Results of the SIFT-PTV Method; (a) The 853th Frame Image by Employ SIFT to Extract Feature Points; (b) The 854th Frame Image by Employ SIFT to Extract Feature Points; (c) The Image by SIFT Feature Point Matching

Table 1. The Coordinate Positions of the Previous 20 Correct Matching Feature Points in the 5m^3/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)

When the coordinate position data which SIFT feature points correctly match is processed, the displacement information can be obtained on the oil droplets x, y direction, further the average velocity of oil droplets can be obtained, in which the size is 0.19m/s that compared with 0.20m/s of the actual fluid velocity. Measurement error is 0.01m/s, *i.e.*, meaning 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 and the actual average velocity is also 0.20m / s.

Figure 7 shows a simulation image in low particle concentration and the particle diameter greatly vary in size, 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 affects the particle centroid determination, so the measurement precision is affected significantly when PTV method is used in measuring.

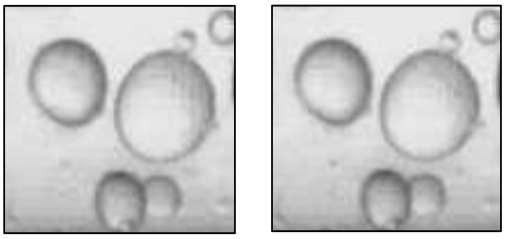

Figure 7. Two Consecutive Frame Particle Images

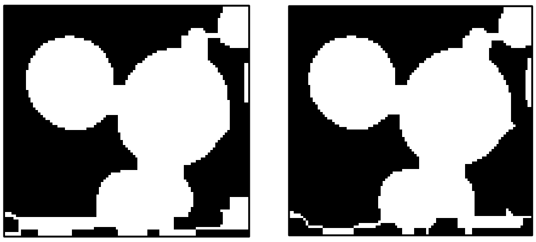

Figure 8. Filled images

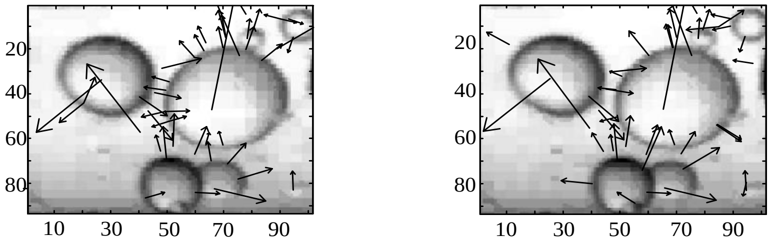

Figure 9. The SIFT Feature Point Extraction Image of Part Flow Field

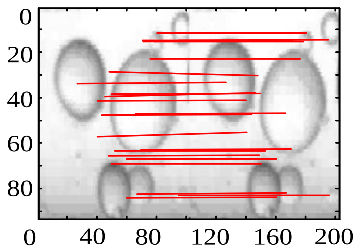

Figure 10. Results of SIFT Feature Point Matching

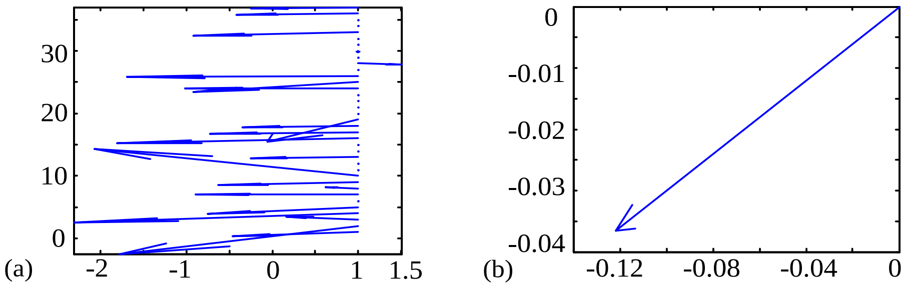

Figure 11. Velocity Vector Obtained by SIFT-PTV Method; (a) Velocity Vector Component Diagram(m/s); (b) Mean Velocity Vector(m/s)

Figure 10 is a feature point matching results map for two images, the red connection line represents correctly matched feature point pairs. Compared to Figure 9 which extracts image feature points, the true feature points match up to almost half. With relative to the individual centroid position information, the feature points of the amont of data is more. The position information of the correct match feature points shows in Table 2. Figure 11 is velocity vector which correct matching feature points calculate and figure, and Figure 11(a) is the corresponding to the velocity vector which all the feature points of correct match and Figure 11(b) is velocity after the estimated average, which the units are m/s.

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)

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

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. It has a strong applicability for phenomenon which oil droplets diameter is larger, droplets is overlapped, droplet size and brightness distribution is unevenness *etc*.

5. Conclusions

The innovation of this paper lies in the 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 obtain 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 significant application prospect.

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