Research on Non-contact Measurement of Open Channel Flow Based on Machine Vision

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Abstract: The two-frame images are captured continuously by vertically shooting the camera, and the strong angle points are used to track the velocity information. This design takes the ARM board of Banana PI (BPI-M2 Ultra) as the core, combines the processing of OpenCV visual function library, extracts and tracks the feature points by using the strong angle extraction algorithm, and uses the pyramid Lucas-Kanade optical flow method can track the feature points. The tracking of the characteristic point information is tracked to remove the distorted displacement information and calculate the velocity information using the relationship of the frame rate displacement.

1. Introduction
Flow measurement plays an important role in industrial production, farmland water conservancy, environmental protection, national defense, transportation and so on. It plays an important role in ensuring product quality, improving production efficiency and promoting the development of science and technology. Open channel flow measurement is an important branch of flow detection, widely used in urban water supply diversion canal, sewage treatment inflow and discharge channels, industrial and mining enterprises wastewater discharge and agricultural irrigation and other occasions. Most of the measured liquids in these cases have a strong corrosive and more impurities, we used conventional ultrasonic tachometer or propeller or swirl flow meter, need to be directly or indirectly on the water. Because of the strong corrosiveness and more contaminants in these water, such as aquatic plants or sediment, which cause the ultrasonic tachometer or propeller or swirl flow meter to be corroded or to lose the effect due to the action of impurities in the water or to result in the measurement Inaccurate. We change the way to use an indirect way to measure the speed of floating water on the open channel to replace the speed of water flow to achieve the measurement of open channel flow.

In this paper, the core of the hardware system is full of Banana PI (BPI-M2 Ultra) ARM development board, first from the BPI official website to download ubuntu Linux operating system, and then install the OpenCV library, and finally write code compilation and simulation and experiment [1].

Compared with the previous PTV tracking matching algorithm (such as the nearest neighbor method, the matching probability method, the PCSS method and so on) [1], the optical flow method is to calculate the image pixel information by the apparent movement (moving target pixel motion speed) to achieve the moving target tracking. In the optical flow algorithm, the Horn-Schunck method [2], the Lucas-Kanade method (L-K method) [3] and the Pyramid Lucas-Kanade method (pyrLK method) are typical examples, and the PyrLK method [4] is widely used Method, which is a sparse optical flow method, which can be applied to the target tracking calculation of large displacement compared with
the other two methods\[5\], so I chose the Pyramid Lucas-Kanade method to track the floating matter.

2. System Design And Working Principle
The system first through the camera to shoot the surface of the vertical texture, grab two consecutive images, and then extract the first frame of the Harris corner of the image, and screen from the strong corner as we want to track the corner, and then second frame of the image to find the first frame of the need to track the strong point, to be tracking the good point velocity vector.

In order to trace the displacement vector of the large angular point of the larger displacement, we can construct the 5-layer image pyramid for the two images respectively, and then use the Lucas-Kanade optical flow method to map the feature points from top to bottom. The layers look for the feature points we need to track and then track them, because by scaling the image to the pyramid of the image, the range of tracking and finding is so much better for tracking the big moving corners.

The camera find out all the tracking of the strong point of the displacement information. Here I picked the 40 feature points to track the displacement, so I put the 40 shifts together and then averaged. We can calculate the current velocity information by the relationship between displacement, frame rate and velocity.

And then the speed of the calculation to filter, because the camera real-time capture track the target, there is no effective target on the water can track the situation, this time tracking the characteristics of the calculation of the speed information is not accurate, so we should put these inaccurate Point to get rid of.

The structure of the system is shown in 1 Figure.

3. Principles Of The Algorithm

3.1 Harris Corner Extraction
Harris corner detection method is a simple and intuitive corner detection method. Assuming that a window is moving on the image, the gray scale of the window in the smoothing area along the movement in all directions does not change. The gray scale of the window in the direction of the edge along the edge does not change. And the window in the corner of the move, its various directions have changed.

The gray scale change produced by the image window translation\(u, v\) is denoted as \(E[u, v]\):

\[
E(u, v) = \sum w(x, y) [I(x+u, y+v) - I(x, y)]^2
\]  

(1)

according to:
\[ I(x + u, y + v) = I(x, y) + Ixu + Iyv + O(u^2, y^2) \]  
\[ \text{available:} \]
\[ E(u, v) = [u \ v] \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} [u \ v] \]

For the local small amount of movement \([u, v]\), the approximation is expressed as:
\[ E(u, v) \cong [u \ v] M [u \ v] \]

Where \(M\) is a \(2 \times 2\) matrix and can be obtained from the derivative of the image.
\[ M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \]

Corner response function is defined as
\[ R = \det(M) - k \times \text{trace}^2(M) \]

Where \(M\) is the upper matrix. Corner response function \(R\) in the region of the corner points is upright, in the region of the boundary is negative, no change in the region of a very small value.

Finally, when \(R\) satisfy "\(R\) thresh greater than a threshold and when \(R\) is a local maximum of a pixel neighborhood of the corresponding point" point of these two conditions is considered to be the corners. If the increase threshold value, reducing the number of the extracted corner point; if lower the threshold, the number of corners increases extraction. In addition, the size of the neighborhood of the local maximum value will also affect the number and tolerance of the extracted corners\[6\].

### 3.2 Harris Corner Extraction

Lucas-Kanade optical flow based on the following three assumptions: ① constant brightness; ② time is continuous or movement is "small movement"; ③ space consistent.

The Lucas-Kanade optical flow method is based on the optical field method and assumes that the light flow in the area centered on the point is constant.

Assuming that the optical flow \((v_x, v_y)\) is a constant in a small window of size \(m \times m\), then one of the following equations can be obtained from pixels \(1,...,n\) \(m \times m\) you can get one of the following equations:
\[
\begin{align*}
I_{x1}V_x+I_{y1}V_y &= -I_{t1} \\
I_{x2}V_x+I_{y2}V_y &= -I_{t2} \\
&\vdots \\
I_{xn}V_x+I_{yn}V_y &= -I_{tn}
\end{align*}
\]

With a minimum root mean square method to solve the system of equations to give
\[
\begin{bmatrix} v_x \\ v_y \end{bmatrix} = \frac{\sum I_{x1}^2 \sum I_{xl} I_{tl} - \sum I_{xl} I_{lu}}{\sum I_{xl} I_{tl} \sum I_{yl}^2 - \sum I_{yl} I_{tl}}^{-1} \sum I_{xl} I_{lu} \\
\sum I_{xl} I_{lu} \sum I_{yl}^2 - \sum I_{yl} I_{tl}
\]

Where \(i = 1, ..., n\).

So that the position of the currently tracked pixel in the next frame can be predicted by the optical flow value.

For most of the 30Hz camera, large and inconsistent movement is ubiquitous. Lucas-Kanade
optical flow is also because of its "small movement" assumptions in the actual tracking effect is not very good. To this end, through the use of image pyramid, it is a good solution to this problem. The process is repeated until the lowest level of the pyramid is reached by calculating the motion estimation result obtained by the optical flow at the highest level of the image pyramid (ie, the lowest resolution layer) as the starting point of the next pyramid. This allows for faster, longer motion tracking.

The image pyramid used in this paper is a 5-layer image pyramid. All of the image pyramids used to construct a fixed image of the source image are used here. The width of the first layer (top layer) is 1/16 of the source image, the second layer is 1/8 of the source image, the image of the third layer is 1/4 of the source image, the image of the fourth layer is the source image 1/2. The fifth layer image is the source image. Thus greatly improving the tracking range so that the effective tracking distance is improved by nearly 16 times \[^{[3,4,5]}\].

3.3 Calculate The Displacement Information
In the calculation of the displacement of the feature points contain many misleading information, so these displacement information must be filtered. According to the characteristics of displacement information, it is found that the correct range of displacement information is very small. Sort the resulting displacement information, and then set a threshold, as long as the difference between the two displacement values is less than this threshold and then add them up and then get an average displacement value, and then according to the maximum number of sets of this group to determine the value of this time should be Which displacement value.

3.4 Filter The Effective Speed Algorithm
Camera frame rate is 30 Hz, the camera's focal length is f. The distance of the camera from the surface is H. The displacement of the feature points between the two frames is known. According to the triangular similarity principle, we can calculate the velocity value of the feature point.

The speed of the calculation to filter, because the camera real-time capture track the target, there is no effective target on the water can track the situation, this time tracking the characteristics of the calculation of the speed information is not accurate, so we should put these inaccurate points to get rid of.

We take the following method to filter the speed.( as shown in Figure 2)
4. Experimental Results

Test environment: open channel width 40cm, water depth 20cm, the camera from the surface of the water 50cm, the frequency of alternating current control the speed of motor pumping and then control the size of open channel flow.

By tracking the floating objects on the water, calculate the displacement of the floating objects between the two frames, and then calculate the speed of floating objects. I use the speed of floating objects to approximate the flow rate of open channel. As shown in Figure 3, these pictures are part of the shooting at the experimental site, and they have a common feature that the camera is scared to float and track it. The red arrow indicates the vector whose feature points are shifted in the first frame to the second frame. For better viewing, I set the length of the arrow to three times the actual length.

In Figure 3, the flow rate from left to right is generally increasing, and we visualize the length of the red arrows from left to right is also variable. The length of the red arrow indicates the size of the feature point displacement value. The greater the displacement of the feature point, the greater the speed of the floating matter.

Figure 3 Float tracked feature points and the displacement vector
Table 1 Point Displacement At Different Flow Rates

| AC frequency control of open channel flow/Hz | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
|--------------------------------------------|----|----|----|----|----|----|----|----|----|
| value                                      | 0.41 | 0.42 | 2.64 | 0.88 | 1.17 | 1.78 | 1.75 | 1.57 | 2.87 |
|                                            | 0.37 | 1.78 | 2.05 | 3.10 | 1.78 | 2.09 | 1.34 | 2.20 | 3.53 |
|                                            | 0.77 | 0.81 | 3.41 | 1.48 | 2.74 | 3.66 | 2.57 | 1.48 | 3.41 |
|                                            | 0.07 | 0.96 | 1.64 | 1.48 | 2.18 | 2.66 | 2.52 | 2.06 | 3.32 |
|                                            | 0.14 | 0.54 | 2.45 | 1.32 | 2.92 | 0.61 | 1.36 | 4.57 | 1.87 |
|                                            | 0.20 | 0.98 | 0.87 | 2.78 | 1.08 | 2.67 | 3.02 | 2.65 | 1.93 |
|                                            | 0.13 | 2.05 | 3.93 | 0.77 | 1.68 | 2.10 | 3.46 | 5.10 | 5.63 |
|                                            | 0.37 | 1.21 | 1.56 | 0.88 | 2.45 | 2.16 | 3.63 | 1.87 | 5.04 |
|                                            | 0.37 | 0.62 | 3.17 | 2.55 | 3.15 | 2.24 | 3.72 | 5.24 | 4.39 |
|                                            | 0.34 | 1.51 | 3.51 | 2.14 | 2.59 | 3.69 | 3.09 | 3.74 | 4.08 |
|                                            | 0.46 | 1.79 | 1.94 | 3.96 | 1.86 | 3.02 | 3.94 | 5.33 | 5.48 |
|                                            | 0.42 | 0.98 | 1.70 | 0.72 | 1.95 | 3.13 | 1.98 | 4.83 | 5.34 |
|                                            | 0.45 | 0.50 | 3.86 | 4.34 | 3.62 | 2.56 | 5.15 | 4.46 | 3.53 |
|                                            | 0.60 | 0.47 | 1.41 | 2.23 | 3.43 | 2.69 | 3.56 | 5.63 | 3.83 |
|                                            | 0.11 | 0.50 | 1.52 | 2.26 | 2.10 | 3.18 | 3.10 | 5.79 | 5.64 |
|                                            | 0.49 | 1.89 | 3.15 | 2.95 | 3.04 | 3.57 | 3.41 | 5.36 | 4.41 |
|                                            | 0.43 | 0.98 | 1.64 | 1.98 | 3.29 | 4.05 | 2.43 | 3.03 | 5.42 |
| and                                       | 6.13 | 17.9 | 40.4 | 35.8 | 41.0 | 45.8 | 50.0 | 64.9 | 69.7 |

The data in Table 1 is the feature point displacement I measured at different flow rates in the laboratory.

In the case of a certain flow rate, there is a large difference in the characteristic point displacement. The analysis shows that when the camera to capture the target when the measured displacement is larger. If the camera does not have floating objects through the measured feature point displacement is very small, otherwise the feature point displacement is very large. This phenomenon is more obvious when the water flow is high.

As the water flow rate increases, we can first measure the displacement of all the feature points at the same water velocity. In Table 1, we can visually see that the displacement of the feature points increases as the velocity of the water increases. But there are also problems, the motor at both ends of the AC frequency is 16Hz when the feature point displacement value is greater than 18Hz when. Possible reason is that the AC frequency at both ends of the motor is 16Hz when the camera under the floating objects in particular, so get the results larger.

5. Conclusion
The PyrLK method is used to track the floating objects, and the ARM processor calculates the velocity of the feature points by calculating the displacement of the feature points. There are some shortcomings in simulating the speed of the flow with the velocity of the feature points. The ARM processor needs to further filter the tracking feature points. In order to improve the accuracy of the measurement results I have to improve the relevant algorithm.
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