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Design and study of water level detection system in Sanmenxia reservoir area of the Yellow River based on image recognition

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Abstract. Since there exist plenty of equipment, such as simple water gauges and monitoring electronic cameras, for the water level measurement of riverways and lakes in the Sanmenxia Reservoir Area of the Yellow River, a water level detection system based on image recognition is designed and developed using existing equipment and its specific process is introduced in this project. Detailed design is conducted for the system using the C++ structured method, and the system function is completed by machine learning and OpenCV technology. The system mainly consists of three parts: water gauge positioning, image preprocessing, and water level data acquisition. Experimental results suggest that the system shows good effect and a high rate for the recognition of water level data; in particular, combined with the characteristic that the water gauge does not move, the system meets the application requirements and has certain practical promotion value.

Keywords. water level measurement, image recognition, C++, machine learning, OpenCV.

Sanmenxia Reservoir Area of the Yellow River, an area where river systems are well-developed and rivers are widely distributed, has seen frequent occurrence of extreme rainstorms in the past two years. In 2021, rainstorms occurred repeatedly in such places as Zhengzhou, Weinan, Sanmenxia, Jiaozuo and Xinxiang, and the level of the surrounding rivers rose rapidly, causing a number of flood disaster accidents. To cope with the sporadic flood disasters, China has set up proprietary water administrators and built high-precision water level measuring instruments in terms of water supervision to facilitate water management and disaster warning. However, manual detection and recording of the water level is laborious, dangerous, error-prone and less time-sensitive, while high-precision water level measuring instruments are of high cost and short service life, pollute the environment and can hardly be widely used.

The frequent occurrence of rainstorms in some areas causes great problems to the safety in flood seasons. Too many telemetry stations, insufficient management personnel and underdeveloped supervisory means may also lead to major blood disaster accidents in flood seasons, resulting in unimaginable consequences. To solve these problems in water management and reduce the stress of administrators at work, the author calculates the water level data from video images by the widely used standard water gauge and electronic camera in real time. In water level detection, there have been some methods relatively available in China. Some scholars have suggested that the number scale lines be recognized based on connected domains, and the number of connected domains of the water gauge scale be obtained by scanning water gauge images [1]. However, the method is only suitable for waters with clear images and significant differences in the water gauge from the surrounding environment, but not for complex water environments. Some scholars have also proposed the method of intelligently recognizing the range of the water gauge by BP artificial neural network [2]. With this method, steps for setting procedures are reduced, but certain requirements are made for the quality and usage environment of water level images. In images of mediocre quality or rainy and hazy weather, the scale of the water gauge is unclear and the digital range is not easily recognized, which reduces the recognition efficiency and accuracy.

With the application of 5G, the informatization degree of water level measurement will be further improved, and more and more dangerous, boring and error-prone work will be replaced by information equipment and technologies. At present, in water level measurement, measuring equipment, such as electronic water gauges, measuring wells and ultrasonic measuring instruments, is used in important waters, and water level detection by image processing instead of huma vision has gradually become a research hotspot.

1. Main steps for design of water level detection system

The author, based on the existing water management conditions, focuses on the detection of water gauges in images of ordinary definition in daytime and the calculation of water level data, and, on the basis of predecessors, eliminates the negative effects caused by the insignificant contrast between water gauges and the surrounding environment, poor image quality and other problems with such methods as fuzzy localization color space screening, E-domain height average calculation of water gauges by machine learning. This not only adapts to the real water environment, but also improves the robustness of the water level detection system.

1.1. Water gauge object recognition by machine learning

Histogram of Oriented Gradient (HOG) features are the descriptors for detecting the object features in computer vision and image processing. According to experiments, the HOG features apply to the detection of the water gauge target in the image. The process of feature calculation is as follows:

(1) Windows form: with a size of 64*128, the top cell of feature calculation in the Windows form.

(2) Block: with a size of 16*16, and a sliding step length of 8*8, Block slides in the Windows form.
(3) Cell: with a size of 8*8, Cells are arranged in parallel in the Block.
(4) Bin: a total of 360°, 40° for each bin, Bins are in the Cell, a Cell is divided into 9 bins.
(5) Calculation: 4*9*((64-16)/8+1)*((128-16)/8+1) = 3 780 dimensions

The support vector machine (SVM) is a dichotomous model, a supervised learning model, which can be used to learn the high-dimension feature vector by category. In this paper, it is mainly used to recognize water gauges [3].

The training results of Hog and SVM can be used repeatedly. Therefore, the training results that meet the standards can be saved so that the results obtained from the first training can be permanently used, thus greatly reducing the computation. However, in practical use, the results of the first training often cannot reach the recognization standard, and the second strengthened training is conducted and the number of results are controlled within 10, so as to achieve the expected results.

1.2. Water gauge image preprocessing

Color space screening: any color in the RGB (Red, Green, Blue) color space can be composed by mixing different components of red, green and blue. The RGB scape can be compared to a cube, from which the specific color range can be hardly separated. Compared with the RGB space, colors can be expressed very intuitively in the HSV (Hue, Saturation, Value) space, and the HSV space can be compared to a cone, from which the regular color range can be easily separated. The range can be obtained by comparing it with the HSV color space table.

1) The HSV range of red, H (0-10,156-180), S (43-255), V (46-255).
2) The HSV range of blue, H (100-124), S (43-255), V (46-255).

Binarization by OTSU method: the OTSU method is a global binarization algorithm, which can be used to select the threshold scientifically and automatically and separate the water gauges from the background to the maximum extent. The threshold at this time can be considered the segmentation threshold of images.

Water gauge tilt correction: the straight line in the water gauge image is detected by Houghline, and the tile angle of the line which has the highest tile angle frequency and is realistic is set as the title angle of the water gauge. Then the water gauge image is rotated to obtain the vertical water gauge image [4].

1.3. Water gauge image cutting and water level calculation

Water gauge image cutting: calculation by image histogram is less costly, and image retrieval and image classification based on the color space can be used [5]. Binary images of water gauges can be obtained after color screening, and the water gauges can be accurately positioned from up and down, left and right intuitively and conveniently in the binary image histogram, so as to improve the recognition speed and accuracy.

Water level calculation: in an accurate water gauge image, the water gauge is divided into the left and right parts with the median line as the baseline, and each E is the same. Thus, the vague scale "E", if any, can be obtained according to the average of the height of E.

Due to the different ranges of +standard water gauges, the water level data cannot be obtained according to the scale only, and the numbers become an auxiliary tool, even if they cannot be read. The water level data can also be obtained by the range and the scale "E" on the left and right.

2. Implementation of water level detection system

2.1. Water gauge positioning

Water gauge positioning can be divided into four submodules, namely the Hog feature extraction, SVM supervised training, difficult sample relearning, and image water gauge positioning. The image to be detected is shown in Figure 1.

HOG, Histogram of Oriented Gradient, is a descriptor of features used in computer vision and image processing [6]. By automatically cutting the script, an image with a size ratio of 1:2 is extracted from the image to be detected, and is equally scaled to sample images (64*128) with and without water gauges; a total of 519 positive samples are obtained, as shown in Figure 2, and a total of 7 492 negative samples are obtained, as shown in Figure 3, for extraction of Hog features.

Figure 1. Image to be detected (720*1 280)

Figure 2. Positive sample image

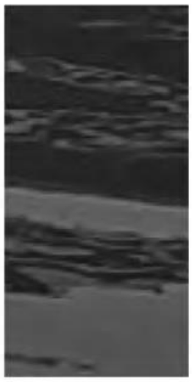

Figure 3. Negative sample image

SVM supervised training: this can be used as a classifier to distinguish water gauges from non-water gauges. The process of difficult sample relearning is repeated saved and trained to obtain the training model with the recognition results within the acceptable range, as shown in Figure 4. In this figure, the number of recognition results is controlled within 10, which reduces the subsequent computation.

Figure 4. Water gauge detection result

There is a certain amount of misrecognition in the water gauge image results obtained by Hog + SVM, and thus the results need to be processed in the next step. The water gauge images have some apriori features that can be easily identified. Color detection is conducted on the recognition results based on the HSV space, and the color distribution of water gauges is compared, so as to screen the boxes where water gauges are from the results. The recognition process is shown in Figure 5, and the results are shown in Figure 6.

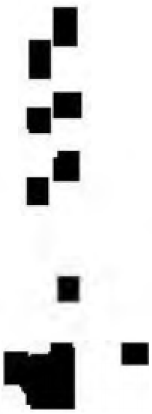

Figure 5. Water gauge HSV space diagram

Figure 6. Results of water gauge positioning

2.2. Image preprocessing and water level calculation

Accurate water gauge cutting: the Canny edge detection can effectively detect the edge of the water gauge, as shown in Fig. 7. The edge image obtained is detected by Houghline, and the results obtained are shown in Fig. 8. Two parallel lines are found within the angle of about 90°±45° according to the angle of the control line, and the water gauge tilt is corrected by rotating images to obtain the vertical water gauge image.

Pixels in the binary image column containing straight lines after tilt correction are counted based on the color space, and the boundary of the water gauges is screened to obtain the accurate water gauge image, as shown in Figure 9.

Figure 7. Canny edge detection

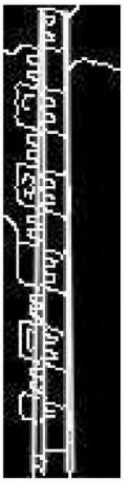

Figure 8. HoughLine tile correction

Figure 9. Precise gauge

Water gauge image binarization: the water gauge can be divided into the left and right parts, each occupying 50%; since the adhesion at the "E" domain may cause troubles to image processing, the domain is cut to leave 40% on both sides to separate the water gauge at the junction of the "E" domain to facilitate the subsequent calculation of the water level data, and the global threshold T is automatically selected by counting the histogram features of the whole image by OTSU, so as to obtain the binary images of the water gauge, as shown in Figure 10 and Figure 11.

Figure 10. Left side of the water gauge

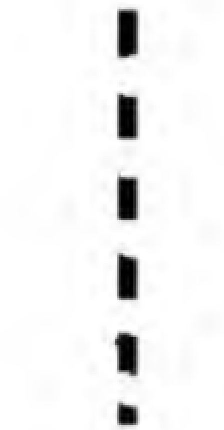

Figure 11. Right side of the water gauge

The content of E domains counted includes the number and height. According to the average height of the "E" domain, the length of the "E" domain touching the water surface is calculated. The current water level is calculated according to the total range of the water gauge, and the number and length of the "E" domains on both sides, as shown in Fig. 12.

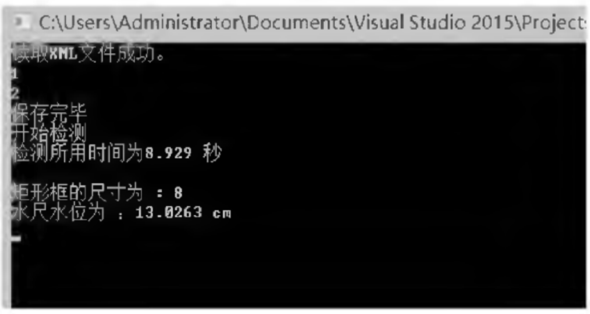

Figure 12. Depth of current water level

3. Test results and analysis

The water level detection system test based on image processing is completed by black-box test, which mainly focuses on performance errors, omission in the target detection of water gauge, errors in the acquisition of accurate targets, output errors and so on. The test platform adopted is Windows 7 (64-bit) Chinese version, with 1 CPU 2G memory, CPU AMD EPYCTM Rome (2.6 GHz).

Table 1. Table of test results

Test item	Test case	Expected result	Test result
Number of water gauge detection results	Keyword: number of results	The detection results are not less than 10	Pass
Whether water gauges are detected	Keyword: water gauge detection	Subimages containing water gauges are detected	Recognition rate 96%
Whether the detection time is too long	Keyword: detection time	The detection time is less than 10 s	9.35 s in average
Whether water gauge images can be screened	Keyword: water gauge screening	The only water gauge can be screened	Pass
Whether water gauges can be accurately cut	Keyword: accurate cutting	Water gauges can be accurately cut	Pass
Whether the gradient of the corrected water gauge is too large	Keyword: gradient	The gradient is 90° with an error of no more than 5° after detection	Pass
Whether water level data can be accurately calculated	Keyword: accurate water level data	Length error of the detected water gauge is no more than 1 cm	Recognition rate 94%

To measure the performance of the water level detection algorithm, we randomly intercept a water level information image at an interval of 30 s, and select several video clips of different dates based on the dictionary for experimental simulation, calculate the water level value at each row, and compare the calculation result with the manual observation data. The effect is shown in Figure 13.

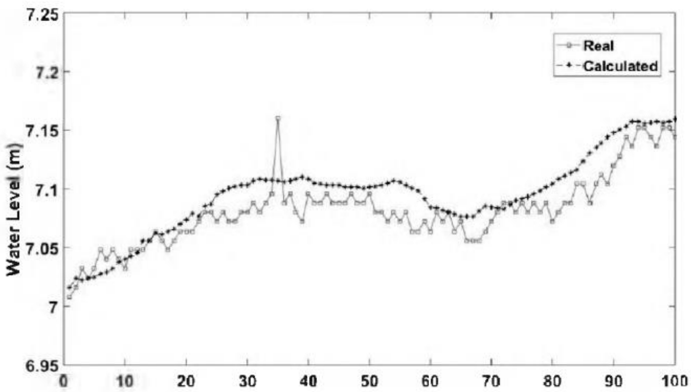

Figure 13. Comparison between manual detection data and video monitoring data

The conclusion reached from the tests shows that after plenty of sample training machine learning, the Hog + SVM training results have a high recognition rate for water gauges in the input image, and the recognition time is generally less than 10 s, which meets the performance requirements for data acquisition. Finally, the system shows good effect and a high rate for the recognition of water level data; in particular, combined with the characteristic that the water gauge does not move, the system meets the application requirements.

4. Conclusion

After a reasonable design process, based on the actual water situation, and repeatedly considering the elimination of noise, reflection and staining, this system ensures the effect of the cutting of the water gauge. Calculating the average height of the E domain can not only improve the calculation speed, but also provide good adaptive capacity in the cases with low definition of the image and poor weather conditions, providing stable and reliable water level data for water level measurement. Meanwhile, this system also has a misrecognition rate, which is related to training samples and the direction angle of the image.

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