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METHOD OF THE HORIZON DETECTION FROM ELECTRO-OPTICAL SENSORS UNDER MARITIME ENVIRONMENT

A new method is presented to detect the sea sky line. In the first step, the original image is transformed into grayscale image and the sea-sky-line region is located by using the textural features gray-level co-occurrence matrix based on texture feature. In the second step, the adaptive segmentation thresholds are obtained by the OTSU algorithm, which produces a set of sea sky line candidate points. Finally, a simple clustering method is adopted to select appropriate points and transform them by straight line fitting. The results of experiments established on real-world sea-sky images demonstrate the effectiveness and robustness of the proposed approach.

Keywords: *horizon detection, textural feature, maritime image, Hough transforms.*

Introduction

In the past few years, large amounts of new arithmetic for sea-sky-line detection have been proposed. In [1], Huang et al. put forward the Laplace-Gauss algorithm for removing noise and detecting edges. Then, same as GAO et al. did in [2], they applied the OTSU algorithm to threshold the images into binary images. Lastly, the sea-sky line was extracted with Hough transform as the longest straight line. Jiang et al. [3] provided a detection method based on histogram analysis, which removed irrespective pixels but lead to the loss of some important information of the line. Lu et al. [4] designed a modified edge detection algorithm according to the traditional Canny algorithm. In [5], a gradient method was presented that extracted the sea-sky line by peak values. However, traditional OTSU and Canny algorithm are vulnerable for denoising because they ignore the local characteristics of the background images. The Hough transformation and gradient are influenced easily by the complex background with clouds and ocean waves. For histogram analysis, the key part of this approach is whether the ocean waves or obstructions such as ships in the sea-sky-line would change the gray distribution of sea-sky images. Yang et al. [6] pointed out that variance weight information entropy could evidently increase the signal-to-noise ratio of the preprocessed image and they used the gradient for sea-sky-line fitting. While the straight line was inclined, the way still cannot solve it. Moreover, the burden of computation is overweight to satisfy practical requirements.

Overview of methods for detecting horizon

As the marine vehicles in long range always appear near the horizon, the target search area can be limited to the sea sky region [10–15]. It can not only greatly reduce the computational cost for searching targets, but also decrease the disturbance brought by illumination changes from sea waves or cloud clutters. Due to the payload constraints, UAV (Unmanned Aerial Vehicle) and MAV (Micro Air Vehicle) prefers video camera which is lighter, smaller and requires less power. Besides, image contains rich information with more details. The pitch and bank attitude of UAV and MAV could be evaluated from the orientation and position of horizon in video images. The horizon is also used to make image registration for subsequent target tracking [10; 14]. There exist several mainstream algorithms for horizon detection and evaluation such as: color-based statistical model [10; 13; 15], edge phase encoding [12], pixels classification [16], linear feature [10; 12–14], color intensity and gradient [12; 14; 16], textural feature [17], region-growing [19] and other physical characteristics near the horizon [14; 17; 19]. In general, the hybrid algorithm performs a higher accuracy rate but it also brings computational burden.

The statement of the research problem

As the spatial relationship is considered to be a function of distance between two pixels, the textural features could be extracted from a visible image using gray-level co-occurrence matrix (GLCM). In order to construct the GLCM, the original RGB image is transformed into gray-level image.

First, there are some samples with M x N resolution cells in total. The RGB image I, which is one of the samples, is transformed into gray image I_{gray}, which is described as:

$$I_{gray} = f(x, y)_{M\times N}, \quad (1)$$

where f(x,y) is represented as the gray level of pixel. As for a RGB image, there is a value of one color channel in the sky region which is close to the clouds region's but far from the region of sea. A new gray-scale transformation formula is adapted to minimize the contrast between clouds and sky with less effect on the classification of sea and sky. Moreover, the value of f(x,y) can be computed by the following equation:

$$f(x,y)=\begin{cases} R(x,y) \text{ if } R>G, R>B; \\ G(x,y) \text{ else if } G>R, G>B; \\ B(x,y) \text{ otherwise,} \end{cases} \quad (2)$$

where R(x,y), G(x,y), B(x,y) represent the pixel's red, green, blue channel value, while R,G,B respectively represent the summation of three distinction image's color channel of red, green, blue.

Based on *YUV* model, the traditional method to compute the intensity component of the color image is:

$$f(x,y)=0.299\times R(x,y)+ \\ +0.587\times G(x,y)+0.114\times B(x,y). \quad (2)$$

Fig. 1 shows the difference between two gray images using formula (2) and formula (3) respectively. From the results, it can be seen that in the produced gray image by using the above presented method, the difference between the sky and cloud is smaller. This is helpful for the separation of sea and cloud.

a – Original image b – Proposed method c – Traditional method

Fig. 1. The obtained gray images using different formulas

The co-occurrence matrix[7] reflects the joint numbers of combination of the gray level i and j along direction θ , with distance d. The GLCM is defined as follows:

$$P(i,j,d,\theta)=\#\left\{ \begin{matrix} \left|\left[(x,y),(x+m,y+n)\right]\right| f(x,y)= \\ =i, f(x+m,y+n)=j \end{matrix} \right\}, \quad (4)$$

where $m=d\cos\theta$, $n=d\sin\theta$, (x,y) and (x+m, y+n) are points in image, # represents the number of elements in this set; *d* is the distance cell, θ denotes the direction to construct the regional co-occurrence matrix. To reduce the computation, values were rescaled from 8 bit (256×256 matrix with 65536 cells) to 4 bit (16×16 matrix with cells). Furthermore, if the gray level number is reduced, the statistical validity is greatly reduced. The rescaled formula is shown as:

$$f(i,j)=f(i,j)/16. \quad (5)$$

A normalized matrix is defined as:

$$P(i,j,d,\theta)=P(i,j,d,\theta)/R, \quad (6)$$

where R is the total number of pixel pairs.

The textural features are extracted from the regional co-occurrence matrix which can make a description of the textural features effectively. The contrast, as an evaluated approach of textural features, is calculated as:

$$C=\sum_i \sum_j (i-j)^2 P(i,j,d,\theta). \quad (7)$$

Since the computational cost of whole GLCM is very large, the angle of 45° from four angles $(\theta=0^\circ,45^\circ,90^\circ,135^\circ)$ was used in computing GLCM. And we found that the contrast measurement has high discriminant validity. Thus, it is regarded as the evaluated criterion.

The gray image I_{gray} is divided into k equal subregions of size $M\times n$ along vertical direction, where $n=N/k$, as described in fig. 2.

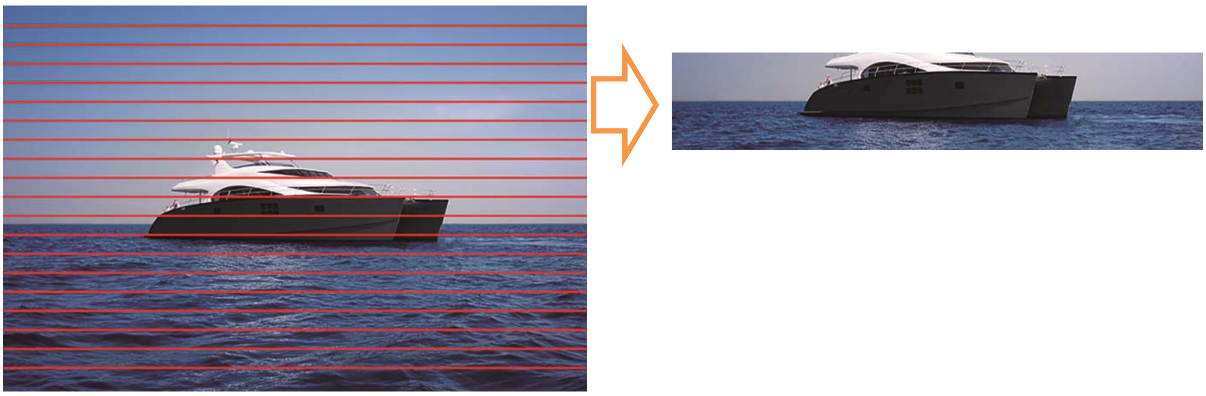

Fig. 2. The location of sea-sky region

Then the textural feature value of each sub-region is calculated using the above mentioned contrast calculation method. The whole gray image can be described by a column vector $F = (f_1, f_2, \ldots, f_k)^T$, where f_i represents the i-th region's textural feature value. The variance ratio is defined as:

$$g_i = \left| \frac{f_i - f_{i-1}}{f_{i-1}} \right| \tag{8}$$

where $2 \le i \le k$ and g_i denotes the variance ratio of textural features between the *i-th* sub-region and *i-1th* sub-region. The gradient vector of the column vector distribution is $G = (g_1, g_2, \ldots, g_{k-1})^T$. In this paper, k=20. Supposing g_{imax} is the maximum of G, the sea-sky-line region could be composed of 5 sub-regions: i_{max}–2th, i_{max}–1th, i_{max}th, i_{max}+1th, i_{max}+2th. So, 25% of the image was located to ensure that the original sea-sky-line is in the extracted region, as shown in fig. 3.

Preprocess of sea sky line point detection

A set of candidate points of sea-sky-line are obtained by using OTSU algorithm. The threshold T of the set segments the image into two classes C_1 and C_2, and the average values of them are μ_1 and μ_2, respectively. And their probability are ω_1 and ω_2. The class variance is defined:

$$\sigma_B^2 = \omega_1 \omega_2 (\mu_1 - \mu_2)^2 . \tag{9}$$

We can get the threshold T when σ_B^2 reaches its maximum value.

At first, we setup a search window with $s \times t$ pixels, step = t and move from left to right along the horizontal direction, where E represents the moving times of the window, $s = M / E$, step=s, $t = N / 4$, as shown in fig. 3.

Fig. 3. The search areas

Secondly, the threshold T_i is calculated in the window, where $x_i = \frac{step+1}{2} + (i-1) \times step, gray(x_i, y_i) = T_i$. Then the window moves continuously until i=E. In this paper, we set E=20. Finally, a set of candidate points were obtained as $(x_1, y_1), (x_2, y_2), \ldots, (x_E, y_E)$ for sea-sky-line extraction. As shown in fig. 4, the red points are sea-sky-line candidate points.

Fig. 4. The obtained sea-sky-line candidate points

Sea sky line detection

Because the ships or ocean waves in the sea-sky-line region may cause the discontinuity of the line, there are some false candidates in the acquired sea-sky-line candidate point set, as shown in fig. 5. Therefore, in order to reduce the side effects, a simple clustering algorithm is designed with a little cost to computation cost but an optimal effect. For a visible sea-sky image with $M \times N$ pixels, the clustering algorithm is illustrated in several steps.

Step 1: Set $diff = scale \times N$, where experiments have shown that scale=0.02 offers excellent performances. The obtained candidate points $\{(x_1, x_2), (x_2, y_2), \ldots, (x_E, y_E)\}$ are dived into E initial classes $\{C_1, C_2, \ldots, C_{max}\}$.

Step 2: For j=1,2,3,…,E, the upper limit of the confidence interval of (x_j, y_j) is y_j+diff while the lower limit of the confidence interval is y_j-diff.

Step 3: For i=1,2,3,…,E, if $y_i - diff \le y_i$ and $y_i + diff \ge y_i$, count(C_j)=count(C_j)+1, add y_i into C_j, where count() was used to count the numbers of elements in the set.

Step 4: Calculate the numbers of C_j and go to step 2.

Step 5: If the maximum value is (count(C_{max})), the elements in C_{max} is what we need.

Fig. 5 shows the final selected points by using the proposed clustering method. They are really in the sea-sky-line.

Fig. 5. The final selected sea-sky-line points

Suppose that the coordinates of the appropriate points in C_{max} are $\{(x_1, x_2), (x_2, y_2), \ldots, (x_n, y_n)\}$. Assuming the sea-sky-line is y=ax+b, where a is parameter of gradient and b is a parameter of intercept. And a,b could be computed as:

$$a = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2},$$

$$b = \frac{n\sum_{i=1}^{n} x_i y_i \sum_{i=1}^{n} x_i - \sum_{i=1}^{n} y_i \sum_{i=1}^{n} x_i^2}{\left(\sum_{i=1}^{n} x_i\right)^2 - n\sum_{i=1}^{n} x_i^2}.$$

Based on the above linear fitting method, the final sea-sky-line was detected which is shown in fig. 6.

Fig. 6. The detected sea-sky-line

Experiment and software test

Tabl. I gives the sea sky line detection precision results of the proposed approach in this paper on the test set. The manually labeled sea sky lines are used as the ground truth to calculate these precision data. From the table it can be seen that on all of the four categories, our approach achieves much better results. The average detection precision of our method is 0.93.

The software is developed by Microsoft Visual studio 2010; the development language is Visual C++; library function is openCV 2.4.6.

Table I

The sea-sky-line detection results on the test set

Categories	The proposed approach
cloud	0.90
wave	0.94
light	0.90
normal	0.96
Average precision	0.93

Fig. 7. The main userinterface

Fig. 8. The result of detection

Conclusion

Sea-sky-line detection in complicated environment is a challenge task. It is also an important step in long-range moving objects detection for the security of sea ports, which can largely reduce the computation cost. A new detection approach is proposed, which consists of a new grayscale scheme, contrast calculation based on the textural feature, sea-sky-line candidate region extraction, sea-sky-line candidate point detection, and linear fitting. The experimental results indicate that the proposed method can detect the sea-sky-line accurately under the complicated backgrounds with many clouds or many ocean waves or much light or some ships.

References

1. Huang, Y., Fan, N. and Li, J. (2008), A method of ship position based on sea-sky-line detection, *Journal of Projectiles, Rockets, Missiles and Guidance*, No. 28(5), pp. 286-288.

2. Gao, Y., Hu, S., Miao, Z. and Xu, S. (2007), Research on seaskyline detection in complex sea background, *the Second IEEE International Conference on Innovative Computing, Information and Control(ICICIC)*, pp. 452-452.

3. Jiang, C., Jiang, H., Zhang, C. and Wang, J. (2010), A new method of sea-sky-line detection, *the Third IEEE International Symposium on Intelligent Information Technology and Security Informatics(IITSI)*, pp. 740-743.

4. Lu, J., Dong, Y., Yuan, X. and Lu, F. (2006), An algorithm for locating sky-sea line, *IEEE International Conference on Automation Science and Engineering (CASE)*, pp. 615-619.

5. Liu, S., Zhou, X. and Wang, C. (2006), Robust sea-sky-line detection algorithm under complicated sea-sky background, *Opto-Electronic Engineering*, Vol. 33(8), pp. 5-10.

6. Yang, L., Zhou, Y., Yang, J. and Chen, L. (2006), Variance WIE based infrared images processing, *Electronics Letters*, Vol. 42(15), pp. 857 -859.

7. Haralick, R. (1979), Statistical and structural approaches to texture, *Proceedings of the IEEE*, Vol. 67(5), pp. 786-804.

8. Otsu, N. (1979), A threshold selection method from gray-level histograms, *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 9, No. 1, pp. 62-66.

9. Carr, J. and de Miranda, F. (1998), The semivariogram in comparison to the co-occurrence matrix for classification of image texture, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 36(6), pp. 1945-1952.

10. Fefilatyev, S., Goldgof, D., Shreve, M. and Lembke, C. (2012), Detection and tracking of ships in open sea with rapidly moving buoy-mounted camera system, *Ocean Eng*., 54, pp. 1-12.

11. Sun, X.W., Xu, Q.S., Cai, Y., Shi, M. and Li, S. (2017), Sea Sky Line Detection Based on Edge Phase Encoding in Complicated Background, *Acta Optica Sinica*, No. 37(11), pp. 1110002-1-1110002-9.

12. Prasad, D.K., Rajan, D., Prasath, C.K., Rachmawati, L., Rajabally, E. and Quek, C. (2016), MSCM-LiFe: Multi-scale Cross Modal Linear Feature for Horizon Detection in Maritime Images, *TENCON*, pp. 1366-1370.

13. Gershikov, E., Libe, T. and Kosolapov, S. (2013), Horizon Line Detection in Marine Images: Which Method to Choose? *IJAIS*, No. 6(1&2), pp. 79-88.

14. Fefilatyev, S., Goldgof, D. and Lembke, C. (2010), Tracking Ships from Fast Moving Camera through Image Registration, *ICPR*, pp. 3500-3503.

15. Lipschutz, I., Gershikov, E. and Milgrom, B. (2013), New Methods for Horizon Line Detection in Infrared and Visible Sea Images, *IJCER*, No. 3(3), pp. 226-233.

16. Moore, R.J.D., Thurrowgood, S., Bland, D., Soccol, D. and Srinivasan, M.V. (2011), A Fast and Adaptive Method for Estimating UAV Attitude from the Visual Horizon, *IEEE/RSJ*, pp. 4935-4940.

17. Tang, D., Sun, G., Wang, D.H., Niu, Z.D. and Chen, Z.P. (2013), Research on Infrared Ship Detection Method in Sea-sky Background, *ISPDI*, pp. 89072H-1-89072H-10.

18. Singhal, A. and Luo, J.B. (2003), Hybrid Approach to Classifying Sky Regions in Natural Images, *Image and Video Communication and Processing*, pp. 562-572.

19. Liu, C.J., Zhang, Y., Tan, K.K. and Yang, H.Y. (2014), Sensor Fusion Method for Horizon Detection From an Aircraft in Low Visibility Conditions, *IEEE T INSTRUM MEAS*, No. 63(3), pp. 620-627.

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МЕТОД ВИЯВЛЕННЯ ЛІНІЇ МОРСЬКОГО ГОРИЗОНТУ НА ЗОБРАЖЕННЯХ З ЕЛЕКТРО-ОПТИЧНИХ ДАТЧИКІВ

С.П. Євсеєв, О.В. Шматко, Лян Дун, Є.В. Бабенко

У статті обґрунтована актуальність досліджень, пов'язаних з виявленням лінії морського горизонту в складних середовищах. Широке використання систем відеоспостереження є важливим кроком у виявленні рухомих надводних об'єктів на великій відстані, що дозволить підвищити безпеку морських портів. Проведено аналіз існуючих методів виявлення лінії горизонту. Запропоновано новий метод виявлення лінії морського горизонту, що дозволяє досягти поставленої мети – зменшення обчислювальних витрат на пошук цілей, та зменшення шуму від перешкоди, які викликані змінами освітлення від морських хвиль або хмар. Запропонований метод складається з нової схеми градацій сірих відтінків, розрахунку контрасту на основі текстурної ознаки, екстракції області кандидатів морської лінії горизонту, виявлення точки кандидата і лінійної підгонки. На першому етапі вихідне зображення перетворюється в зображення у відтінках сірого. На другому етапі порогові значення адаптивної сегментації отримуються за допомогою алгоритму, який створює набір точок кандидатів на морське небо. Нарешті, використовується простий метод кластеризації для вибору відповідних точок і їх перетворення. Експериментальні результати показують, що пропонований метод може точно визначити лінію морського горизонту в складних умовах хмарності або океанських хвиль, за наявності надводних об'єктів. Запропонований метод може використовуватися для відстеження морських цілей безпілотними літальними апаратами.

Ключові слова: *виявлення горизонту, текстурна особливість, морське зображення, перетворення Хафа.*

МЕТОДЫ ВЫЯВЛЕНИЯ ЛИНИИ МОРСКОГО ГОРИЗОНТА НА ИЗОБРАЖЕНИИ С ЭЛЕКТРО-ОПТИЧЕСКИХ ДАТЧИКОВ

С.П. Евсеев, А. В. Шматко, Лян Дун, Е.В. Бабенко

В статье обоснована актуальность исследований связанных с выявлением линии морского горизонта в сложных средах. Широкое использование систем видеонаблюдения является важным шагом в выявлении подвижных надводных объектов на большом расстоянии, что позволяет повысить безопасность морских портов. Проведен анализ существующих методов обнаружения линии горизонта. Предложен новый метод обнаружения линии морского горизонта, который позволяет достичь поставленной цели – уменьшение вычислительных затрат на поиск целей, и уменьшение помех, вызванных изменениями освещения от морских волн или облаков. Предложенный метод состоит из новой схемы градаций серых оттенков, расчета контраста на основе текстурных признаков, экстракции области кандидатов морской линии горизонта, выявление точки кандидата и линейной подгонки. На первом этапе исходное изображение превращается в изображение в оттенках серого. На втором этапе пороговые значения адаптивной сегментации получаются при помощи алгоритма, который создает набор точек кандидатов на морское небо. Наконец, используется простой метод кластеризации для выбора соответствующих точек и их преобразования. Экспериментальные результаты показывают, что предлагаемый метод может точно определить линию морского горизонта в сложных условиях облачности или океанских волн, при наличии надводных объектов. Предложенный метод может использоваться для отслеживания морских целей беспилотными летательными аппаратами.

Ключевые слова: *выявление горизонта, текстурная особенность, морское изображение, преобразование Хафа.*