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Visual Enhancement of Aerial Flight in High Plateau Low Visibility Conditions

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ABSTRACT

A method for automatic detection of airport runways in low visibility, forward and downward looking aerial airport images is proposed. Firstly, the recursive Otsu segmentation method is used to extract the main contour of the airport from the complex background; then the morphological filtering is performed by using the morphology-based open and swell operations, the open operation is used to filter out the isolated noise points and the swell operation is used to connect the segmented airport components into a complete whole; finally, the morphological filtered image is subjected to the region growth to localize the main runway of the airport. Finally, the morphology filtered image is processed to localize the main airport runway by its region growth. It is proved that this method can quickly and accurately detect and localize the main and auxiliary runways of airports in low visibility and forward and downward looking aerial images of airports.

KEYWORDS

Low visibility; Otsu Split; Regional growth; Morphological filtering

1. INTRODUCTION

1.1. Characterization of the Highland Environment and Its Impact on Vision

High plateau environments, which refer to areas of high altitude and special climatic conditions, are characterized by low pressure, low oxygen, a dry and cold climate, high wind speeds, and significantly increased solar and ultraviolet radiation exposure. In such environments, the human body faces multiple challenges, including the impact on visual function.

First of all, the climatic conditions of high plateau environments have a non-negligible impact on human vision. Intense sunlight and high intensity of ultraviolet radiation in the plateau region tend to cause visual damage. On the one hand, intense sunlight and ultraviolet rays may lead to damage to the retina, which in turn may lead to problems such as reduced visual acuity and narrowing of the field of vision. On the other hand, the dry climate of the plateau region may also lead to dryness and discomfort in the eyes, affecting visual comfort [1].

Secondly, the oxygen content in the highland environment is low, and the human body will feel insufficient oxygen when breathing, which will cause a series of plateau reactions, including headache, nausea, vomiting, etc. This lack of oxygen will also affect visual function. This hypoxia also has a significant impact on visual function. Hypoxia leads to impaired retinal rod cell function, resulting in decreased light sensitivity and dark adaptation. As the degree of hypoxia worsens, visual contrast sensitivity decreases, central vision may begin to diminish, the visual field shrinks, and problems such as impaired color vision may occur [2].

In addition, living in a highland hypoxic environment for a long period of time may also lead to brain function damage, which also has an indirect effect on visual function. Because visual information needs to be processed and analyzed by the brain, damage to brain function may lead to a decrease in the ability to process visual information, which in turn affects the overall visual performance [3].

To summarize, the characteristics of the high altitude environment have a multifaceted impact on human visual function.

1.2. Low Visibility Challenges to Visual Perception

The low visibility environment at high altitude poses a great challenge to pilots' visual perception. In this environment, pilots not only face the physiological effects of low oxygen and dryness caused by high altitude, but also have to deal with the visual obstacles caused by low visibility, which increases the complexity and risk of flight operations.

First, low visibility significantly reduces the visual range of pilots, making distant objects and obstacles blurred or even difficult to recognize. This increases the difficulty of pilots in navigating, localizing, and avoiding obstacles, requiring them to be more alert and responsive.

Second, low visibility conditions may lead to deviations in pilots' perception of flight instruments and surroundings [4]. In low light or poor visibility conditions, pilots may have difficulty in accurately reading instrument data and may misjudge critical information such as flight altitude, speed and direction. Such perceptual deviations may cause pilots to misoperate, thus jeopardizing flight safety.

In addition, weather changes in high plateau areas are often more drastic, and low visibility conditions may be accompanied by severe weather conditions such as strong winds, rain and snow. This complex meteorological environment further increases the visual perception difficulty of pilots, requiring them to have higher flight skills and coping ability.

In order to cope with the challenges of visual perception in a high plateau low visibility environment, pilots need to take a series of measures [5]. First, they should receive specialized visual training to improve their visual adaptability and perception accuracy under low visibility conditions. Second, pilots should be proficient in the use of flight instruments to ensure that key information can be read accurately in poor visibility conditions. In addition, pilots should pay attention to weather forecasts and meteorological changes, and make flight plans and emergency preparations in advance to cope with possible low visibility conditions.

In summary, the high plateau low visibility environment poses a serious challenge to pilots' visual perception. Pilots need to cope with these challenges through specialized training and skill enhancement to ensure flight safety.

1.3. The Need and Importance of Visual Augmentation Technology

The need and importance of visual enhancement technology is reflected in several aspects, especially in the high plateau environment, its necessity is more prominent.

First of all, from the perspective of demand, high plateau environment is often accompanied by low visibility, low oxygen, strong ultraviolet rays and other unfavorable factors, which seriously affect the human visual perception ability. Visual enhancement technology can effectively improve the clarity and recognition of visual information through a series of technical means, such as image enhancement, contrast adjustment, color correction, etc., to help people better adapt to and cope with the complex and changing visual environment. Especially in the military, aviation, aerospace and other fields, visual enhancement technology is an indispensable key technology, which is vital to ensure the successful completion of the mission and the safety of personnel [6].

Secondly, from the point of view of importance, visual enhancement technology not only improves the perception quality of visual information, but also expands the visual range and ability of human beings. Enhancing and processing visual information through technical means can enable people to observe longer distances, smaller details, and richer color information, thus enhancing their perception and cognition of the environment. In addition, visual enhancement technology can also help people better cope with night, fog, sandstorms and other adverse weather conditions, and improve the ability to survive and combat effectiveness in complex environments.

Specifically, the importance of visual enhancement technology [7] is also reflected in the following aspects:

Improve work efficiency: through visual enhancement technology, people can acquire and process visual information faster, reducing the possibility of misjudgment and mistakes, thus improving work efficiency and accuracy.

Ensure safety: In the fields of transportation, medical treatment and rescue, visual enhancement technology can help people better identify and respond to potential dangers and threats, and ensure the safety of personnel and equipment.

Expanding application fields: With the continuous progress and innovation of technology, visual enhancement technology can be applied to more fields and scenarios, such as virtual reality, augmented reality [8], intelligent monitoring, etc., bringing more convenience and possibilities to people's life and work.

To summarize, the demand and importance of visual enhancement technology is self-evident. In the future, with the continuous development of technology and the expansion of application fields, visual enhancement technology will play an important role in more fields and make greater contributions to the progress and development of human society.

2. OVERVIEW OF VISUAL ENHANCEMENT TECHNOLOGIES

2.1. Definition and Classification Of Visual Enhancement Technology

Visual enhancement techniques, in simple terms, are processing techniques that highlight pixels or image information with the aim of improving the clarity, contrast, or recognition of visual information, thereby enhancing visual perception. Visual enhancement techniques can be categorized in a variety of ways, depending on the object that is desired to be enhanced and the task to which it is applied [9].

In terms of the object to be enhanced, visual enhancement techniques can be categorized into enhancement of individual pixels, enhancement of passages, and enhancement of trends. This categorization is mainly based on different layers and objectives in image processing.

From the perspective of the information or task being enhanced, visual enhancement techniques can be further categorized into image-driven enhancement tasks and data-driven enhancement tasks [10]. Image-driven enhancement tasks are those where the enhanced object data has been presented in the visualization by means of color coding and so on, but the visual effect is not obvious enough and needs to be strengthened by technical means to enhance its visual impact. The data-driven enhancement task means that the enhanced object data are not presented in the visualization [11], but the user is concerned about the external information outside the visualization, and wants to represent the external information through visual enhancement.

In addition, visual enhancement techniques can be subdivided into various types according to the specific technical means used, including but not limited to light wheels, colors, deformations, shadow lines, shapes and symbols. Each of these techniques has its own characteristics and can be selected and combined according to the actual needs and application scenarios.

Overall, visual enhancement technology is a broad and diverse field, covering a variety of categorization methods and specific technical means [12]. With the continuous progress and innovation of technology, visual enhancement technology will play an important role in more fields, providing people with clearer and more accurate visual information and improving the effect of visual perception.

2.2. Domestic and International Research Status

2.2.1. Current Status of Foreign Research

Foreign research in this field began earlier, mainly studied the two technology systems of LiDAR and video. Lidar technology, Germany thyssenkrupp company created a visual berth guidance system, in the 1970s launched the first generation of visual guidance system, this system is based on pneumatic sensors; and in the 1990s launched the first laser scanning guidance system. Later, the Swedish company safegate developed a more mature berth guidance technology. Video technology, the United States of America's Honeywell and Germany's Siemens developed the berth guidance system has also been part of the application in the airport [13]. However, due to the video sensor itself has certain defects, Honeywell is also studying the combination of laser scanning technology to upgrade technology.

For the airport's remote hosting technology, foreign countries now have relatively complete solutions. Japan in 1974 used relevant video processing means to provide flight information services to remote airports; Europe in the early 21st century for the first time put forward the concept of remote hosting of airports, and was included in the Single European Sky Air Traffic Management Research Program (SESAR); in April 2015, the Swedish Saab Group and the Swedish air traffic service provider LFV carried out a test at the Enshelzvik Airport in Sweden, the The Remote Tower Center in Sundsvall can remotely direct operations at Ensherzvik Airport, making Ensherzvik Airport the first airport in the world to successfully implement off-site air traffic control; In November 2017 [15], Austria's Frequentis AG, Deenjali air navigation service provider HungaroControl, the German Aerospace Center (DLR), and Italy's aerospace Selex ES GmbH, a wholly owned German subsidiary of the enterprise Leonardo, successfully validated for the first time in Braunschweig the remote off-site joint control for controlling multiple airports, which showed that it is feasible for a single controller to provide control remotely for multiple airports; and in May 2018, the Norwegian air navigation service provider AVINOR, together with Indra and its Norwegian subsidiary Indra Navia, successfully validated for the first time the simultaneous control of three airports from a single remote location, with the test platform based on Indra's ATC system, which is able to provide a fully integrated 3D tower environment reproduction for simulated traffic at three Norwegian airports (Lestat, Hejugsund, Bodø).

The German Aerospace Center (DLR) carried out the PAVE project (Pilot Assistant in the Vicinity of Helipads) in 2003 [16], which was aimed at designing helicopter flight path tunnels that could better guide helicopters to safer flights and indicate the helicopter's flight status parameters, etc.; and the second phase of the PAVE project, carried out in 2016, was dedicated to the design of a helicopter flight path tunnel. PAVE project, the second phase of which is dedicated to enhancing the pilot's situational awareness and providing technical support for the helicopter's landing and takeoff process [17]. Pilots rely on visual cues to fly safely during flight and landing, and the DVE environment complicates flight and landing conditions, making it easy to collide with the ground. The overall technical approach of this project is to build, integrate, and test the research model and to evaluate it using ground-based simulations and the overall technical approach of the project was to build, integrate and test research models and evaluate them using ground simulations and flight tests [8].

Daedalean Switzerland provides certifiable situational intelligence built on machine learning.Daedalean's co-pilot systems include vision-based traffic detection, navigation and landing guidance. The first product, PilotEye, a traffic avoidance system with integrated visual traffic detection developed in collaboration with Avidyne, will soon be the first DAL-C certified machine learning application.

2.2.2. Current Status of Domestic Research

Domestic in the berth guidance technology field started late, Chengdu University of Electronic Science and Technology, Civil Aviation University of China and Beijing University of Aeronautics and Astronautics and other colleges and universities have carried out laser and visual fusion of ramp aircraft detection, identification and other related technology research work, but lack of systematic application verification. Shenzhen CIMC Tianda Airport Equipment Co., Ltd. and Nanjing Les Information Technology Co., Ltd. have completed the imitation, which is still in the stage of testing and validation, with no formal engineering application cases. Through the research and analysis of different systems of berth guidance system practical application. Found that the laser radar and video technology system has its own advantages and disadvantages. Gargling radar has the advantages of strong target detection capability, high three-dimensional positional accuracy, and all-weather round-the-clock operation, etc., but its resolution and frame rate are lower, the role of the distance is closer, the cost is higher, and the data are sparse and uneven, especially for the more distant people and cars and other city-wide multi-target detection and recognition capability is insufficient. The adopted mechanical LiDAR is costly; the video camera has high resolution and frame rate, rich color and texture information, and strong multi-target detection, tracking, and intelligent recognition capability, but its stability is greatly affected by environmental factors such as light and visibility, and the target attitude and position accuracy is not as good as that of laser scanning due to insufficient three-dimensional sensing capability.

Problems and deficiencies of a single technology system lead to the “berth automatic guidance system” can not meet the application requirements of intelligent and safe operation of the whole city of the apron. With the low-cost, large airports [11], high-precision, general high, high frame rate of domestic multi-line solid-state LiDAR manufacturing technology is gradually mature and the rapid development of the image of intelligent vision technology, the development of LiDAR and the camera tightly coupled with a new generation of low-cost, multi-target, multi-angle, intelligent berth guidance system has become a new development trend [19].

Compared with foreign research and application of remote joint control and surveillance technology, China is slightly weak in this area. At present, there is no unit in the well to carry out joint control and surveillance of regional feeder airports and through airports. The Civil Aviation Institute of China has initially realized the application of remote surveillance technology at regional airports in Xinjiang and Inner Mongolia, but it is limited to panoramic video monitoring, which is relatively single-function, and there are still many technologies that need to be perfected and strengthened in order to have a full-featured remote control.

2.3. Research Significance

The meteorology of high plateau airports is complex and variable, with obvious time differences, as well as geographical and localized characteristics. For example, the rapid change of meteorological conditions at Jiuzhai Huanglong Airport can reduce visibility from 10km to only a few hundred meters in 2 minutes. Moreover, the clouds inside the ravine on the west side of the runway drift to the runway as low clouds, affecting the line of sight. High plateau airports are often located in places with complicated terrain, resulting in poor clearance conditions around the airport and difficulties in setting up navigation facilities, making it difficult to maneuver the aircraft for takeoff and landing, as well as for re-flight. Most of the highland airports in China need to prepare special single-engine re-flight procedures. In addition, highland airports have very little maneuvering airspace and maneuvering altitude available, which makes it difficult to deploy aircraft in the air. For example, the mountains around Chamdo Bunda Airport are more than 4,000 and 5,000 meters high, and there are more than 5,300 meters high within 10km, and close to 6,000 meters high within 20km. The re-flight procedure is extremely complicated, and in many places, both altitude and distance have to be restricted at the same time. Due to the terrain masking and reflection, the radio waves of plateau airports generate multi-path interference: ground communication has a short distance and weak signals; airport VHF Omni-directional beacon station/range finder has a small distance and coverage, unstable indication, and the instrument landing system generates false signals in some directions [20]. Due to the above difficulties at plateau airports, coupled with the increased difficulty in maneuvering and poor maneuverability, pilots are easily intimidated by flying at plateau airports.

The study of visual enhancement technology in low visibility conditions at plateau airports has the following significance: to more accurately grasp the terrain environment in which the aircraft is navigating at plateau; to help pilots assess the route in low visibility conditions at plateau; to reduce pilots' fear of flying in plateau areas [17].

Therefore, the study of visual enhancement technology in low visibility in high plateau area has profound research significance and strategic value.

3. ALGORITHM DESCRIPTION

3.1. HSV Color Space Conversion

3.1.1. Principle overview

For each pixel point of a color image, its color is represented by a value in the three dimensions of RGB, which represents how much of the red, green, and blue components, respectively.

Thus a set of RGB values (corresponding to each point within the RGB cube) represents a color, and vice versa, any color can be represented by a set of RGB values (being a point within the RGB cube). However, for human beings, a color is intuitively perceived in terms of its hue, brightness, and other information, which is not intuitively represented by RGB values [21]. By looking at the size of the RGB values alone, it is difficult to perceive the corresponding hue and other information, and naturally, it is not easy to modify them.

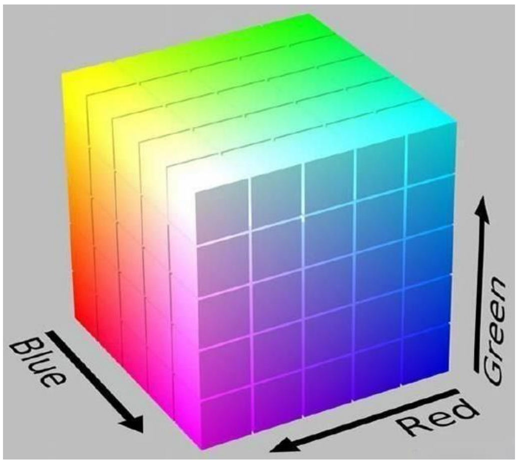

Figure 1. RGB space

The RGB cube is mapped to an HSV cone (or cylinder) by defining a mapping transformation: for every position in the RGB cube, there is a corresponding position in the HSV cone.

Thus, any color will correspond to a set of HSV values (i.e. a position in the HSV cone), and this HSV value can visually represent the hue, brightness, etc. of the color.

HSV three values, H full called Hue hue, in the cone for the horizontal angle around the cone axis. It indicates the color type, range 0-360 degrees, with the value change color hue gradient cycle. s is called Saturation saturation, in the cone for the horizontal distance from the cone axis. It reveals the fullness of the color (the higher the color is the more obvious, the lower the color is closer to black and white gray, the specific black and white gray depends on the brightness), the range of 0-1. V is known as the brightness Value, in the cone refers to the vertical distance from the tip of the cone. It indicates the brightness of the color (the higher the brighter and whiter the color is, and vice versa, the darker and blacker the color is), with a range of 0-1.

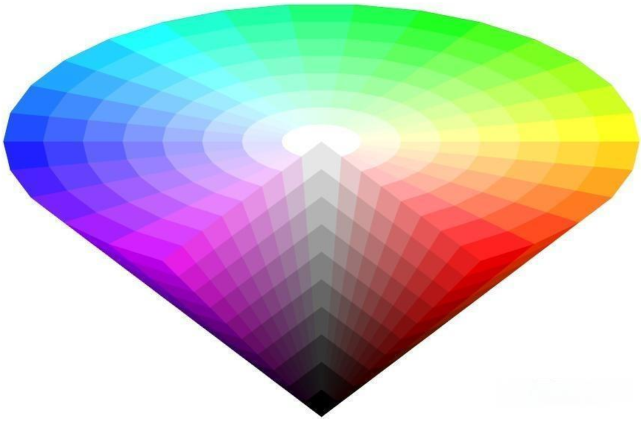

Figure 2. HSV space

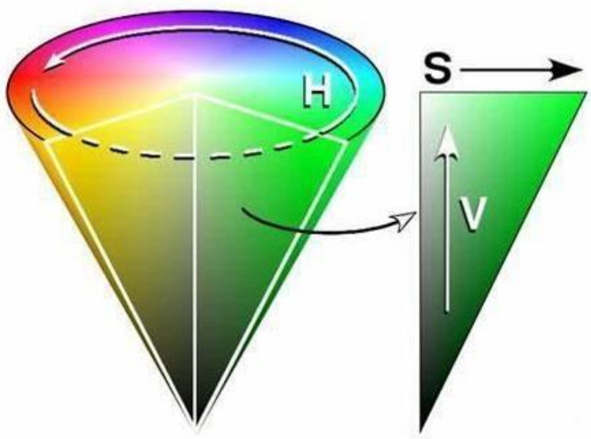

Figure 3. Conversion of RGB cube space to HSV cone space

3.1.2. Formulas

The process of RGB to HSV conversion is as follows:

$$V=\max(R, G, B) \tag{1}$$

Brightness Value takes the maximum of the three RGB channels; the larger the maximum in the RGB values, the brighter it is (white and the three primary colors are equally bright). This means that the three outer faces of the RGB cube are deformed into the base of the HSV cone, and the body diagonal of the RGB cube becomes the axis of the HSV cone.

$$S=\begin{cases}(V-\min(R,G,B))/V, ifV \neq 0 \\ 0, ifV=0\end{cases} \tag{2}$$

The formula for saturation expresses color purity. the lower the minimum of the RGB values, the higher the saturation. Or the greater the difference between the maximum and minimum of the three RGB values, the higher the saturation. If the three RGB values are the same, this corresponds to the saturation of 0, that is, the axis of the HSV cone, black, white and gray. HSV saturation at the circumference of the maximum value of 1, which can be corresponded to the RGB cube of several prongs, these prongs are guaranteed that the maximum value of RGB is 255, the minimum value of 0, as for the intermediate value of the can be arbitrary, will not affect the saturation.

$$H = \begin{cases} 60(G-B)/(V-\min(R,G,B)), if V = R, G \geq B \\ 360 + 60(G-B)/(V-\min(R,G,B)), if V = R, G \leq B \\ 120 + 60(B-R)/(V-\min(R,G,B)), if V = G \\ 240 + 60(R-G)/(V-\min(R,G,B)), if V = B \\ 0, if R = G = B \end{cases} \quad (3)$$

The color formula, though complex, is simple: the 360 degree angle is divided into 3 parts, with RGB each occupying 1/3 of the area. whichever of the RGB values is largest is in whichever area; whichever of the two remaining values in RGB is larger in that area favors whichever side is more favorable.

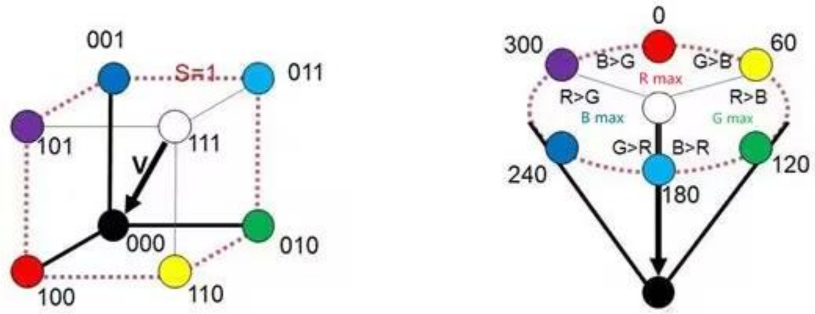

Figure 4. RGB to HSV conversion

3.2. Airport Image Segmentation Based on Recursive Otsu Algorithm

Firstly, the recursive Otsu segmentation based method is used to extract the main contour of the airport from the complex background; then morphological filtering is carried out by using morphology-based open operation and expansion, the open operation is to filter out some isolated noise points, and the expansion operation is to connect the segmented airport components into a complete whole; finally, the morphology filtered processed image is subjected to the growth of its region, so as to the main airport runway Localization. This method can quickly and accurately detect and localize the main and auxiliary runways of airports in low visibility, forward and downward looking aerial airport images.

It should be noted that although the recursive approach can be applied to multi-threshold segmentation, the computational effort increases significantly as the number of thresholds increases, which may lead to a decrease in the efficiency of the algorithm. In addition, if the size ratio of the target and the background in the image is disparate, or the gray scale distribution of the image does not satisfy single-peakness, the Otsu method may not be able to obtain the desired segmentation results.

3.3. Morphological Filtering

Mathematical morphology consists of a set of algebraic operators of morphology. The most basic morphological operators are: erosion, expansion, open and closed operations. The open operation is a geometrically based filter that smoothes the boundary to remove convex corners. And the expansion operation is to connect the segmented airport components into a whole. Different structural elements lead to different segmentations, i.e., different features are extracted. In practice, two structure templates are used, a 5×5 all 1 structure S1 and a 3×3 rhombus structure S2. The image after recursive

Otsu segmentation is first opened twice with template S1 and then the expansion operation is performed twice with template S2. After this process, some noise can be removed to a large extent, and the geometric structure of the runway is preserved to the maximum extent.

3.4. Fast Search Tracking Algorithm Based On Region Growing

Region growing based fast search algorithm is an image segmentation method in which region growing starts with a set of "seed" points and combines neighboring pixels or sub-regions with similar properties (e.g., gray level, texture, color, etc.) as the seed points into the growing region. The image is segmented by iterating the process until no new pixels or sub-regions can be added to the growing region. In region growing algorithm, determining the seed point is a critical step and a difficult one. Seed points are the starting point of region growing, and their selection will directly affect the range and shape of the growing region, which in turn determines the effect of image segmentation.

Region growing algorithms usually only consider the similarity between local pixels, so they may not be able to achieve ideal segmentation results when facing complex images. In order to solve this problem, region growing algorithms can be considered to be combined with other image segmentation methods (such as threshold segmentation, edge detection, graph theory-based segmentation, etc.), in order to fully utilize the advantages of various methods and achieve better segmentation results.

Combining the fast search algorithm based on region growing with the Otsu segmentation method can reduce the shortcomings of each of the two algorithms. One of the difficulties of region growing is how to determine the seed points. To this end, the recursive Otsu and morphology filtered airport image is tracked and searched with a 3×3 template, if the tracked point and its 4-neighborhood are found to be the target point (with a gray value of 255), the center point of the template corresponding to the image region is set to be the seed point, and region growth is carried out, and the result of the growth is preserved (position coordinates and area). Then set the gray value of the currently growing region to the background color (gray value of 0), continue to search for seed points, and if it is found that there are still eligible seed points, then continue to grow the region. Finally, the results of the growth are analyzed to find the centers of gravity corresponding to the two regions with the largest areas and mark the two runways. The steps of the algorithm are as follows: a. Search for seed points; b. Search for the 4-neighborhood of the current seed point, if it is the target (255), then the coordinates of the corresponding point will be pressed into the stack and mark the search point; if the stack is non-empty, then continue searching; otherwise, a regional growth is completed, turn c; c. Record the location information, area, and center of gravity of the growth region; d. Set the current growth region as the background color (0); e. If there is no seed point, then end, otherwise go to a; f. Describe and label the airport runway and locate the runway.

4. EXPERIMENTAL RESULTS AND ANALYSIS

One airport image was selected from more than 1000 images and its step-by-step results are given in accordance with the algorithm flow as shown in the figures below.

Figure 5. Original Airport Images

Figure 6. Image after recursive Otsu segmentation

Figure 7. Morphological filtered image

Figure 8. Marking of airport runways

As can be seen from the above images, the original airport image is segmented using the recursive Otsu algorithm, which basically detects the airport runway from the complex background, and then uses morphological filtering to filter out some noise points, especially some scattered noise points, while retaining the geometry of the airport runway. The implementation of the fast search algorithm based on area growth can quickly obtain the positional and geometric parameters of the airport runway, and accurately locate the center of gravity of the airport runway and then detect and locate the airport.

Experiments have proved that the algorithm has good performance and can quickly and accurately detect and localize the airport runway. It can be used for automatic detection and localization of airports in specific occasions.

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