

Article

# Automatic Airport Recognition Based on Saliency Detection and Semantic Information

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**Abstract:** Effectively identifying an airport from satellite and aerial imagery is a challenging task. Traditional methods mainly focus on the use of multiple features for the detection of runways and some also adapt knowledge of airports, but the results are unsatisfactory and the usage limited. A new method is proposed to recognize airports from high-resolution optical images. This method involves the analysis of the saliency distribution and the use of fuzzy rule-based classification. First, a number of images with and without airports are segmented into multiple scales to obtain a saliency distribution map that best highlights the saliency distinction between airports and other objects. Then, on the basis of the segmentation result and the structural information of airports, we analyze the segmentation result to extract and represent the semantic information of each image via the bag-of-visual-words (BOVW) model. The image correlation degree is combined with the BOVW model and fractal dimension calculation to make a more complete description of the airports and to carry out preliminary classification. Finally, the support vector machine (SVM) is adopted for detailed classification to classify the remaining imagery. The experiment shows that the proposed method achieves a precision of 89.47% and a recall of 90.67% and performs better than other state of the art methods on precision and recall.

**Keywords:** saliency distribution; BOVW; semantic information; fuzzy classification

## 1. Introduction

Recent advances in the quality and availability of very high resolution (VHR) imagery have opened new prospects in the field of the automatic detection of geospatial objects for multiple purposes [1–3]. Among these objects, airports have been the focus of considerable attention because of their significance in civil and military applications. Thus, efficiently finding airports from VHR remote sensing imagery has attracted the attention of many researchers, and many methods for airport detection or recognition have been proposed [4–12].

Current methods, according to their usage of semantic information, can be classified into two major strands. One strand focuses on the use of multiple features, including line features [4–6], or texture features [7–9], or point features [10,11], to directly extract runways or extract patches to extract runways for airport detection. These methods, while using VHR imagery data, only focus on the extraction of features such as line features, texture features or point features to only detect part of the airport, such as runways, and fail to take other items of the airport into meaningful account, so they are unable to utilize the semantic information of the complete airport to achieve better performance. The other strand uses multiple features and the knowledge of airports to help detect or interpret airports. McKeown et al. [12] introduced a system named system for photo interpretation of airports using MAPS (SPAM). This system is knowledge-based and uses the MAPS database [13,14] to coordinate and control image segmentation and to provide several capacities, including the use of

spatial constraints, explicit camera models, image-independent metric models and multiple image cues to help extract the semantics and to interpret the airport scenes on VHR imagery. Zhao et al. [15] proposed a saliency-constraint method for airport detection on low-resolution aerial imagery. This method uses a saliency-based constraint to detect the possible regions of interest (ROI) and adapts a refined version of the popular semantic model of the BOVW model to decide whether the ROI is an airport. These methods adapt the semantic information to improve the detection or interpretation of the airport, but they have drawbacks that limit their usage. The drawbacks include the limit of image resolution and the heavy dependence on external data and information, including geodetic coordinate data and camera model parameters, which serve as a priori information and are often unavailable for VHR imagery, for the extraction of abstract and detailed semantics. In sum, traditional methods rely heavily on external data and information or fail to effectively combine the semantics and VHR imagery for the efficient recognition of airports.

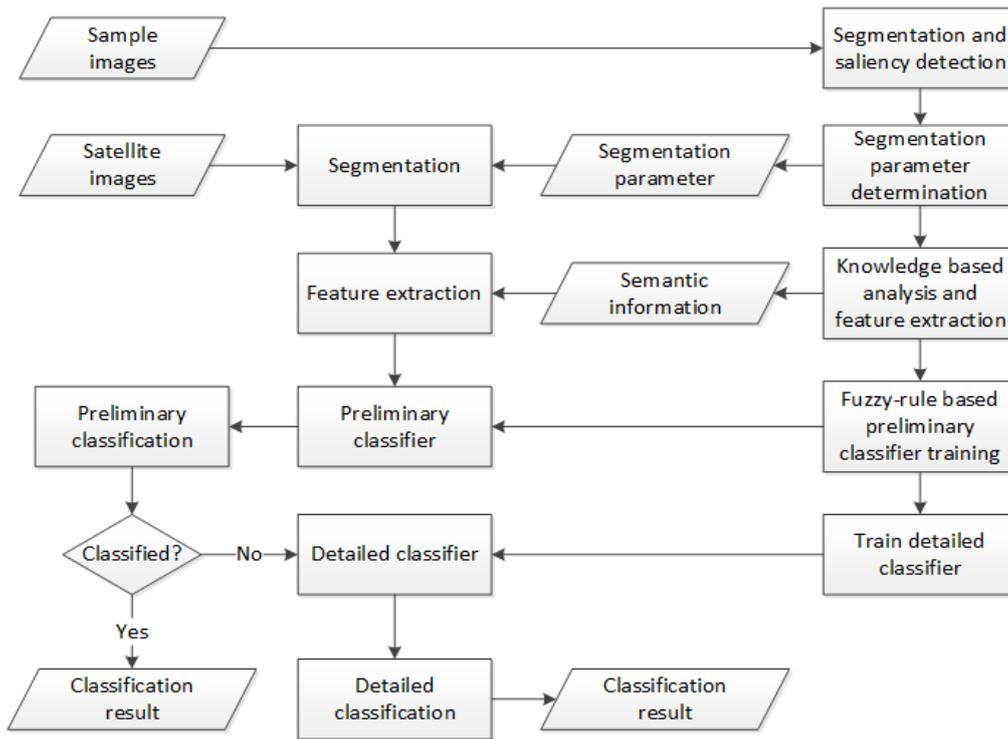
The efficient recognition of airports from imagery requires the understanding, learning and expression of semantic information. Semantic information can help improve the performance of object recognition. For a given image, regardless of the type, semantic information refers to the meanings of an image. The meanings of an image can be further divided into four levels from the lowest level to the highest: semantic types, object composition, abstract semantics and detailed semantics, according to [16]. In airport recognition, the semantic types are all fixed to remote sensing imagery. What is supposed to be done is the extraction and usage of the abstract semantics (components that make up the object) and the detailed semantics (relationship between the component, i.e., a detailed description of the image) to decide the object composition (whether the type of object in the image is an airport or not). However, extracting and using the abstract semantics and detailed semantics are challenging tasks since there exists “semantic gaps” between low-level features and the relationships between the components (i.e., detailed semantics), and while research has been conducted to eliminate the gap since the end of 20th century [17], it still remains a challenging topic [18–20].

In this paper, a content-based method is proposed to recognize and retrieve airports from VHR remote sensing imagery. The proposed method combines the semantics and VHR imagery and adapts image-based analysis of the structural information of airports, which will be further discussed in Section 2.2, as well as the use of features to extract semantic information to recognize airports from VHR remote sensing imagery. This method is suitable for VHR imagery, and it does not require heavy dependence on external data or information. It is based on the learning of features of the VHR image to extract semantics for a better representation and recognition of airports.

The outline of this paper is as follows. Section 1 introduces the background of the research. Section 2 introduces the details of the proposed method. Section 3 introduces the experiment and compares the result with competing methods. Section 4 concludes about the efficiency of the proposed methods and presents the plan for future research.

## 2. Proposed Method

The proposed method is based on the use of VHR remote sensing imagery. It uses saliency detection to derive the best segmentation to describe the structural information of the airport. The BOVW model and the segmentation result are combined to help describe the airport from features. The image correlation degree is combined with the BOVW model and fractal dimension analysis to extract the object composition under fuzzy rules for preliminary classification. SVM is used for detailed classification. The overall procedure of the proposed method is shown in Figure 1.



**Figure 1.** Overall procedure of the proposed method.

### 2.1. Segmentation for Saliency Detection

Saliency detection helps to detect the salient regions in the image. The result of saliency detection benefits many other fields, such as computer vision and remote sensing. For a scene on the given image, the kind of objects forming the scene and the spatial-context relationship between the scenes are important parts of both abstract semantics and detailed semantics according to the definition in [16]. The objects contained in an image of an airport can be briefly classified into runway, terminals, tarmacs and other accessories. These objects are on the patch-level scale, i.e., their sizes in the image exceed the pixels, but are still smaller than the entire image, and vary in number, size and other low-level features; and they may be mixed together, but their consistency is uniform with a relatively distinct saliency distribution from other object or scenes in VHR images. According to [21], there are three major strands for the definition of saliency: interest points, class-specific saliency and generic saliency. Among these three methods, class-specific saliency aims to best distinguish a particular class of objects from others. Considering the complexity and hybridization between airports and other objects, saliency detection methods should emphasize such a difference from other objects and scenes in the form of differences in the saliency distribution. Currently, many state of the art saliency detection methods belong to generic saliency and are mainly used for close-range target detection or simple target detection [22–24]. In this study, we focus on class-specific saliency detection. First, the sample images are grouped into two collections, namely one with airports and one without airports. Then, each image is segmented into patches, and multiple sizes of segmentation patches are employed to derive different segmentations for each image. Next, for each image and each segmentation result, we apply a saliency detection method via joint embedding of spatial and color cues [25] for detecting the best segmentation scale that best highlights the saliency differences between airports and other objects. We adapt the saliency detection method from the pixel level to the patch level. Each patch is considered as a pixel, and we combine the spatial-constraint-based saliency, color-double-opponent saliency and similarity-distribution-based saliency to derive the saliency values for each patch. Finally,

for each image in the two collections, and for each scale, the saliency values of the patches are ranked. The number of salient image patches is set as follows:

$$Num = \lceil M \times M/2 \rceil \quad (1)$$

where  $Num$  is the number of salient patches and  $M$  is the parameter defining how segmentation will be applied.

For one value of  $M$ , one image is segmented into  $M \times M$  segmentation patches with the same size. For all images, we can count how many times each segmentation patch is ranked among salient patches and generate the  $M \times M$  saliency distribution maps for each collection. The intensity of each pixel in the saliency distribution map equals the times of the appearance among salient patches of the corresponding patch.

Different values of  $M$  lead to different segmentations and distinct saliency distribution maps. These maps are different, and the differences between the frequencies of their patches can be salient. In this study, we use the following equations to assess the performance of the segmentation of different levels:

$$AD_1(M) = |MaxS1 - MinS1| \quad (2)$$

$$AD_2(M) = |MaxS2 - MinS2| \quad (3)$$

$$Sa(M) = AD_1(M) / AD_2(M) \quad (4)$$

where  $AD_1(M)$  is the absolute value of the difference between  $MaxS1$  and  $MinS1$ ;  $MaxS1$  and  $MinS1$  are the maximum and minimum sums, respectively, of each row in the  $M \times M$  saliency distribution map of the collection of images with airports;  $AD_2(M)$  is the absolute value of the difference between  $MaxS2$  and  $MinS2$ ;  $MaxS2$  and  $MinS2$  are the maximum and minimum sums, respectively, of each row in the  $M \times M$  saliency distribution map of the collection of images with other objects; and  $Sa(M)$  is the ratio of  $AD_1(M)$  to  $AD_2(M)$ . Here, a larger  $Sa(M)$  indicates a better performance of highlighting the saliency distribution difference between two collections. The relationship between variable  $M$  and  $Sa(M)$  is shown in Figure 2. Each test collection contains 50 images.

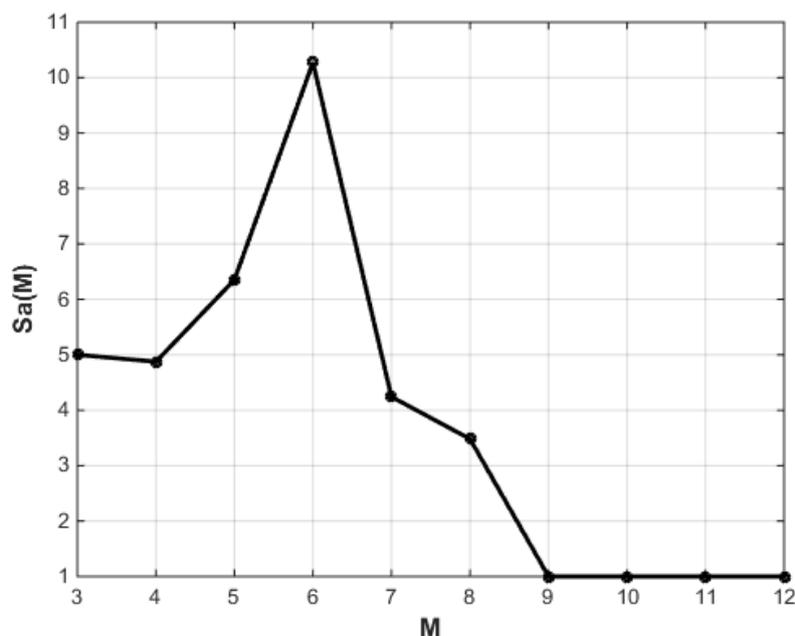


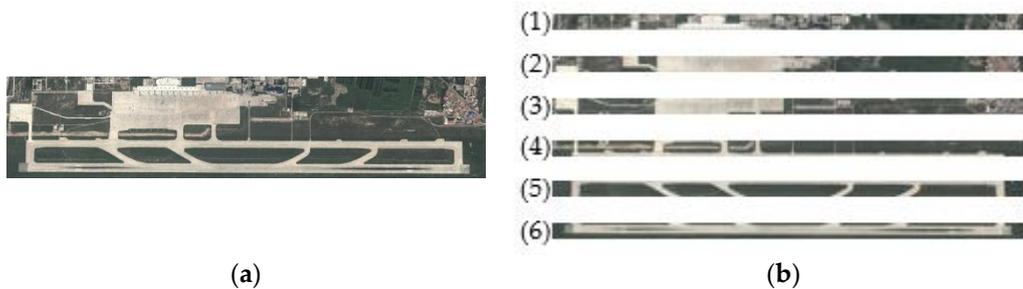
Figure 2. Relationship between the segmentation scale variable  $M$  and  $Sa(M)$ .

Figure 2 shows that when scale variable  $M$  is set as 6, segmentation exhibits the best performance. However, when scale variable  $M$  is set above 9, the saliency distribution maps of the two collections become uniform. Therefore,  $M$  is set as 6 to obtain the best performance.

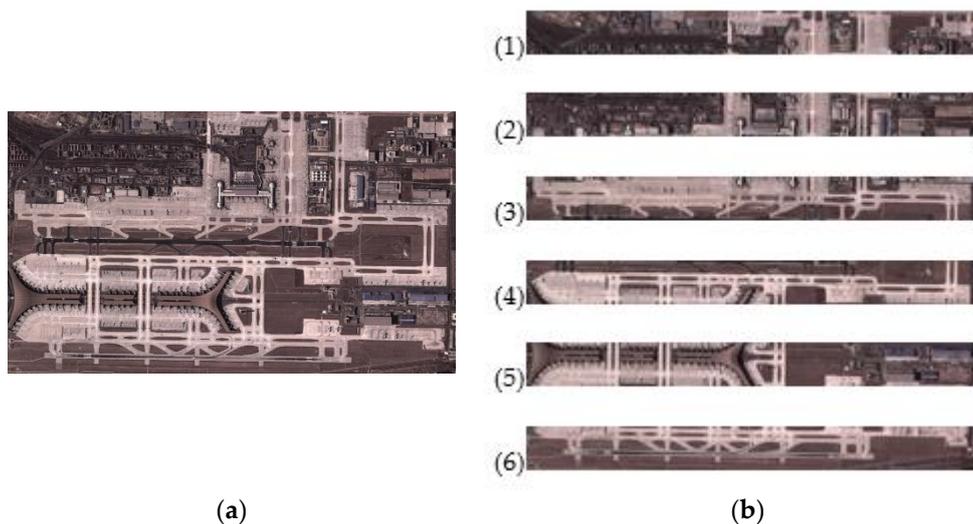
## 2.2. Semantic Information Extraction

Sample images are used to extract the semantic information of an airport to guide the recognition of airports on testing images. For complex scenes, such as airports, salient patches can be the most representative, whereas other non-salient objects and backgrounds can also correspond to the given scenes [26]. Therefore, after segmenting sample images with airports, we combine the patches in the same row into six major patches for each image. Then, we proceed to analyze the major patches.

The airport is a hybrid of relatively simple components, including runways, terminals, tarmacs and other accessories. They are components of the airport (abstract semantics) and have a certain spatial relationship [27]. The segmentation result can describe their spatial relationship, which is part of the detailed semantics. Figure 3 shows the segmentation result of the airports with runways on one side of the terminal, and Figure 4 shows the segmentation result of airports with runways on more than one side of the terminal. The six major patches are marked from 1 to 6.



**Figure 3.** Segmentation result of airports with runways on one side of the terminal. (a) Original image; (b) segmentation result.



**Figure 4.** Segmentation result of airports with runways on more than one side of the terminal. (a) Original image; (b) segmentation result.

We can see from Figures 3 and 4 that in Major Patch 1 and Major Patch 2, terminals and tarmacs appear together, while runways and other objects also appear when the airport has runways on more than one side of the terminal. We can also concluded from Figures 3 and 4 that in Major Patch 3 and

Major Patch 4, tarmacs, terminals and runways appear together with other objects. Besides, it can be observed from Figures 3 and 4 that in Major Patch 5 and Major Patch 6, runways begin to be the major component, while other accessories also appear. In general, while the components of airports mix with each other, they have certain spatial distribution rules, and when the image is segmented, these rules become obvious. These six major patches contain part of the airport scene, and we can have a complete description of the airport scene by describing them. Based on the analysis of major patches, we can extract semantic information to better describe the airport. In this paper, the BOVW model is used to describe features from the major patches to help extract and express the semantic information.

The BOVW model is an effective and traditional way of representing the semantic information of objects [28,29]. The BOVW model was first introduced for text analysis [30] and was soon adopted for image classification and retrieval. It requires the extraction and the rearrangement of primitive features into visual “words” to help extract, analyze and express the semantic information. When using BOVW, the image scene is considered as a collection of visual “words”. In this paper, considering the variation in spatial resolution, illumination and rotation, we extract the robust scale-invariant feature transform (SIFT) [31] features for the BOVW model and generate the 6 corresponding dictionaries to encode the SIFT features.

### 2.3. Fuzzy Rule-Based Method for Preliminary Classification

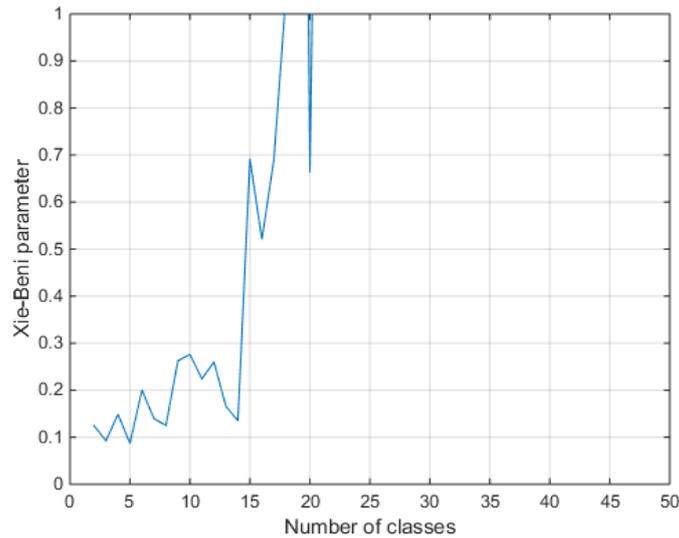
When the number of visual “words” is very large, the BOVW model will encounter the drawback of being unable to effectively encode the low-level features [32], which limits its ability to express the object composition (what object is on the given image) completely and accurately. Since the BOVW model was proposed, studies on the improvement of the BOVW model for accurately finding and expressing the object composition in a given image have been conducted. Many methods assume that the BOVW model has the object composition directly expressed in the statistical distribution of visual “words” [33,34]. These methods rely on a prior statistical assumption and are only practical for close range imagery, such as medical imagery. Fuzzy-rule classification provides a new and effective approach to express the object composition.

In recent decades, fuzzy-rule classification has been the focus of considerable attention from researchers worldwide [35–37]. Fuzzy-rule classification is characterized by its ability to deal with incompleteness of knowledge, which indicates that this method is capable of deriving potential semantic information from different scenes on VHR images. For various purposes, different types of knowledge and rules are selected. Among these types of knowledge and rules, the image correlation degree stands out because of its efficiency in deriving the object composition from features [38]. Therefore, we select the image correlation degree and utilize the visual words generated to build the fuzzy classifier for preliminary classification.

First, we divide the sample images into two groups, namely Group 1 with airports and Group 2 without airports, and calculate the average wordlist *Ave1* of Group 1. As for Group 2, since the non-airport objects are too complicated to be expressed with a single average wordlist, an improved fractal dimension calculation method [39] is adapted to get the estimated fractal dimension of each image with other objects. The improved fractal dimension calculation method is based on box-counting strategies and considers the image as a 3D continuous surface. Its procedures can be summarized as follows:

1. Divide the image into blocks of size  $s \times s$  with two adjacent blocks overlapping at the boundary pixels.
2. Assign a column of boxes starting with the pixel with the minimum gray level in the block.
3. For different sizes of boxes, compute  $N_s$ , the corresponding total number of boxes covering the entire image surface.
4. Plot the least squares linear fit of  $\log(N_s)$  versus  $\log(s - 1)$  for the calculation of the fractal dimension.

5. After calculation of the fractal dimension, fuzzy C mean is used to further divide Group 2 into several smaller groups. To assess the classification, we use the Xie-Beni index [40] to decide the number of classes. The Xie-Beni index identifies overall compact and separate fuzzy C partitions, and a smaller Xie-Beni index indicates a better classification. Figure 5 shows the performance of different numbers of classes.



**Figure 5.** Relationship between the number of classes and the Xie-Beni index.

From Figure 5, it can be concluded that when class number is 5, the Xie-Beni index is the smallest, and that when the class number exceeds 20, the Xie-Beni index is larger than 1. Therefore, we divide Group 2 into 5 classes and generate the corresponding average wordlists. Then, the Euclidean distance from the wordlist of each image to the two mean wordlists is calculated as follows:

$$\begin{aligned}
 Ed_i(j, k) &= |Avek - wordlist(j, i)| \\
 i &= 1, 2, 3, 4, 5, 6 \\
 j &= 1, 2, \dots, n \\
 k &= 1, 2, 3, 4, 5, 6
 \end{aligned} \tag{5}$$

where  $wordlist(j, i)$  is the wordlist of image  $j$  in group  $i$  and  $Ed_i(j, k)$  is the Euclidean distance between the wordlist of image  $j$  in group  $i$  and  $Avek$ .

Next, we calculate the relational degrees of each image to its own group and the other group by using the following equations:

$$\begin{aligned}
 Ri(j, k) &= 1 - \frac{Ed_i(j, k)}{\sum_{k=1}^6 Ed_i(j, k)}, \\
 i &= 1, 2, 3, 4, 5, 6 \\
 j &= 1, 2, \dots, n \\
 k &= 1, 2, 3, 4, 5, 6
 \end{aligned} \tag{6}$$

where  $Ri(j, k)$  is the correlation degree of image  $j$  in group  $i$  to group  $k$ .

Finally, we calculate the average value of the relational degrees of Group 1 and the threshold for further use, as follows:

$$f1 = \frac{\sum_{i=1}^{NUM_{group\ 1}} R1(i, 1)}{NUM_{group\ 1}} \tag{7}$$

$$TH1 = 2\sqrt{\frac{\sum_{i=1}^{NUM_{group\ 1}} [f1 - R1(i, 1)]^2}{NUM_{group\ 1}}} \tag{8}$$

where  $TH1$  is the threshold of Group 1,  $NUM_{group1}$  is the number of images in Group 1 and  $f1$  is the average image correlation degree of Group 1.

Given  $f1$  and  $TH1$ , the fuzzy classifier can be built to start the preliminary classification. The test image is rotated clockwise to  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $270^\circ$  to segment it and to generate the corresponding wordlists. Then, for each direction, the Euclidean distance and the correlation degree of each test image are generated. Given that the object on the test image is unknown, we suppose that an airport exists on the test image to obtain the variable of each direction via the following equation:

$$D_{11} = |R1(i,1) - f1| \quad (9)$$

where  $D_{11}$  is the variable.

For one direction, if  $D_{11}$  is smaller than  $TH1$ , then this direction is considered to contain an airport. If  $D_{11}$  is larger than  $TH1$ , then this direction is considered to contain other objects. If all four directions have  $D_{11}s$  that are smaller than  $TH1$ , then the test image is classified as an image that contains an airport. If all four directions have  $D_{11}s$  that are larger than  $TH1$ , then the test image is classified as an image that contains other objects. Otherwise, the test image is not classified and left for the detailed classification. The complete procedure is shown below (Figure 6).

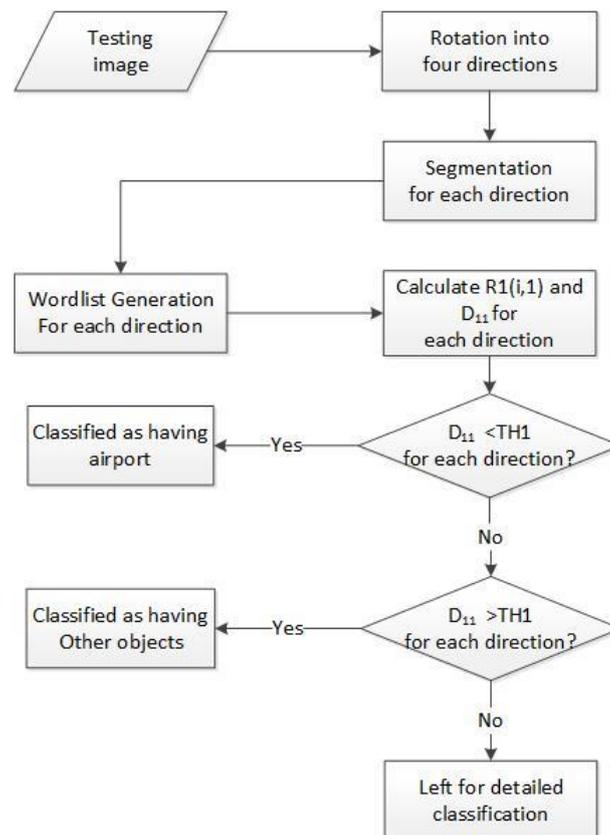


Figure 6. Procedure of preliminary classification.

#### 2.4. Detailed Classification

Scenes with airports and scenes with other objects are complex. In this case, airports may be mixed with other non-airport objects. As such, fuzzy classification methods are able to find only a part of the imagery with airports. Thus, conducting a second classification taking multiple aspects into account and giving a definite classification result is necessary. In this paper, we use SVM in conducting this classification, and this classification is defined as “detailed classification”, since this

classification will provide a definite classification result for the image that cannot be classified by preliminary classification. The four wordlists of the corresponding directions of each sample image with airports are set as positive samples to increase the rotational stability, whereas the wordlists of other sample images are set as negative samples. We use the sampling data to generate a classifier and use it for detailed classification. For each test image, if two or more of its four wordlists are classified as having airports, then the image is considered to contain an airport. Otherwise, the image is identified to contain other objects.

### 3. Experiment and Analysis

#### 3.1. Comparison and Analyses between the Proposed Method and Other Methods

We used imagery with and without airports from Google Earth and Tianditu. We collected 150 images with airports from Google Earth. These airports are for civil use and are in different construction standards and at multiple scales and ranges. The airports in the images are located in various parts of the world, including the Far East, the Middle East, Europe and North America. We also randomly obtained 250 images containing various scenes, such as harbors, waters, residential areas, farmland, forests and bare land, from Google Earth and Tianditu in various parts of the world. The spatial resolutions range from 1 m to 4 m. We set 75 images with airports and 100 images without airports for building the classifier and the remaining images for testing and assessment. Figures 7 and 8 show examples of the images used in the experiment.

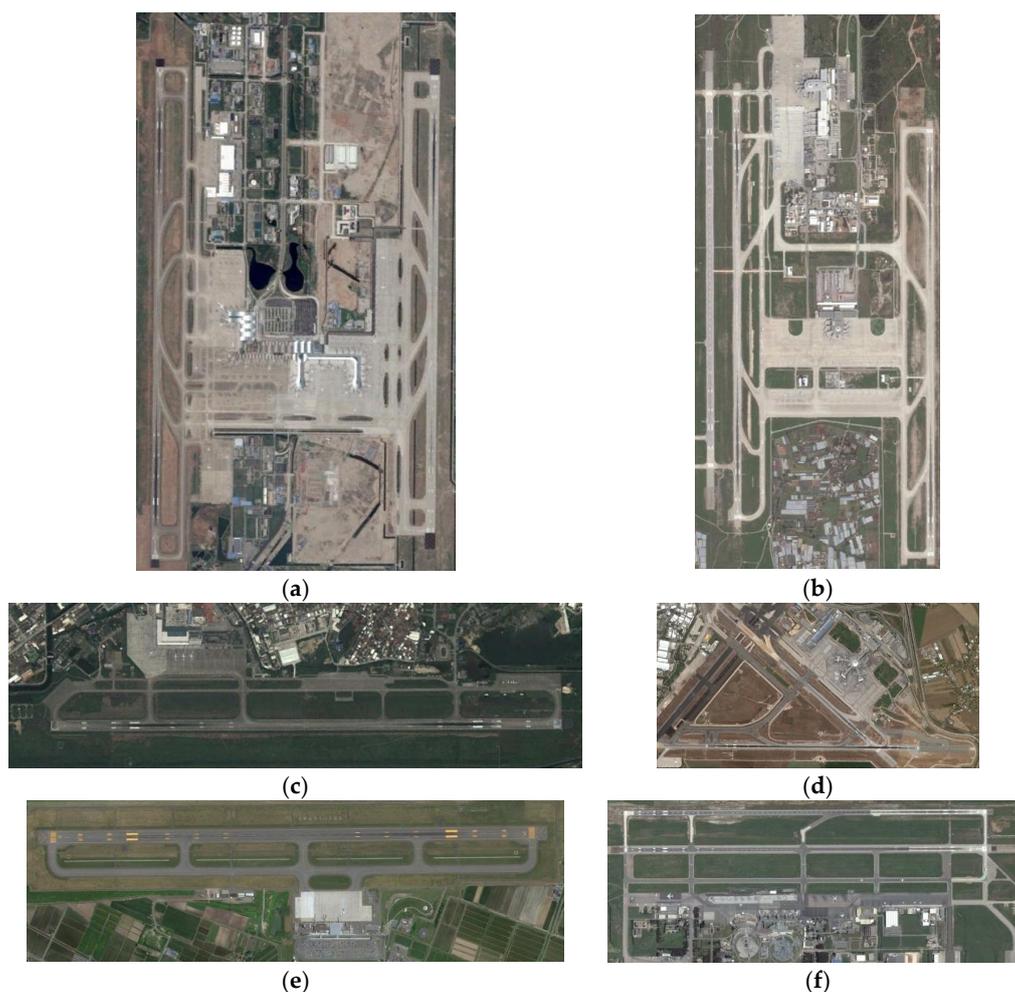


Figure 7. Examples of airports.

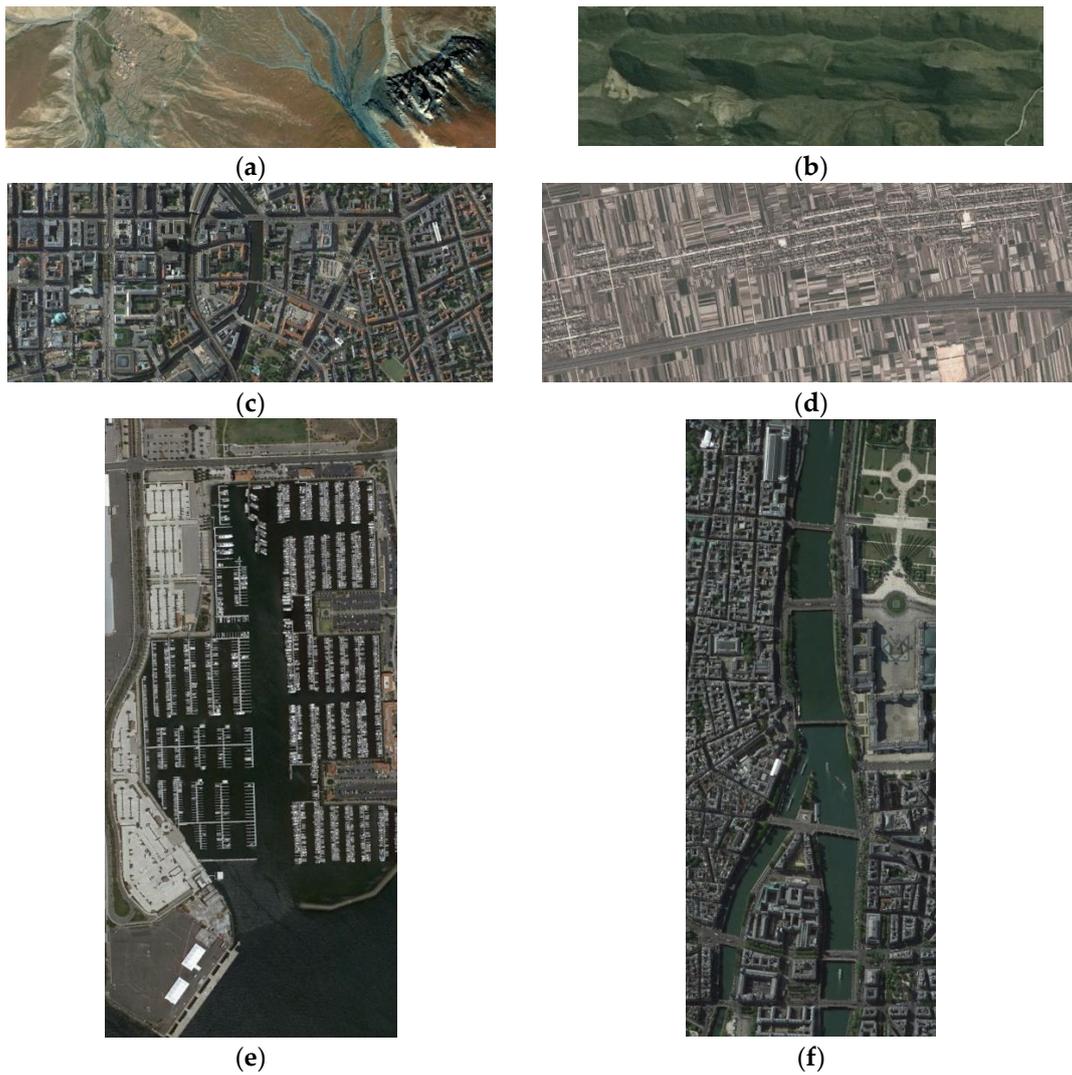


Figure 8. Examples of non-airport objects.

In the experiment, several state of the art methods are chosen for comparison. They are BOVW, the probabilistic latent semantic analysis (PLSA) method [41], a fractal fuzzy C means method adapted from [42] and the traditional recognition methods based on image matching via SIFT and speeded up robust features (SURF) [43].

We first use precision, recall and the F-measure, denoted as  $P$ ,  $R$  and  $F_\beta$ , to assess the proposed method's performance of recognizing airports and to compare it to other previous methods.  $P$ ,  $R$  and  $F_\beta$  are as follows:

$$P = \frac{TP}{TP + FP} \quad (10)$$

$$R = \frac{TP}{TP + FN} \quad (11)$$

$$F_\beta = \frac{(1 + \beta^2) P \times R}{\beta^2 \times P + R} \quad (12)$$

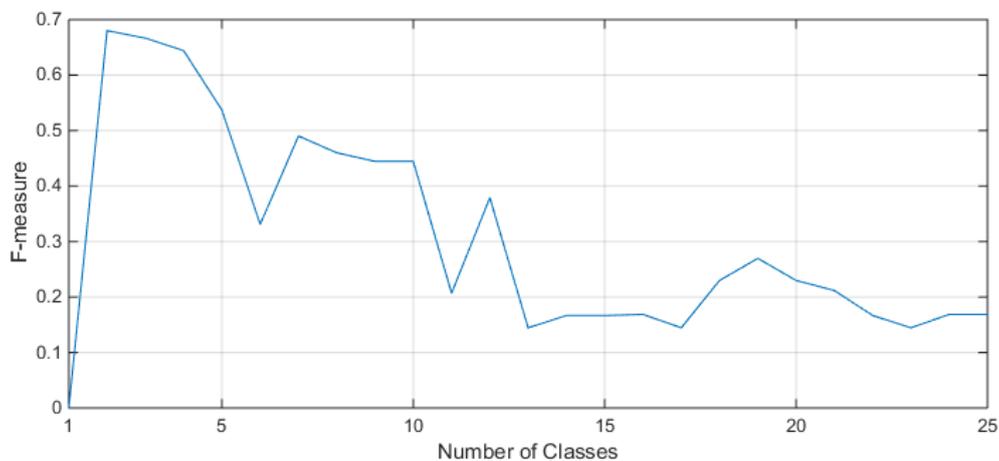
where  $TP$  is the number of images correctly classified as having airports,  $FP$  is the number of images wrongly classified as having airports,  $FN$  is the number of images wrongly classified as having other objects and  $\beta$  is a non-negative real number that serves as an indicator for the relative importance of precision and recall. High recall means that a method returns most of the targets, while high precision

means that a method returns substantially more targets than other non-relevant objects. The F-measure is the harmonic mean of precision and recall. A larger  $\beta$  weights recall higher than precision, while a smaller  $\beta$  puts more emphasis on precision than recall. In this application, high precision and high recall are both required. Therefore, we should take precision and recall as equally important and choose  $\beta = 1$ .

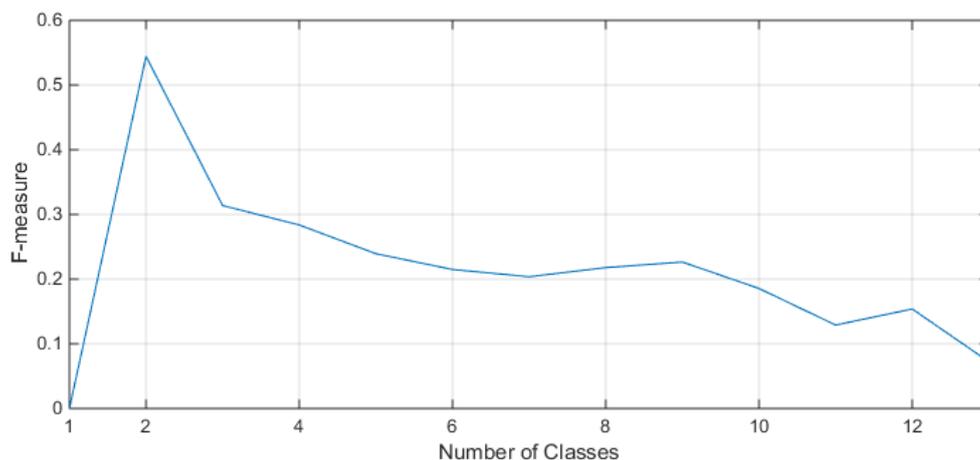
In the experiment, considering the amount and complexity of the image, some necessary steps are adapted for each method.

For SIFT and SURF matching method, random sample consensus (RANSAC) is applied to refine the matching key points.

For the fractal fuzzy C means method and the PLSA method, the F-measure is chosen as the assessment to choose the number of classes that leads to the largest F-measures for these two methods. Figure 9 shows the influence of the number of classes on the F-measure of the fractal fuzzy C means method, and Figure 10 shows the influence of the number of classes on the F-measure of the PLSA method.



**Figure 9.** Influence of the number of classes for the F-measure of the fractal fuzzy C means method.

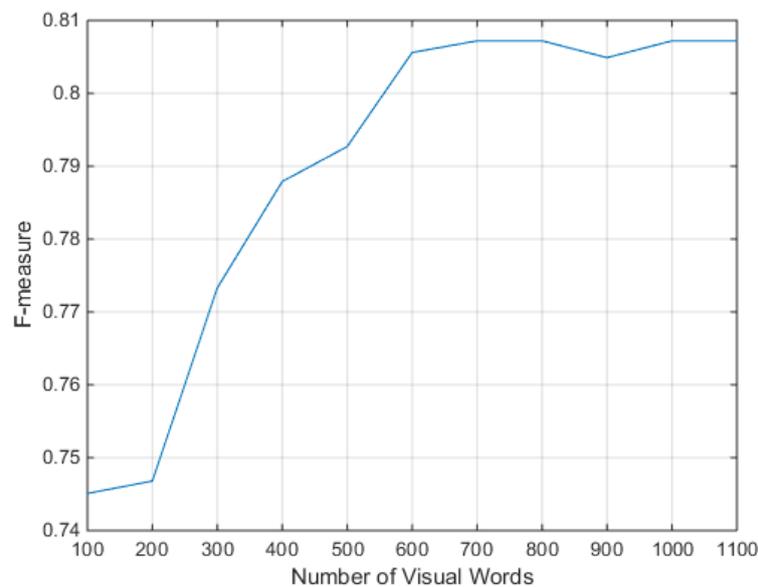


**Figure 10.** Influence of the number of classes for the F-measure of the BOVW method.

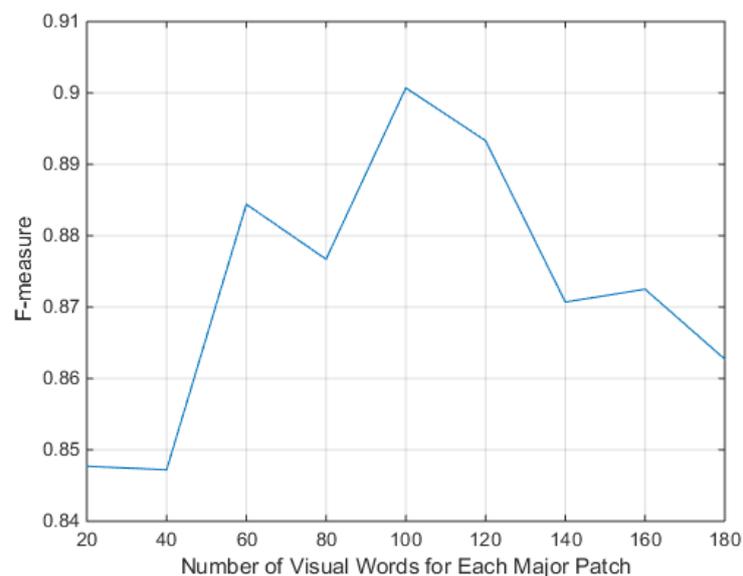
We can see from Figure 9 that when the number of classes equals two, the fractal fuzzy C means method gets the largest F-measure, and that when the number of class exceeds 10, the F-measure is below 0.4. We can also observe from Figure 10 that when the number of classes equals two, the PLSA method gets the largest F-measure, and that when the number of class exceeds two, the F-measure

is below 0.5. Therefore, we choose the number of classes as two for both the fractal fuzzy C means method and the PLSA method.

For the BOVW method and our proposed method, the F-measure is chosen as the assessment to choose the number of visual “words” that can lead to the largest F-measures for these two methods. Figure 11 shows the influence of the number of visual “words” on the F-measure of the BOVW method, and Figure 12 shows the influence of the number of visual “words” of each major patch on the F-measure of our proposed method.



**Figure 11.** Influence of the number of visual “words” for the F-measure of the BOVW method.

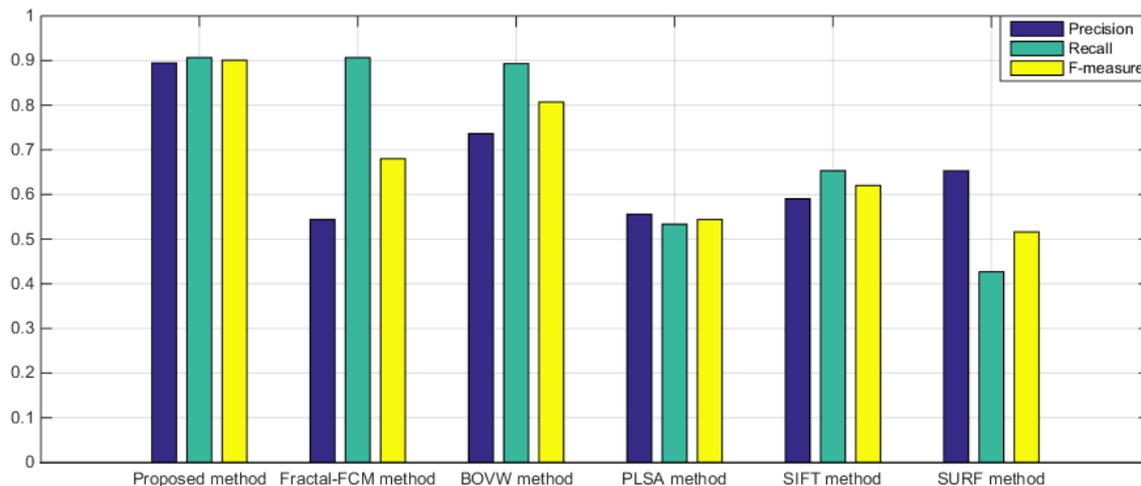


**Figure 12.** Influence of the number of visual “words” of each major patch for the F-measure of our proposed method.

We can find from Figure 11 that for the BOVW method, when the number of visual “words” reaches 700, the F-measure reaches the peak, and when the number of visual “words” increases, the F-measure begins to remain stable. We can also conclude from Figure 12 that when the number of visual “words” for each major patch reaches 100, our proposed method gets the largest F-measure.

Therefore, we set the number of visual “words” as 700 for the BOVW method and set the number of visual “words” for each major patch as 100 for our proposed method.

Then, we proceed to compare the largest F-measure and the corresponding precision and recall of each method. Figure 13 shows the precision, recall and F-measure of the performance of the proposed method and the competing models.



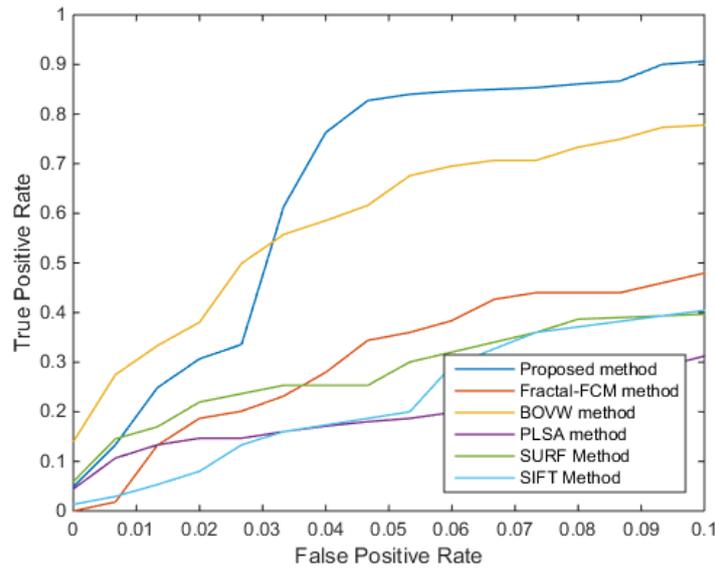
**Figure 13.** Precision, recall and F-measure of the performance of the proposed method and the competing models.

According to Figure 13, the fractal fuzzy C means method has a very high recall of 90.67%, but the lowest precision of 54.40%, which leads to a small F-measure. The PLSA method has a low recall of 53.33%, and the precision is 55.56%; therefore, the F-measure is small. The SIFT matching method has a moderate recall of 65.33%, but a relatively low precision of 59.04%, which also leads to a small F-measure. The SURF matching method has a moderate precision of 65.31% and the lowest recall of 42.67%, and the F-measure is the smallest. The BOVW method has a relatively high precision of 73.63% and a high recall of 89.33%, so the F-measure is the second largest. Our proposed method, while having a recall as high as the fractal fuzzy C means method, has a high precision of 89.47%, which is much higher than the competing methods. Therefore, the F-measure of our proposed method is the largest. This means that our method can not only extract semantic information to have a good representation of airports, but also highlight the difference between airports and other objects effectively to avoid a relatively low precision, which is the major drawback of those competing methods with high recalls.

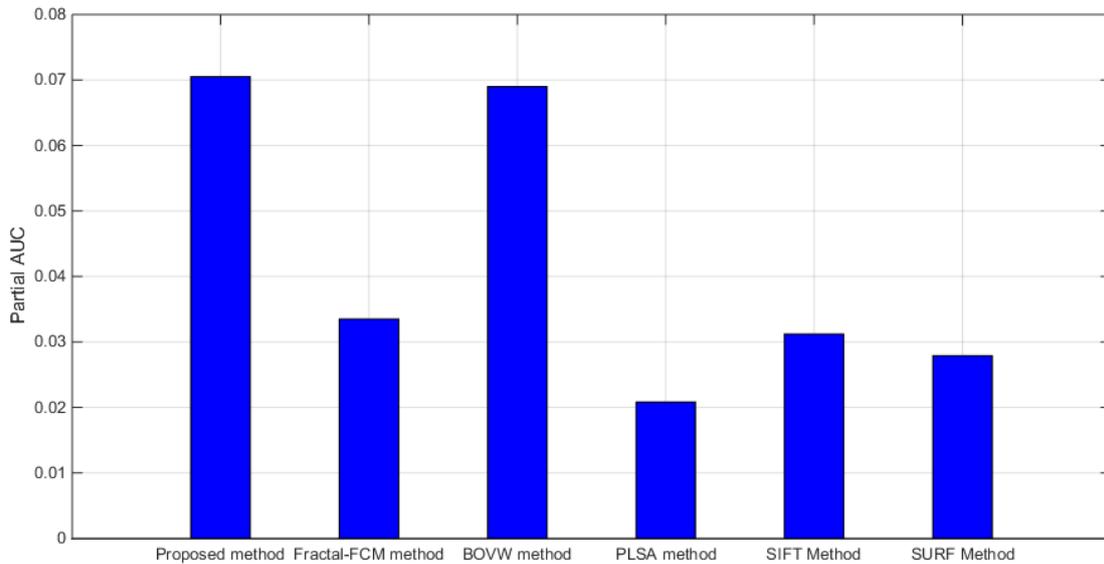
In addition, we use receiver operator characteristic (ROC) curves to quantitatively compare the methods’ performance. The ROC curves were generated by using the classification result of each method under different thresholds of prediction values. The prediction values range from zero to one, and 0.5 is chosen as the threshold to distinguish between positive and negative. The ROC curves and the corresponding area under curve (AUC) values can illustrate the performance of our method and the competing methods. In this application, we are only interested in the analysis of situations where a high true positive rate and a low false positive rate are realized at the same time, i.e., only the left part of the ROC curves is of practical interest to us. Therefore, according to [44,45], we compare the partial AUC values under only a portion of the ROC curves. In the experiment, we choose the part of the ROC curves corresponding to false positive rates ranging from zero to 0.1 according to the experiment in [46] for the assessment of the competing methods and our proposed method. Figures 12 and 13 show the partial ROC curves and the AUC values corresponding to false positive rates ranging from zero to 0.1 of the methods.

From Figure 14, we observe that under the range of zero to 0.1 for the false positive rate, our method achieves the largest partial AUC value. We can also conclude from Figures 14 and 15 that

when both the low false positive rate and the high true positive rate are required, our method can meet the requirement with the best performance.



**Figure 14.** Partial ROC curves of the proposed method and other methods. PLSA, probabilistic latent semantic analysis.



**Figure 15.** AUC of the proposed method and other methods.

In general, all of these analyses mean that our method performs better than the competing methods.

### 3.2. Analyses of the Performance of the Proposed Method on Different Types of Airports

In this part, we continue the analysis of the proposed method. Recall is used to analyze the proposed method’s performance for recognizing different types of airports. Table 1 shows the total numbers, the correctly-classified numbers and the corresponding recalls of different types of airports in the testing imagery. In this paper, we classify the airports in the testing imagery into two types:

Type 1 for those with runways on one side of the terminal and Type 2 for those with runways on more than one side of the terminal.

**Table 1.** Number and recall of different types of airports.

Name	Total Number	Correctly-Classified Number	Recall
Type 1	60	54	90.00%
Type 2	15	14	94.12%

It can be concluded from Table 1 that the proposed method does better at detecting airports with runways on more than one side of the terminal. Airports with runways on more than one side of the terminal are usually large, international airports with higher demand for land than smaller airports. They require large areas of open field, and this leads to less hybrid non-airport objects with airports.

Then, the false positive rate is used to analyze what kind of non-airport objects may be more likely to be wrongly classified as airports. Table 2 shows the total numbers, the wrongly-classified numbers and the corresponding false positive rate of each type of non-airport object. In this paper, according to the analysis in Section 2.3 and the testing data, we classify the non-airport objects in the testing imagery into five classes: farmland, residential area, forest, bare land and harbor.

**Table 2.** Number and false positive rate of different types of non-airport objects.

Name	Total Number	Wrongly-Classified Number	False Positive Rate
Farmland	27	4	0.1481
Residential Area	85	2	0.0235
Forest	12	0	0.0000
Bare land	15	2	0.1333
Harbor	11	0	0.0000

From Table 2, it can be observed that farmland has the highest false positive rate, while forest and harbor have zero false positive rates. Mountain has a high false positive rate, while residential area has a low false positive rate. Airport has a high demand for open field and usually has to be located in the suburbs or even wild areas. Such areas belong to sparsely-populated residential areas, farmland or bare land, and they may be mixed with airports.

#### 4. Conclusions

VHR images have been extensively used in recent years. Recognizing and retrieving objects or scenes from VHR images is a challenging task. Among the objects that are often detected, airports play a key role because of their significance in civil and military fields. Traditional methods are ineffective; thus, a new method was proposed. The new method adapts the traditional pixel-based saliency detection method into the patch-based method for class-specific saliency to find the best segmentation to highlight the differences between airports and other objects and to analyze the spatial relationship between components of the airport to help with the abstract and detailed semantics. The new method also combines the traditional BOVW method with fractal dimension estimation, fuzzy C means clustering and image relational degree on the basis of fuzzy rule-based classification to extract the object composition for better representation of airports. The experiment proves that the proposed method outperforms the traditional methods in terms of precision and recall.

However, there is still room for improvement. First, the proposed method can tell whether there is an airport in the given image or not when the airport takes up the dominant part of the image, but when an airport only takes up a small part of the given image, the method cannot tell the possible locations. Second, the proposed method can extract abstract semantics and detailed semantics from BOVW features and fractal features with analysis of the general knowledge of the airport, but lacks the

ability to use more specific knowledge of the airport or other mid-level or low-level features for more efficient analysis and extraction of abstract semantics and detailed semantics. Finally, the two-step classification of the proposed method should be further improved to reduce the false positive rate and to realize higher recall and precision.

Therefore, for future research, we will focus on the following aspects. First, we will focus on the extraction and usage of multiple features based on more specific knowledge of the airport to express the semantic information of the airport more precisely. Second, we will propose improved saliency detection methods to extract the possible area of airports on optical imagery and present class-specific saliency more precisely. Finally, we will perform further research into the use of the image correlation degree and adapt the concept of deep learning to improve the precision and recall.

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