SAR image matching area selection based on actual flight real-time image

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***Abstract*—Matching suitability analysis is a key issue of INS/SAR integrated navigation mode. The existing suitability area selection methods use the simulated real-time image to calculate the matching probability of the scene area and further label it "suitability" or "unsuitability". If the imaging mode of the simulated image is the same as that of the real image, the suitability area selection model based on the simulated real-time image works well. Otherwise, the model is impractical. In order to address this issue, a novel method is proposed in this paper. The sample dataset is built on the actual flight real-time images, and a hybrid feature selection method based on D-Score and SVM is used to select the suitability features and build the suitability area selection model simultaneously. Experimental results show that the consistency between the prediction results of the model and the ones experts label reaches 81.92%.**

Keywords—INS/SAR integrated navigation, suitability area selection, suitability features, real-time image, feature selection

I. INTRODUCTION

Inertial/Synthetic Aperture Radar (INS/SAR) integrated navigation mode is an ideal navigation mode because of its high autonomy and strong anti-jamming capability [1]. The principle of the INS/SAR navigation system is to match the real-time image taken by the aircraft with the pre-loaded satellite SAR reference image to get the real-time coordinate position, and to correct cumulative errors of the inertial navigation device after long-time working. In order to ensure the matching reliability, the suitability areas needed to be selected before the flight.

The suitability areas are the scene areas that meet the requirement of the matching probability. The matching probability is the probability that the real-time image can be located correctly by the image matching with the reference image when the real-time image is in the specified area, which size is determined by the parameters of the aircraft platform, the sensor, and the inertial navigation system. The problem of the suitability area selection is to estimate the matching probability of a scene area without the real-time image. Some researchers, such as in [2], [3], [4], [5], tried to construct a synthesized feature, which is homomorphic with the matching probability. Unfortunately, the synthesized feature that meets the need remains unfound. Some researchers simplify the matching probability estimation problem into a binary classification problem [6][7]. Firstly, the matching probabilities are calculated with the reference images and the simulated real-time images, which are mostly satellite images now. Then, the scene areas are labeled as "suitability" or "unsuitability" according to a specified threshold. Finally, the function between the suitability features and the scene area classes is established by supervised learning. If the imaging mode of the satellite sensor is the same as the one of the aircraft sensor, the function works well. Otherwise, this function is impractical.

The remainder of the paper is organized as follows. A novel SAR image suitability area selection method based on actual flight real-time is detailed in Section II. In Section III, the effectiveness of the proposed method is verified by taking aerial RAR images and TerraSAR images as an example. Finally, conclusions are reported in Section IV.

The work is sponsored by The National Key Research and Development Program of China (2018YFB0505402), the National Key Basic Research Program of China (973 Program) (2012CB719903)
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II. METHODOLOGY

A. *Sample dataset*

At the stage of test flight, the aircraft flied along the route designed by experts. The real-time image was taken in every specified area and was located by image matching with the reference image. Each real-time image is regarded as a stochastic sampling. Statistically, small probability event is unlikely to happen in a single test. According to the small probability principle, the scene areas are labeled as "Suitability" as long as the real-time images match the reference images correctly. Otherwise, they are labeled as "unsuitability".

B. *Suitability features*

The core issue of the scene area matching suitability analysis is extraction and evaluation of the suitability features. Although the suitability features selected by different experts are various, the principles of informativeness, robustness, and uniqueness for the suitability features are undisputed [8][9]. Referring to the research results from other scholars and our practical experience, the image features in this paper include information entropy, image gray variance, Harris corner response value, edge density, surface density, correlation plane statistic features. Edge density is defined as the percentage of edge pixels derived from image edge detection in whole image. Surface density is defined as the percentage of the foreground pixels derived from image segmentation in whole image. The Correlation plane is a two-dimensional surface that measure the similarity between two images in each position.

For SAR images, besides the image features, the suitability features should include the topographic features. In this paper, elevation variance and maximum height difference are used to describe the topographic relief. The maximum height difference equals the maximum elevation value subtract the minimum elevation value.

C. Suitability feature selection and suitability area selection model

Generally, more features will provide more information, but too many features will greatly increase the computing complexity. Worse still, redundant information, irrelevant information, and even noise can mislead decisions and judgments. Feature selection from initial feature sets needs to be carried out firstly. There are two aspects must be considered in feature selection: one is evaluation criteria, and the other is search strategy.

Obviously, for suitability feature selection, the evaluation criterion should be maximizing matching probability. If the matching probability estimation problem is simplified into a binary classification problem, the evaluation criterion should be minimizing classification error probability. There are three types of search strategy: global optimal search, random search and heuristic search, and three strategies have their own advantages and disadvantages. In practice, if the rules of the heuristic search strategy are well designed, it can achieve the similar results of the other two search strategies and compute faster [10].

There are definitely exist some errors in the sample dataset, therefore, support vector machine with soft-margin is used for classification. The hybrid feature selection method based on D-Score and SVMs is used to spit out the suitability features from the candidate feature set [11][12][13]. The flow chart is shown in Fig. 1: (1) Sort the candidate feature set A in descending order by D-score value; (2) Initialize the suitability feature set B into an empty set; (3) Move the first element in A into B; (4) Train the SVM classifier based on the suitability features in B; (5) If the classification accuracy is not improved, delete the newly moved element from B; (6) Repeat (3) – (5) until A is empty. When the suitability feature selection is finished, the suitability area selection model will be generated simultaneously.

The D-Score value uses the ratio of the inter-class variance to the intra-class variance to reflect the intrinsic characteristics of the data, and is able to fix the difference of order of magnitude among the different features. The larger the value is, the better the classification performance of the corresponding features is. The calculation formula is as follows:

$$D_i = \frac{\frac{1}{l-1}\sum_{j=1}^{l}\frac{(\overline{x}_i^j - \overline{x}_i)^2}{\overline{x}_i}}{\sum_{j=1}^{l}\frac{1}{n_j\text{-}1}\sum_{k=1}^{n_j}\frac{(x_{k,i}^{(j)} - \overline{x}_i^{(j)})^2}{\overline{x}_i^{(j)}}} \tag{1}$$

In (1), $\overline{x}_i$ stands for the mean value of the *i*th feature in the whole data set, and $\overline{x}_i^j$ stands for the mean value of the *i*th feature in the *j*th class. l is the number of classes, $x_{k,i}^{(j)}$ is the *i*th feature of the *k*th sample in the *j*th class.

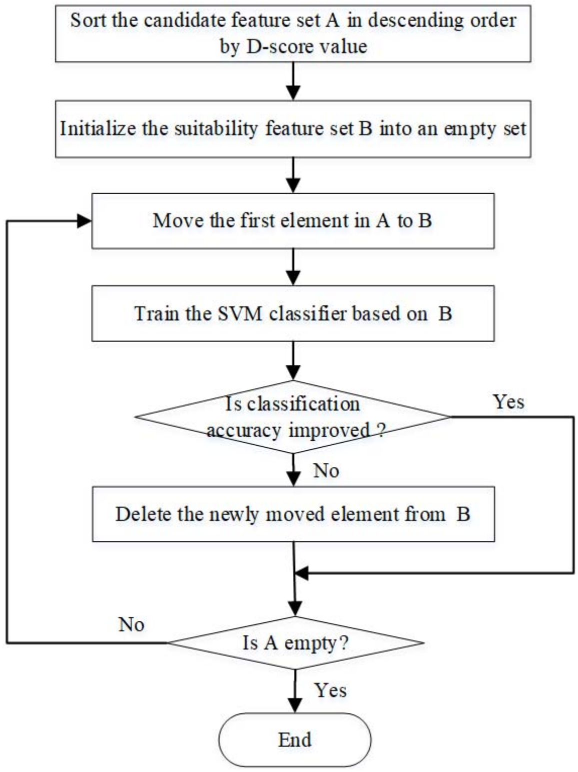
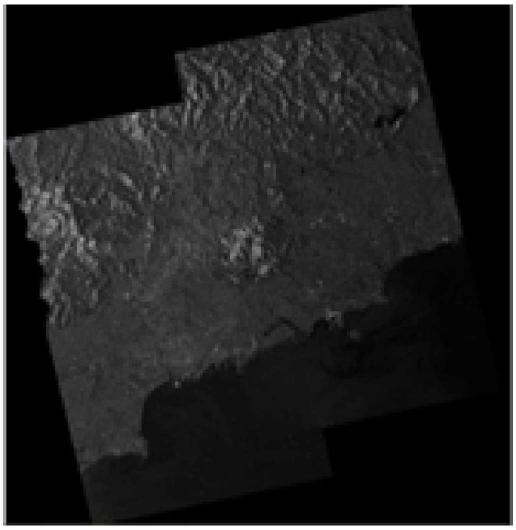


Fig.1. Hybrid feature selection method based on D-Score and SVM

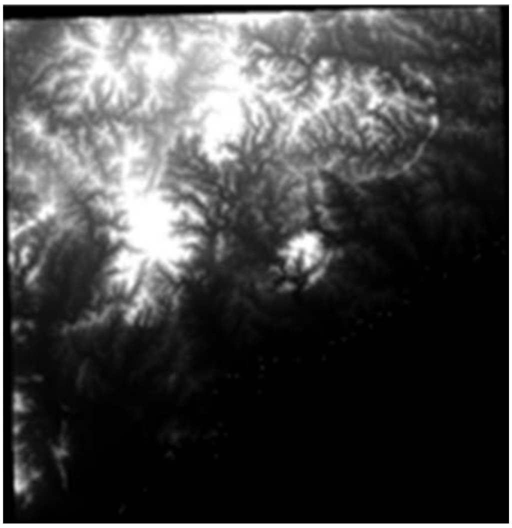
III. EXPERIMENT

A. Study areas and experiment data

The reference images used in the experiment are the X band of TerraSAR images after ortho-rectification and image mosaic. There are various types of land cover in the study areas, such as city, mountain, river, desert and so on. Figure 2 shows the SAR image (Fig. 2(a)) and the corresponding DEM (Fig. 2(b)) in Shanhaiguan, and the resolution of both is 5m. The size of the matching area is 1500×1500 m2. The real-time image is real aperture radar image (RAR), shown as Fig. 3 (a). The real-time image taken by aircraft along the planned route is located by image matching with the reference image based

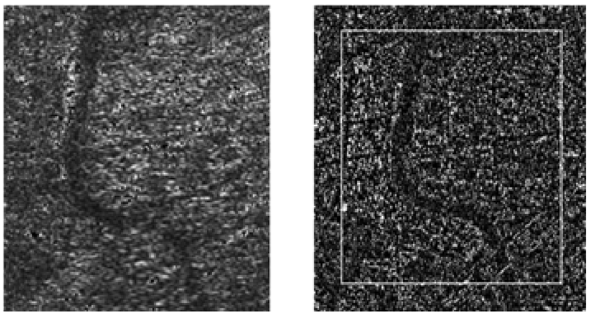


(a) TerraSAR image



(b) DEM image

Fig.2. The reference image and the DEM image of the study area



(a) RAR image (b) SAR image

Fig.3. The real-time image and the reference image, the white rectangle in (b) displays the position of the real-time image (a)

on normalized cross-correlation algorithm. "Suitability" and "Unsuitability" will be labelled on the scene areas for the correct matching results and the mismatching ones checked by experts. In fig. 3(b), the white rectangle denotes the location of the real-time image in the reference image. Both images in Fig. 3 are processed by image enhancement for visualization.

B. Results and discussions

The D-Score value of each feature calculated by formula (1) in descending order is shown in Table 1. It is obvious that topographic features have a great influence on SAR image matching. The suitability features are selected from the initial feature set by using sequential forward selection method, and the SVM classifiers based on different suitability features are trained by supervised learning, and the corresponding overall classification accuracies are shown in Table 2. The optimized suitability feature set contains 2 topographic features and 4 image features, which are elevation variance and the maximum height difference, image gray variance, autocorrelation coefficient, edge density extracted by Sobel operator and surface density extracted by OTSU. The highest classification accuracy is 81.92%. The kernel function used in SVM is radial basis function. The training samples are 512 positive samples and 512 negative samples, and the test samples are 512 positive samples and 793 negative samples.

The results selected by experts and the prediction model are visualized separately in Fig. 4, the suitability areas are shown in light grey, the unsuitability areas are shown in the dark grey and areas in white are undetermined due to lacking of DEM. Most of both results are identical. Several small areas are selected to analyze in detail. Fig. 5 shows the examples of correct classification. The suitability area shown as Fig. 5(a) is flat and its image is rich in feature information. The mountain and hill area shown as the left image of Fig. 5(b) is an unsuitability area although its image is informative. If an image is short of feature information like the right image of Fig. 5(b), the area covered by the image must be an unsuitability area. Fig. 6 shows an area that the expert labels it an unsuitability area, but the class labeled by the model is on the contrary. Because half of the image is rich in information, and the other half is poor in information. The suitability features used in this paper are all statistics of the scene area, which can't describe the spatial arrangement of the image features.

TABLE I. THE FEATURES AND THE D-SCORE VALUES

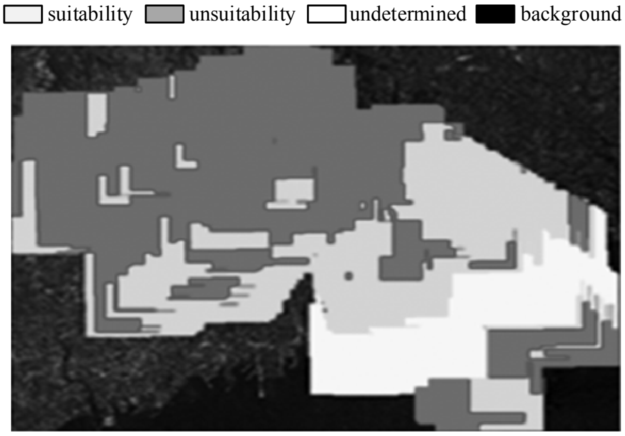
Feature	**F1**	**F2**	**F3**	**F4**	**F5**
D-Score	166.55	151.29	139.04	82.05	41.19
Feature	**F6**	**F7**	**F8**	**F9**	**F10**
D-Score	34.98	30.55	28.18	2.41	0.56

F1 - elevation variance, F2 - image gray variance, F3 – the difference of the highest and secondary peak of the correlation plane, F4 – autocorrelation coefficient, F5 – information entropy, F6 - edge density extracted by Sobel operator, F7 - surface density extracted by OTSU, F8 – Harris corner response value, F9 - edge density extracted by Canny operator, F10 – the maximum height difference.

TABLE II. THE FEATURE SUBSETS AND THE CORRESPONDING CLASSIFICATION ACCURACY

Feature subset	**F1**	**F1F2**	**F1F2F4**
OCA[a] (%)	69.58	71.72	78.93
Feature subset	**F1F2F4F6**	**F1F2F4F6F7**	**F1F2F4F6F7F10**
OCA (%)	80.77	81.04	81.92

[a] OCA - Overall classification accuracy

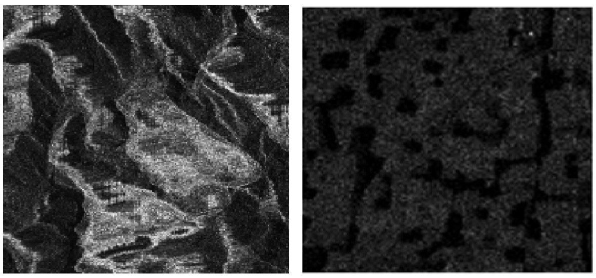


(a) Labelling by experts

(b) Labelling by the prediction model

Fig.4. Labelling by experts compared with the prediction model

(a) Suitability Areas



(b) Unsuitability Areas

Fig.5. Examples of correct classification

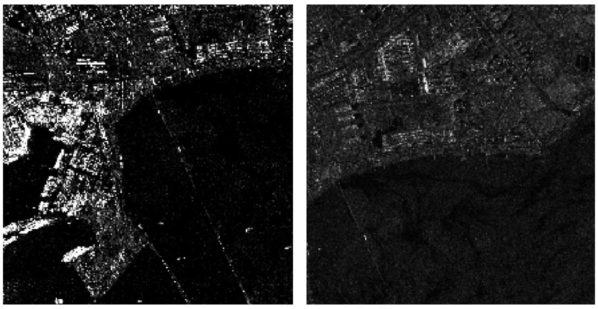


Fig.6. Examples of misclassification

IV. CONCLUSIONS

In this paper, a novel method is proposed to build the sample dataset of suitability analysis. The real-time images taken by aircraft at the stage of test flight are used to match the reference image, and the scene areas are labeled as "suitability" or "unsuitability" according to the matching results. Experimental results verify the prediction model trained based on D-score and SVM by supervised learning can select the suitability area effectively. The suitability features used in this paper are all statistics that are unable to describe the structure information and spatial arrangement of the scene areas, and will lead to some errors. In future study, deep learning will be used to extract the better suitability features to improve the prediction accuracy.

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