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学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　TIAN Ying

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Absent Colors and their Application to Image Matching
（非顕在性色特徴とその画像照合への応用）

A novel approach called absent color indexing (ABC) is proposed for robust image matching in similar objects and cluttered scenes. Image matching plays an important role in the field of computer science and technology; color features have been frequently utilized as a statistical measure of color distribution to analyze image similarity. In particular, color histograms are widely used for image matching because they have good characteristics for handling different challenges, such as rotation, deformation, scale variation, and occlusion. However, existing color histogram-based approaches focus on the main color. For similar images with few, but prominent, color features, mismatches may occur during the comparison process. Therefore, we are interested in how to make this type of color feature work.

The proposed approach provides a balanced method to focus on the contributions of absent or minor colors belonging to low-frequency or vacant bins in the histograms, which are realized by separating the source color histogram into apparent and absent color histograms. Among them, apparent colors are an essential element of conventional algorithms, serving as the main image color. Then, a threshold for this separation is obtained from the mean color histogram by considering the statistical significance of the absent colors, the frequency of which in the histogram bin is relatively low. Therefore, the inverting operation becomes particularly important. After inverting, we can effectively increase the proportion of absent colors by reversing the absent color histogram after separation. Finally, we evaluate a variety of similarity measures that can be combined with the proposed ABC, which exhibited robust image matching and distinguishability.

Algorithms based on color histogram matching exhibit better robustness, but the location information of the search target is missing in the process of color statistics. Furthermore, offset or drift often occurs in the image matching process. To overcome this problem, we propose a method that combines ABC with correlation filtering (CF) to improve matching accuracy. The CF algorithm calculates the filter by learning a template image as input and generating a two-dimensional, peak-centered, Gaussian-like model as output. Further, it relocates the matching position searched by ABC according to the generation filter to obtain the response map. The highest point in the response graph represents the best-matched position found using the combination of ABC and CF (ABC-CF).

To improve the ABC approach, the offset or drift problem can be addressed by using only the color information. A multiple-layered (ML) structure is designed to add location information to the histogram-based matching process. The ML structure divides the image into three layers based on the principle that the color information of the central area remains unchanged, with the central location as the common base point. To combine ABC and ML structures (ABC-ML) in the image matching process, we perform ABC on the image of the corresponding layer. The similarities of each layer are weighted

and summed to obtain the final result. These two improved algorithms improve the matching accuracy while maintaining the advantages of ABC. This thesis is organized into the following chapters.

Chapter 1 introduces the related works in image matching and describes the importance of our research. Some of the challenges are included and discussed in image matching. Furthermore, the motivations and contributions of this study are described.

Chapter 2 presents the details of the novel concept of ABC based on the color histogram in image matching. We introduce the definitions of apparent and absent colors obtained by separating the original color histogram. Subsequently, the selection of color space is illustrated. Threshold h_{T} is defined to obtain apparent and absent color histograms using the mean color histogram. Four similarity measurements are discussed, which were each separately combined with ABC to evaluate the similarity of images. Therefore, many measurements can be combined with our proposed ABC methods. The margin discussion shows the distinguishability of ABC with different measurements on the Mondrian pattern. We further analyze the performance of ABC under different challenges, such as variations in illumination and scale as well as rotation, deformation, and occlusion.

Chapter 3 introduces our proposed method to utilize the proposed ABC in combination with CF. The scheme presented is effective for precise registration based on Fourier domain training and filtering, which can generate a sharp peak in the relevant output to precisely position the matching image. We train the reference as the first step. An optimal filter is obtained by calculating the minimum output sum of squared error (MOSSE) on inputs and outputs. Subsequently, the optimal filter is applied to the position selected from the search by pre-processing ABC to transform its response map into the Fourier domain. Finally, we convert the space to find the best matching position. We verify the ability of ABC-CF with adequate experiments.

Chapter 4 presents the proposed ABC-ML in detail, including the new concept of total color space and how to combine ABC and ML. An ML structure based on the isotonic principle to keep the center location is not changed. Because target images involve scale variation, rotation, and deformation, the image features at the center zone are largely retained, especially color features. Next, we aim to accurately position the target by dividing the image into multiple layers. Ultimately, each layer plays a role in restraining each other' s positional relationship to obtain an optimized matching effect. We report the results of measurements of the robustness and efficiency of our proposed ABC-ML on real-world images and open data.

Chapter 5 introduces the experimental evaluation. The experimental setup is described in detail. Parameter selection is discussed for comparison with fixed values. The matching performance of ABC, ABC-CF, and ABC-ML were compared experimentally, and the results are reported. We also discuss some aspects of the advantages and disadvantages of the proposed technique in this chapter. ABC has some notable benefits, including technical simplicity as well as invariance in rotation, distortion, and to some extent scaling. Furthermore, we compare ABC, ABC-CF, and ABC-ML to describe their respective performance characteristics.

The final chapter summarizes the main points of our research. Finally, we present the conclusion and suggest some possible avenues for future research.