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Adaptive fusion algorithm of heterogeneous sensor networks under different illumination conditions

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ABSTRACT

This paper presents an adaptive fusion method used in heterogeneous sensor networks, which consist of infrared sensors and visible sensors. A fuzzy system is applied to classify the imaging illumination conditions. We select three image quality evaluation parameters as the inputs of the fuzzy system, and the system's output will determine the fusion weights of the two kinds of images. It means that the classification results are used to guide the fusion process. An adaptive fusion scheme according to blended basis functions is used to fuse the images. Our adaptive fusion rule is compared with the weighted average fusion scheme in the experiments under both high illumination conditions as well as low illumination conditions. The simulation results on the Matlab platform verify that our adaptive fusion algorithm has better applicability to different illumination environments when compared with the fixed weights fusion algorithm.

1. Introduction

The proliferation of heterogeneous sensor networks (HSN) has created a large amount of multi-sensor signals across multi-modality. Traditional approach often makes detection at each sensor and integrates the binary decision information at a central processor. In doing so, much of the important sensor signal information is lost. Recent information theoretical approach [1] has laid out a new methodology on information fusion in HSN. However, quite often visible and infrared sensors may contain linguistic knowledge, and it is not always possible to obtain the statistical information. Fuzzy system is capable to handle such uncertainties and has been widely used in wireless sensor networks [2–4]. In this paper, we focus on the fusion problem of visible and infrared image sensors in heterogeneous sensor networks based on fuzzy system.

Visible and infrared imageries can provide disparate but complementary information about a same scene due to their different imaging principles. Visible images can demonstrate the reflective light properties of the target objects, while infrared cameras capture the thermal emissivity of the same scene. Visible images have rich contrast and color information, which is in accordance with human visual habits, can help us to monitor and measure the target quickly and accurately. While in total darkness, over-exposing brightness, smoke, heat and other special environments, infrared imagery shows its advantages. Image fusion is an effective way to synthesize the information that comes from different image sensors [5], so as to achieve a more precise description of the scene. The image fusion technology makes the outdoor all-weather monitoring become an easy task.

2. Imaging illumination condition classification

In order to make our fusion method applicable to different imaging environments, we propose to classify

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the illumination conditions of the imaging environments before the fusion, and then fuse the images of different classes distinctively. As for normal conditions, visible images with rich detail information should be given greater weights; while under special conditions, total darkness for example, the visible images become unreadable, so the weights of infrared images can be tuned to a larger degree. So our algorithm falls into two phases, including illumination condition classification and adaptive fusion.

2.1. Choice of the classification method

Classifying the illumination conditions of the imaging environments by human judgment cannot get rid of subjective factors, and cannot meet the demands of processing automatically yet. While assorting the images by the objective parameters of images often leads to a rigid result, which lacks of flexibility and reliability. For instance, Fig. 1 shows a visible image. When it is judged from the subjective perspective, the conclusions may be various among observers. Some observers may consider that the imaging environment is too bright and it leads to an over-exposing visible image; while others will probable to say that the image's brightness is just fine. So it is difficult to draw a unified conclusion. However, the common way of objective classification needs to select proper parameters and preset an exact threshold value for each of them. The classification result lies in the ranges that the parameters belong to according to the thresholds. So the selection of parameters and the determination of thresholds need to be cautious. And when the value of the parameter falls in the vicinity of the threshold, it will be difficult to achieve a desired classification result, for a slight value difference of the parameter will probably cause a converse judgment.

In order to ensure the objectivity of the image classification and deal appropriately with the unclear boundaries between classes, we propose to introduce fuzzy logic theory to the classification process. A fuzzy system is designed to classify the visible images according to the illumination conditions of their imaging environments.

Fig. 1. The visible image which is controversial in the illumination subjective evaluation.

The fusion rules of different images are various according to their classification results.

2.2. Introduction to fuzzy logic

Fuzzy logic can mimic the way of human reasoning, predicting and concept formation, so it is adept in describing objects with unsharp boundaries by qualitative information [6]. Fuzzy logic argues that there is a "gray" zone between "black" and "white". It is a branch of fuzzy theory. Fuzzy theory was proposed by professor L.A. Zadeh in 1965. He used the concept of "membership function" to express the fuzzyness of things for the first time. Since then the foundation of fuzzy theory has been established. Soon after, in 1966, P.N. Marinos published a research report in which the concept of fuzzy logic was formally proposed. Fuzzy logic is the extension of the classical two-valued logic. It excludes the simple "either-or" judgment of the two-valued logic, replacing it by the membership function to represent the degree of things belonging to a certain category [7]. It provides a potential option for us to simulate the reasoning process of human being by computer.

2.3. Design of the fuzzy system

For the sake of getting the appropriate image fusion scheme under different environment conditions adaptively, we have to get a clear vision of the characteristics of the imaging environment, such as "darkness", "over-explosion" and so on. However, as previously described, if the objective assessment could be combined with the human-like reasoning process, a more intelligent judgment will be obtained [8]. So we introduce fuzzy system to the phase of analyzing the illumination features of imaging environment. Several image quality evaluation parameters are chosen as the inputs of the system, and the output is set to be the classification result.

The design process of the fuzzy system on the Matlab platform includes the following phases [9]: selecting the input and output parameters, determining the membership functions, generating the fuzzy rules and so on.

2.3.1. Design of the input and output variables

In the selection of the input parameters, the ones that show obvious differences or present regularities in different imaging conditions will be set as the candidates. So we choose three parameters: average gray, contrast and information entropy as the input variables.

The average gray of image directly reflects the mean value of the image's brightness. For the same object, the average gray values of the images taken under different illumination conditions show a good linear relationship within a certain range.

Image contrast is an attribute of visual perception. It is determined by the difference in color or brightness between the object and other objects within the same field of view. The visible images that shot in dark environments will show low contrast. The contrast enhances gradually with the increase of the illumination intensity of the