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Dual-band stereo vision based on heterogeneous sensor networks

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ABSTRACT

This paper presents an approach of dual-band imagery based on heterogeneous sensor network which consists of infrared and optical sensors, and our approach of imaging reconstructs the three-dimensional shapes of the objects in some special environments such as smog, darkness, glare and so forth. Two dichroic mirrors are used for the construction of the binocular stereo vision system which consists of two optical (visible) and two infrared cameras. We make use of the complementarity between infrared and visible images to form two fused images as the source images of the stereo vision system. A stereo matching algorithm based on dual-band images is proposed as well. We use the gray, gradient direction and gradient magnitude of the pixels taken from the two bands of images to compute the disparity value of each pixel. Experiments show that the stereo matching algorithm is robust and not sensitive to the environmental variations. As a result, the dual-band stereo vision system has a good support for the target recognitions and measurements in different environments, such as all-weather traffic monitoring, searching and rescuing in fires, and so forth.

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1. Introduction

The proliferation of heterogeneous sensor networks (HSN) has created a large amount of multi-sensor signals across multi-modality (e.g., optical, EO/IR, acoustic/seismic, RF, electromagnetic, mechanical, thermal, electrical, etc). 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 has lost. In [1], an opportunistic sensing approach was proposed to integrate different modality sensors. To fuse different modality data for situation understanding in heterogeneous sensor network, a human-inspired favor weak Fuzzy Logic System was proposed [2]. A hybrid network approach which considered different wireless devices modes was studied in [3]. Quite often, all these heterogeneous sensor networks consider modalities such as RF [4,5], acoustic [6], and different sensor status such as energy [7], spatial information [8], link quality [9], etc. In this paper, we are interested in heterogeneous sensor network with optical and infrared modalities, and apply it to binocular stereo vision.

The binocular stereo vision based on visible light has developed rapidly in recent years. Visible light imaging has rich contrast, color and shape information. Hence it can identify, monitor and measure the target quickly and accurately [10,11]. As a contrast, the imaging technology of infrared band shows its advantages in some special environmental conditions such as darkness, smog, high temperature, etc. [12,13]. With the development of the multi-sensor data fusion technology, image fusion has been widely used in computer vision field [14–16]. The information contained in the images, which are captured by the multi-band image sensors, can reduce the system's dependency on the natural environment based on the

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image fusion process. As a result, applying multi-band image sensing into stereo vision can expand the application fields of binocular stereo vision.

The binocular stereo vision technology usually focuses on the accurate acquisition of the binocular disparity information, which can be used to compute the depth information of the scene, and then reconstruct the 3D positions of the objects. Stereo matching is the main way to obtain the point correspondence between the two fields of view [17,18]. In the process of stereo matching based on the single-band images, the effect of stereo matching is hard to be guaranteed in some special circumstances. Taking the binocular stereo vision system of visible light as an example, the object cannot be clearly imaged and the corresponding pixels in a pair of stereo images can hardly be obtained in the darkness, smog and other environments, so the 3D shape reconstruction of the object cannot be realized either. The dual-band stereo vision system proposed by this paper can take the two bands of images simultaneously, and the image information is more abundant than the single-band stereo vision system. The accuracy of the stereo matching and the adaptability to different environments can be improved by the complementarity and redundancy of different bands of information.

2. Design of the dual-band stereo vision system

2.1. System structure design

One of the core issues needed to be resolved, during the design process of the dual-band stereo vision system, is to unify the optical path of the two bands of cameras in the same view. When we design the relative posture and position of the four cameras, there are two factors needed to be considered in advance. One is to ensure that the object to be measured can be completely imaged by each camera. The other is to guarantee that the perspectives of both the infrared and visible light cameras in the same field of view are consistent. A well-done design will lay a good foundation for the following image registration and fusion. The structure of the system is shown in Fig. 1.

The design of the system is based on the structure of the traditional parallel binocular stereo vision system. The images of each field of view are acquired by a camera group, since the two fields of view are required to obtain both visible band images and infrared images simultaneously. Each group of cameras includes an optical camera and an infrared camera respectively, so the system is called dual-band stereo vision system. For each side, a dichroic mirror is set between the two bands of cameras. The optical path of the system is shown in Fig. 1. The optical channel is shared between the visible light reflected from the measured object and the infrared light emitted by the object. The light is then divided into two parts by the dichroic mirror, which is used as the specific wavelength selective lens. Finally, the light of different bands can be imaged in their own sensors. That is the infrared radiation is reflected into the infrared camera via the dichroic mirror, while the visible light is transmitted to the optical camera directly. The light of different bands can be imaged respectively. Each camera is seated in its own base. The angles and heights of the four cameras' bases can be adjusted freely. The structure of the system can effectively guarantee that the two cameras of the same perspective of view have the same visual range, and the two baselines of the two bands of cameras are consistent, so the difficulty of image registration can be reduced.

The dual-band stereo vision system shown in Fig. 1 can be equivalent to the structure model of Fig. 2.

It can be seen from Fig. 2 that the dual-band stereo vision system is equivalent to the superposition of two sets of binocular stereo vision system. The base band of the system should be determined according to the features of the working environment. The band which has better imaging effect in the environment will be selected as the base band of the system. For example, the infrared band will be chosen as the base band in total darkness, while in a crisp and bright environment, setting the visible band as the base band will be a better choice.

The image of the base band will be used as the reference image of the image registration. Then the image of the other band has to be registered with the reference image through geometric transformation, so as to form the image source of the stereo vision by image fusion. In the 3D reconstruction process, the binocular stereo calibration parameters of the base band can recover the 3D shape of the object from the disparity map.

2.2. Work flow of the system

There are many processing steps in the work flow of the dual-band stereo vision system, as is shown in Fig. 3. On one hand, the basic steps of the traditional stereo vision should be included, such as image acquisition, stereo matching, and 3D reconstruction, etc. On the other hand, several special processing steps of dual-band stereo vision system are also added, such as the environmental feature analysis, adaptive image fusion and stereo matching based on dual-band images and so on.

After the system collecting the images of both infrared and visible band separately, the environmental features are firstly analyzed. The purpose of the environmental features analysis lies in two aspects, one is to determine the base band of the system, and the other is to determine the image fusion criterion according to the current environment. In the process of image preprocessing, the image quality can be improved by denoising and image enhancement. In the stage of image fusion, the images of the two bands are fused according to the adaptive fusion algorithm, and the fused images are used as the source of the texture mapping after morphology reconstruction. In order to make full use of the redundancy of the dual-band information, the system will combine the image information of the two bands for stereo matching and form the dense disparity map. Finally, the disparity information and the calibration parameters of the base band are used to compute the 3D information of the measured object. After the surface profile of the points cloud information is reconstructed, the fusion images are used to map the

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