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Target recognition of log-polar ladar range images using moment invariants ☆

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ABSTRACT

The ladar range image has received considerable attentions in the automatic target recognition field. However, previous research does not cover target recognition using log-polar ladar range images. Therefore, we construct a target recognition system based on log-polar ladar range images in this paper. In this system combined moment invariants and backpropagation neural network are selected as shape descriptor and shape classifier, respectively. In order to fully analyze the effect of log-polar sampling pattern on recognition result, several comparative experiments based on simulated and real range images are carried out. Eventually, several important conclusions are drawn: (i) if combined moments are computed directly by log-polar range images, translation, rotation and scaling invariant properties of combined moments will be invalid (ii) when object is located in the center of field of view, recognition rate of log-polar range images is less sensitive to the changing of field of view (iii) as object position changes from center to edge of field of view, recognition performance of log-polar range images will decline dramatically (iv) log-polar range images has a better noise robustness than Cartesian range images. Finally, we give a suggestion that it is better to divide field of view into recognition area and searching area in the real application.

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1. Introduction

As theoretical and technical developments continued, ladar has attracted considerable attentions and has been widely applied in every aspect of the modern world [1–3]. In general, ladar can be sorted into two types: scanning type and non-scanning type [4]. Different ladar type has its own merit and demerit [5,6], so it is very difficult to conclude which type will replace another type in the future. Ladar is capable to effectively acquire range images which are closely related to real three dimensional (3D) surface information of target. Hence, target recognition using range image is less sensitive to various inherent problems in two dimensional (2D) images [7], and has been extended to various field [8–10].

The target recognition algorithm based on range images can be classified as local feature representation algorithm and global feature representation algorithm [11,12]. The local feature representation algorithm describes small scale shape features around feature points, and it is not affected by clutter and occlusion. However, this algorithm requires a lot of computation time as well as storage space, and it is sensitive to noise [12,13]. In the field of local feature representation algorithm, many excellent algorithms have been proposed, such as Spin Image(SI) [14], Local Surface Patch(LSP) [15], Intrinsic Shape Signatures(ISS) [16], Variable Dimensional Local Shape Descriptors(VD-LSD) [17], Tri-Spin Image(TriSI) [18], and so on [11]. In [11], there is a comprehensive survey of 3D object recognition based on existing local feature representation algorithms. The global feature representation algorithm does not require a lot of computation time and storage space, and is also less sensitive to noise. However, global feature representation algorithm generally needs complicated image preprocessing, and its characters make it very difficult to solve the occlusion problem [11,19]. In the field of global feature representation algorithm, many excellent algorithms also have been proposed, such as Slice Image [13], Geometric 3D Object [20], Shape Distribution [21], Viewpoint Feature Histogram [22], and so on [12]. In [12], there is a detailed overview about target recognition algorithms based on transform coefficient which belong to global feature representation algorithm. In real application, ladar range image always inevitably contains strong noise [23,24]. Many existing local shape descriptors cannot work effectively with these degenerated range image because of their dependency on dense and smooth full-body sampling points [12]. Therefore,

☆"Log-polar" is used to describe an image taken by log-polar detector; "Cartesian" is used to describe an image taken by Cartesian detector; "CARTESIAN" is used to describe an image generated by inverse mapping of log-polar image.

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global feature representation algorithm is more popular for target recognition based on ladar range images.

The development of ladar technique has undergone several decades. However, previous techniques mainly focus on space-invariant detection or approximate space-invariant detection. The research on space-variant detection is comparatively rare. Recently, in [4], our team presented a log-polar 3D imaging ladar system based on micro-opto-electro-mechanical-systems (MOEMS) mirror, and validated its effectiveness by real experiment. Furthermore, in [25], our team proposed a model of log-polar 3D imaging ladar system based on non-scanning principle. To the best of our knowledge, there are no relevant studies covering target recognition of log-polar ladar range images prior to this research. Therefore, in this paper, we construct a target recognition system based on log-polar ladar range images, and fully analyze the effect of log-polar sampling pattern on recognition performance of whole system. In this system, considering the existence of strong noise and requirement of real-time running, Hu moments and affine moments are used as global feature representation method, and backpropagation neural network (BPNN) is used as feature classifier. Eventually, we draw several important conclusions: (i) if combined moments are directly computed by log-polar ladar range images, translation, rotation and scaling invariant properties of combined moments which is necessary for shape descriptor in the object recognition application will be invalid (ii) when object is located in the center of field of view(FOV), recognition rate of log-polar ladar range images is less sensitive to the changing of FOV than that of Cartesian ladar range images (iii) as object position changes from center to edge of FOV, recognition performance of log-polar ladar range images will decline dramatically, and it is not affected for Cartesian ladar range images (iv) recognition rate of log-polar ladar range images is less sensitive to noise than that of Cartesian ladar range images. Moreover, the results also prove that the recognition network trained by log-polar range images has a better recognition performance than that trained by Cartesian range images in the real condition with noise. In the last, we present a suggestion that in the real application FOV should be divided into recognition area and searching area, so that it can balance the conflict between excellent recognition performance and large searching area.

The paper is organized as follows. In Section 2, we firstly review the basic structure of whole target recognition system based on log-polar ladar range images. Then, we show every portion of this system in detail, respectively. In Section 3, several comparative experiments based on ladar range images are performed. In Section 4, several conclusions based on the previous experiments are drawn.

2. Theory

2.1. Target recognition system

Target recognition algorithm based on moment invariants is a very popular algorithm, and it has been successfully applied to target recognition of ladar range image [27,28]. In this paper, the key components of the whole target recognition system based on log-polar ladar range images are summarized in Fig. 1.

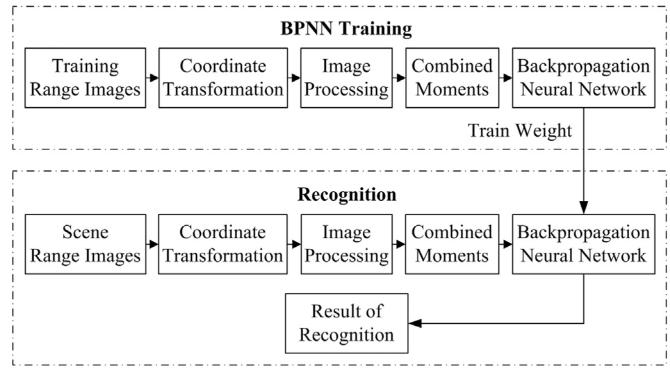

Fig. 1. Block diagram for target recognition system.

In this system, considering the existence of strong noise and requirement of real-time running, combined moments(CM) which contain Hu moments and affine moments are used as global feature representation descriptor, and BPNN is used as feature classifier. The system consists of two processes: BPNN training and recognition. In the BPNN training process, firstly, a series of log-polar ladar range images which are used to construct training sample set are sampled at preset attitude angles. Secondly, all the log-polar ladar range images are converted into CARTESIAN ladar range images. Thirdly, the regions of targets are extracted from all CARTESIAN ladar range images, and their shape features are represented by CM. Finally, all the CM vectors are used to train BPNN classifier. In the recognition process, firstly, a log-polar ladar range image is sampled at random attitude angle. Then its CM vector can be obtained after undergoing the same image preprocessing. Finally, this CM vector is inputted the above BPNN, and the final recognition result depends on the output result of BPNN.

2.2. Coordinate transformation

With the development of imaging technique, human have been trying their best to get higher image resolution. However, higher image resolution is naturally conflicted to larger FOV. In order to address this problem, a log-polar imaging technology, which comes from bionic technology, has been proposed, and it can encode a large FOV with variable spatial resolution [26]. There is a high resolution in the center of FOV and low resolution in the edge of FOV for every log-polar image. Furthermore, log-polar image is rotation invariant and nearly scale invariant [29]. For these reasons, log-polar imaging technology has been widely applied in visual attention, target tracking, egomotion estimation, and 3D perception [30]. Recently, in [4,25], our team had extended log-polar imaging technology to the hardware field of ladar. In this paper, we continue to research the software part of log-polar imaging technology. The mathematical expression of log-polar sampling pattern can be written as [25]:

$$r_1 = \frac{R_0}{1 - \sin(\pi/N)}, \tag{1}$$

$$D_1 = \frac{2R_0 \sin(\pi/N)}{1 - \sin(\pi/N)}, \tag{2}$$

$$q = \frac{1 + \sin(\pi/N)}{1 - \sin(\pi/N)}, \tag{3}$$

$$r_i = q^{i-1} \cdot r_1, \tag{4}$$

$$D_i = q^{i-1} \cdot D_1, \tag{5}$$

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