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A novel method for quantifying target tracking difficulty of the infrared image sequence

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HIGHLIGHTS

- Factors interfering with target tracking in infrared image sequences are analyzed.
- Five metrics are proposed to quantify tracking difficulty of infrared sequences.
- An integrated metric is proposed to represent the sequence-level tracking difficulty.

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ABSTRACT

Metrics to measure the difficulty of target tracking on the infrared image sequence were seldom studied. This paper proposes an effective method for quantifying target tracking difficulty of the infrared image sequence. We first analyze the factors interfering with infrared target tracking, and conclude that the intra-frame image quality and the inter-frame variation will jointly make great effects on infrared target tracking. Furthermore, five metrics concerning target tracking difficulty of the infrared image sequence are proposed: intra-frame degree of occlusion (*IFDO*), intra-frame degree of confusion (*IFDC*), inter-frame variation degree of target texture (*IFVDTT*), inter-frame variation degree of target size (*IFVDTS*) and inter-frame variation degree of target location (*IFVDTL*). These metrics complement each other and measure the infrared image sequence concerning target tracking difficulty together. An integrated indicator named sequence difficulty degree (*SDD*) is proposed by combining these five metrics to intuitively represent the sequence-level tracking difficulty of the infrared image sequence. Related experiments are designed to illustrate the effectiveness of the proposed metrics. Experimental results prove that the proposed metrics are valid to measure infrared image sequences concerning target tracking difficulty, and the performance of the proposed metrics is superior to that of the traditional infrared image sequence metric.

1. Introduction

Automatic target recognition (ATR) system needs to detect, track and recognize many different targets. ATR algorithms require extensive testing before they can be considered robust enough to perform effectively under a variety of scenarios. However, in most cases, algorithm testing is executed over a limited set of scenarios and the image database generally only includes a small set of collected images or artificially generated images. Limited variability of experimental images lead to the question that how robust the algorithm performance is for all scenarios of practical relevance. One way to solve the problem is to correlate image characteristics with the algorithm performance and measure images using quantitative metrics [1], which is called "image metric" in this study.

It should be noted that the concept of "image metric" in the field of automatic target recognition and tracking is different from its normal concept for an ordinary image or video: they are conceived to describe the factors interfering with the performance of the ATR algorithms [2]. While ordinary image metrics, such as peak signal-to-noise ratio (PSNR) [3], mean square errors (MSE) [3], V-Factor [4] and mean structural similarity (MSSM) [5] usually focus on measuring information losses in image communication and video compression [2]. Therefore, these metrics have not been applied to evaluate the performance of target tracking algorithms on the infrared image sequence.

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Numerous infrared image metrics based on various theories have been proposed in the field of infrared target detection and tracking. Based on the number of infrared images used to extract metrics, these metrics can be classified into two categories: the metrics for a single infrared image and the metrics for an infrared image sequence. The metrics for a single infrared image are extracted from just one infrared image, such as target to background entropy difference (TBED) [1,6], signal-to-noise ratio (SNR) [7], signal-to-clutter ratio (SCR) [8], target interference ratio (TIR) [9], probability of edge (POE) [10], target to background contrast (TBC) [6,11], texture-based image clutter measure (TIC) [11] degree of target being shielded (DTS) and degree of target being confused (DTC) [12]. However, all of them are designed for a single infrared image without considering the sequence information of multi-frame infrared images. Therefore, they will cause inevitable deviations when they are used to measure an infrared image sequence. The research on the metric for the infrared image sequence is still in the initial stage such that very few metrics have been proposed so far. There is only one infrared image sequence metric that has been proposed in previous work [2]: inter-frame change degree (IFCD). However, the metric IFCD does not take the factors that affect the infrared image sequence quality into full consideration. Meanwhile, the metric IFCD has several deficiencies. We will review the IFCD and analyze its drawbacks in detail in Section 2.

As current metrics have the deficiencies above, it is necessary to propose more suitable metrics for the infrared image sequence. Due to the fact that the infrared image sequence is mainly applied to track a target, we first analyze the factors interfering with infrared target tracking. Then we obtain a conclusion that intra-frame image quality and the inter-frame variation will make great effects on the infrared target tracking together. Based on this conclusion, five metrics are proposed to measure the quality of the infrared image sequence from the perspective of describing target tracking difficulty. Related experiments are designed to illustrate the effectiveness of the proposed metrics. Experiments prove that the proposed metrics are valid to measure infrared image sequences and the performance of the proposed metrics is superior to that of the traditional metric IFCD. Overall, our main contributions can be listed as follows:

(1) We analyze the factors interfering with infrared target tracking, and find that the intra-frame image quality and the inter-frame variation will jointly make great effects on infrared target tracking.
(2) We propose five metrics, including three metrics that are new versions or improvements over previously published work [2]. These five metrics complement each other and measure the infrared image sequence concerning target tracking difficulty together. An integrated indicator is proposed by combining these five metrics to intuitively represent the sequence-level tracking difficulty of the infrared image sequence.
(3) Related experiments are designed to verify the effectiveness of the proposed infrared image sequence metrics by comparing the performance with the traditional infrared image sequence metric IFCD.

This work focuses on quantifying target tracking difficulty of infrared sequences with a single target. Computing the proposed five metrics in practice will require the bounding box of the target. The proposed method is mainly applied to the performance evaluation of target tracking algorithms.

The rest of the paper is organized as follows. Section 2 briefly reviews the traditional infrared image sequence metric IFCD and analyzes its drawbacks. Section 3 first analyzes the factors interfering with infrared target tracking and then introduces the proposed infrared image sequence metrics. Experimental results and analysis are given in Section 4. Conclusions and future work are provided in Section 5.

2. Related work

The research on the metric for the infrared image sequence is still in the initial stage such that only one metric has been proposed so far. A conclusion is drawn in work [2] that inter-frame change degree of target information is the main cause interfering with target tracking on the infrared image sequence. Based on this conclusion, the metric IFCD is proposed. In fact, some works [13–18] have looked at inter-frame quality issues in visual video domain before the work [2]. The work [15] presents a methodology for evaluating the performance of surveillance tracking systems using pseudo-synthetic video. Ground truth (GT) tracks are automatically selected from the surveillance database and then used to construct a comprehensive set of pseudo-synthetic video sequences that are used to evaluate the performance of a tracking algorithm. When constructing pseudo-synthetic video sequences, three measures are utilized to identify the inter-frame consistency with respect to path coherence, color coherence, and shape coherence, respectively. The main objective of the work [16] is to present an approach to evaluate video object tracking algorithms. To decrease the required reference information, it is proposed the use different types of reference information and the combination of GT and NGT (non-ground truth) metrics for the purpose of approximating the ideal error. In the NGT metrics, three measures related to inter-frame change are computed for each object. They are intended to measure color differences, motion difference and histogram difference, respectively. The work [17] presents a comparative evaluation of online tracking quality measures that do not make use of GT. It compares the performance of these measures corresponding to different inter-frame issues including clutter, appearance change and occlusion. The work [18] analyzes the factors affecting automatic tracking algorithms in visual video, such as the ground sample distance of the image, motion of the targets, motion of the camera, frame rate (temporal resolution), and scene complexity. It offers helpful conclusions about inter-frame issues for automatic tracking in visual video: the effects of clutter are compounded by the temporal nature of target–clutter interaction; spatial effects, such as jitter and camera motion require consideration. In this section, we focus on the metric for the infrared image sequence. Thus, we briefly review the infrared image sequence IFCD and then analyze its drawbacks in detail. The metric IFCD is calculated as follows:

$$IFCD = \sqrt{IFCDT^2 + IFCDTS^2 + IFCDTL^2}, \quad (1)$$

where *IFCDT*, *IFCDTS* and *IFCDTL* are the inter-frame change degree of texture, target size and target location in an infrared image sequence, respectively. Since the calculation details of IFCD are complicated, please see literature [2] for more details.

The metric IFCD has obtained some achievements for measuring the infrared image sequence concerning target tracking difficulty. However, we find that it does not take the factors affecting infrared target tracking into full consideration and has following drawbacks:

(1) Given the initialized state of a target in a frame of an image sequence, the goal of tracking is to estimate the states of the target in the subsequent frames [19]. It indicates that factors