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Improving counterflow detection in dense crowds with scene features ☆

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ABSTRACT

This paper addresses the problem of detecting counterflow motion in videos of highly dense crowds. We focus on improving the detection performance by identifying scene features – that is, features on motionless background surfaces. We propose a three-way classifier to differentiate counterflow from normal flow, simultaneously identifying scene features based on statistics of low-level feature point tracks. By monitoring scene features, we can reduce the likelihood that moving features' point tracks mix with scene feature point tracks, as well as detect and discard frames with periodic jitter. We also construct a Scene Feature Heat Map, which reflects the space-varying probability that object trajectories might mix with scene features. When an object trajectory nears a high-probability region of this map, we switch to a more time-consuming and robust joint Lucas–Kanade tracking algorithm to improve performance. We evaluate the algorithms with extensive experiments on several datasets, including almost three weeks of data from an airport surveillance camera network. The experiments demonstrate the feasibility of the proposed algorithms and their significant improvements for counterflow detection.

1. Introduction

Counterflow detection is a critical problem in security-related surveillance. For example, a person moving the wrong way through the exit corridor of an airport can prompt an entire terminal to be "dumped", resulting in hundreds of delayed flights and inconvenienced passengers. By tracking low-level feature points, the typical flow direction can easily be determined. However, most of the cameras deployed in security surveillance networks have poor resolution and quality compared to a consumer digital camera, which can negatively affect tracking algorithms, especially during long-term operation. Another issue preventing automatic video analytic algorithms from replacing manual monitoring is that the false positive rate is likely to be very high compared to the small number of true positives in 24/7 continuous operation.

This paper presents three contributions. First, we demonstrate that counterflow detection can be significantly improved by introducing a novel classifier to identify scene features in the image, which are then used to mitigate cases in which foreground and background features are mixed in the same point trajectory. Second, by monitoring the statistics of scene features, we identify jitter frames that should not play a role in tracking. Third, we construct a Scene Feature Heat Map that enables the automatic selection of a suitable tracking scheme for point tracks in different locations of the image to achieve more robust performance. We conducted extensive experiments on both a standard dataset (CAVIAR) and several real-world video datasets acquired from an airport surveillance camera network, demonstrating that our counterflow detection algorithm is significantly improved by using the scene-feature-based algorithms. The resulting framework was in continuous operation for three weeks at a major airport, successfully detecting hundreds of counterflow events with no misses and only three false alarms.

2. Related work

The problem of detecting dominant motions in crowded video and classifying outlying motions has been widely studied (Buzan et al., 2004; Junejo et al., 2004; Alon et al., 2003; Antonini and Thiran, 2006). Tu and Rittscher (2004) introduced a crowd segmentation algorithm by clustering interest points into groups by determining maximal cliques in a graph. However, both the algorithm and experiments are based on videos from overhead views only, which is the easiest case for counterflow detection. Andrade et al. (2006) proposed an algorithm for detecting abnormal movements in crowds by applying principal component analysis to optical flow maps and spectral clustering to hidden Markov models, but did not perform any real-world experiments. This algorithm identifies abnormal motion based on a trained flow map, which is sensitive to noise and may cause false positives for normal motions not covered by the training set. Brostow and Cipolla (2006) used an unsupervised Bayesian detection algorithm to segment

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Fig. 1. Results of feature tracking. (a) Features detected in the image. (b) Point tracks extracted from a video sequence.

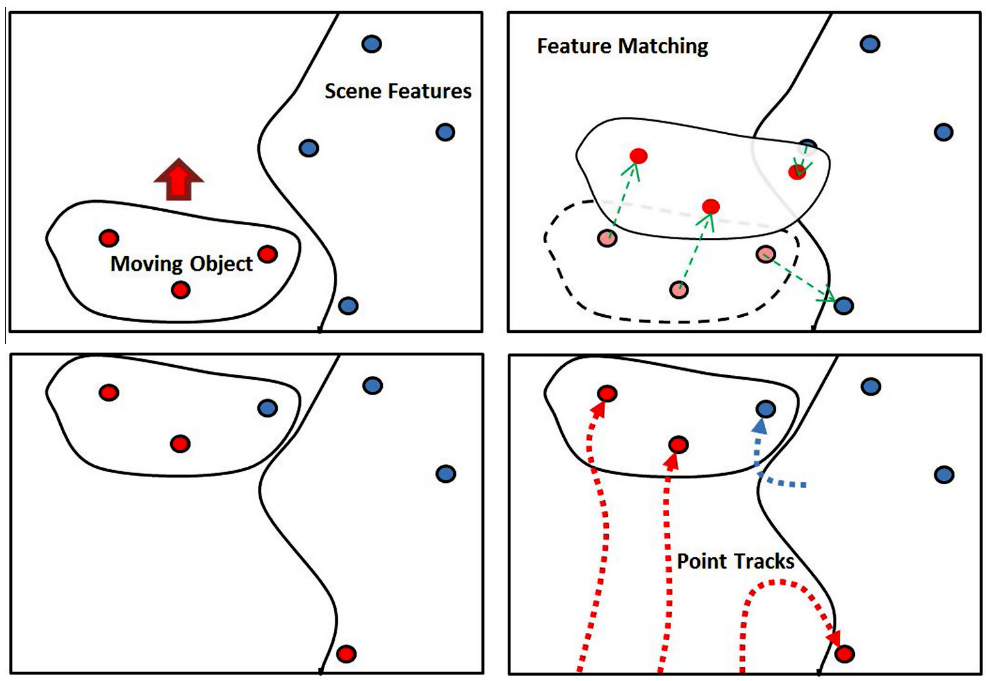

Fig. 2. Foreground points mixing with scene points.

low-level feature tracklets based on a spatial prior and a likelihood model of coherent motion. Ali and Shah (2007) modeled a highly dense crowd as an aperiodic dynamical system that can be studied with Lagrangian particle dynamics techniques. Antonini and Thiran (2006) introduced a trajectory clustering method based on independent component analysis. Junejo et al. (2004) applied graph cuts to segmenting tracklets. Cheriyadat and Radke (2009) proposed a trajectory clustering algorithm based on non-negative matrix factorization.

Cheriyadat and Radke (2008) proposed an automatic dominant motion detection method by clustering trajectories based on longest common subsequences. Since individual people are difficult to segment, the inputs to the algorithm are tracked low-level features obtained using optical flow. Our algorithm takes a similar approach. However, these types of algorithms might not yield good results in situations involving low-resolution cameras and poor image quality. Marcenaro and Vernazza (2001) proposed an image stabilization algorithm based on feature tracking in which scene features are used as references to compensate for the motion of the camera. In this paper, we propose a classifier to identify scene features in the context of detecting counterflow motion. We show that by using information from the scene features, the performance and accuracy of foreground object point tracking can be improved under low-quality, complex-background conditions.

An earlier version of this paper appeared in Wu et al. (2012). Here, a new concept, the Scene Feature Heat Map, and a joint processing mechanism within a camera network are proposed in order to further reduce the false alarm rate. A new experiment on the CAVIAR dataset and a more extensive long-term experiment using a camera network at an airport are presented, demonstrating the effectiveness of the proposed algorithm.

3. Feature tracking

Even in the age of high-quality consumer digital cameras, videos from surveillance camera networks are frequently low-resolution (e.g., 352×240). Since we want the system to process video streams from tens of cameras in real time, and the dominant (or allowable) direction of motion is all we need to know, we use low-level features to track the flow. We first identify low-level features in the initial frame using the FAST corner detector