Contents lists available at ScienceDirect
Digital Signal Processing
www.elsevier.com/locate/dsp

# Dust particle detection in traffic surveillance video using motion singularity analysis

Li Chen [a,b], Dawei Zhu [a,b], Jing Tian [a,b], Jiaxiang Liu [a,b]

[a] School of Computer Science and Technology, Wuhan University of Science and Technology, Wuhan 430081, China
[b] Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan University of Science and Technology, Wuhan 430081, China

ARTICLE INFO

*Article history:*
Available online xxxx

*Keywords:*
Dust detection
Motion estimation
Optical flow
Motion singularity
Temporal voting

ABSTRACT

Dust particle detection in video aims to automatically determine whether the video is degraded by dust particle or not. Dust particles are usually stuck on the camera lends and typically temporally static in the images of a video sequence captured from a dynamic scene. The moving objects in the scene can be occluded by the dusts; consequently, the motion information of moving objects tends to yield singularity. Motivated by this, a dust detection approach is proposed in this paper by exploiting motion singularity analysis in the video. First, the optical model of dust particle is theoretically studied in by simulating optical density of artifacts produced by dust particles. Then, the optical flow is exploited to perform motion singularity analysis for blind dust detection in the video without the need for ground truth dust-free video. More specifically, a singularity model of optical flow is proposed in this paper using the direction of the motion flow field, instead of the amplitude of the motion flow field. The proposed motion singularity model is further incorporated into a temporal voting mechanism to develop an automatic dust particle detection in the video. Experiments are conducted using both artificially-simulated dust-degraded video and real-world dust-degraded video to demonstrate that the proposed approach outperforms conventional approaches to achieve more accurate dust detection.





## 1. Introduction

Traffic surveillance video is recorded in outdoor scenarios and usually suffers from dusts, when the camera's view gets obstructed by dirt on the lens. The high resolution of video camera also makes small dust specks very apparent. These dust defects have become an important issue for consumers since they will damage important scene information for applications in computer vision or digital forensics. A few examples of video degraded by dust are demonstrated in Fig. 1. The performance of this video surveillance system can be deteriorated or the system might fail. Therefore, it is important that the traffic surveillance systems can run self-checks in order to evaluate if the image quality is degraded by dust particles or not [1]. Once the dust can be located accurately in the video, the removal of dust artifacts can be further performed using many computer vision techniques such as image inpainting. Note that our paper focuses on dust detection only, the dust removal is out of the scope of this paper and will be studied in future works.

### 1.1. Related works

The dust detection in real-world traffic surveillance video, which is the focus of this paper, is related with conventional camera dust defect detection or old film restoration. A brief survey on these related works is provided as below.

*Dust detection for image acquisition optics*: The dust can be stuck in some part of the camera optics so that the dust will then be impressed on the same position along a sequence of frames captured by the camera [2–4]. In terms of image intensities, the dust particles usually appear as small dark artifacts in the image. These dust defects usually have significant differences compared with their surrounding objects in the scene [5,6]. In [7] the sensor dust is detected by studying the correlation of the multiple images captured by the camera to develop reliable dust particle detection.

*Dust in old film restoration*: The dust particles can get stuck on the film so that the film dust will appear as random dots on individual images. They are usually not repetitive along multiple

*E-mail addresses:* chenli@ieee.org (L. Chen), jingtian@ieee.org (J. Tian).

http://dx.doi.org/10.1016/j.dsp.2016.07.020
1051-2004/© 2016 Elsevier Inc. All rights reserved.

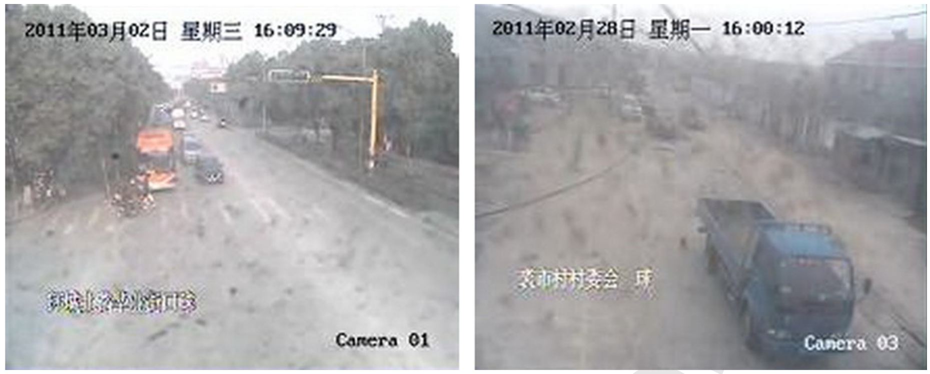


**Fig. 1.** An example of dust-degraded videos. The objective of dust particle detection in video is to automatically make a decision whether the video is degraded by dust or not.

consecutive frames of the old film [8,9]. In [10], a three-frame sliding window method is proposed to calculate the optical flow based on adjacent frames. Then the optical flow validity is studied in order to detect non-repetitive dust particle in the video.

*Dust in outdoor traffic surveillance video*: The dust artifact can be distinguished from other objects, if the original dust-free image is available. The difference between the dust-degraded image and dust-free image can be taken as a useful measure for dust particle detection. However, in real-world surveillance applications, the actual scenario is complicated and changing due to the moving vehicle and weather, etc. This leads to the acquisition of the ground-truth image inapplicable. Therefore, the proposed approach performs blind dust detection without the need for ground-truth dust-free image available. For that, Einecke et al. observed that most artifacts are temporally stable in the image and proposed to use pixel-wise correlations between images to detect dust artifacts [11].

### 1.2. Motion estimation

To tackle dust particle detection in traffic surveillance video, our key observation is that artifacts are typically temporally static in the images captured from a dynamic scene. The moving objects (such as vehicles) in the scene could be occluded by the dusts. Therefore, the motion information of moving objects tends to yield singularity. Various methods have been developed to perform motion estimation in the literature, such as correlation-based method, block-matching method, feature matching method, and energy-based method [12]. Optical flow method is considered as a promising method in this paper, since it does not require specific parametric motion models on the video [13]. The dense motion field can be estimated to provide corresponding to the displacement of each pixel. Most optical flow methods are developed from the original formulation proposed by Horn and Schunck [14]. Their method combined two terms to formulate the optical flow of two successive frames, including (i) a data term that assumes image intensity constancy, and (ii) a spatial regularization term that models how the flow is expected to change over the whole image. 3D motion can also be estimated by [15]. Furthermore, to address the acceleration and robust implementation of the optical flow methods, various works have been done in the literature using bio-inspired sensor and hardware [16,17], and GPU computing structure [18,19].

### 1.3. Contribution of the proposed approach

A dust detection approach is proposed in this paper by exploiting motion singularity analysis in the video. Optical flow [20] is the distribution of apparent velocities of movement of object patterns in a video. Discontinuities in the optical flow can help in segmenting region of interest corresponding to different objects. This paper studies on automatic dust detection in the video. The optical model of dust is theoretically studied in by simulating optical density of artifacts produced by dust particles. The proposed approach establishes the singularity model of optical flow for dust detection. Comparing the amplitude with the direction of flow field, the latter is preferred to deliver a robust and consistent motion feature using weighted neighborhood calculation. The inhomogeneous local direction field among a smooth-motion provides a clue for singularity point detection. Furthermore, a voting mechanism is used to perform dust detection in the video.

The rest of this paper is organized as follows. The optical flow model for the dust particle in the video is presented in Section 2. The proposed motion singularity analysis approach is presented in Section 3. The proposed approach is evaluated in Section 4 using both artificially-simulated dust-degraded video and real-world surveillance videos. Finally, Section 5 concludes this paper.

## 2. Optical flow model for dust particle in video

The motion analysis is conducted on both dust-free video and dust-degraded video using optical flow method in this Section. Dust scattering light away at the glass of protective housing, the light reaching the CCD will be decreased or blocked. For dust particles smaller than the aperture area, the image artifact size is determined by the size of the lens aperture and not the size of the particle [21]. This leads to the "gray-spot" in the captured image. The dust is the nearest object to the camera CCD compared to other objects in the scene. Its image is relatively stationary under a changing scene. This has inspired the exploitation of the inhomogeneous local optical field among a "smooth-motion", which will provide a clue for singularity point detection.

Considering a moving target in a stationary scene, the optical flow reflects its relative motion velocity from one frame to the next frame. The classical optical flow objective function expressed in its spatially discrete form [20] as

$$E(V_x, V_y) = \sum \rho_d \left( I_n(x, y) - I_{n-1}(x + V_x, y + V_y) \right) + \lambda \rho_s \left( \Delta V_x, \Delta V_y \right), \quad (1)$$

where $V_x$ and $V_y$ are the horizontal and vertical components of the optical flow, respectively, $\lambda$ is a regularization parameter, $\rho_d$ and $\rho_s$ are the data and spatial penalty functions, respectively. As illustrated in Fig. 2(a), the ideal motion vector related to the moving vehicle is continuous and consistent along a specific direction. However, if the moving vehicle enters the area covered by the dust particles, the appearance of the object will be occluded by the dust. In the optical flow domain, the smooth motion will



Please cite this article in press as: L. Chen et al., Dust particle detection in traffic surveillance video using motion singularity analysis, Digit. Signal Process. (2016), http://dx.doi.org/10.1016/j.dsp.2016.07.020