

Dust Particles Detection on Camera Lens

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Abstract

In most of the imaging applications the camera is placed in outdoor conditions with the lens open to the environment. Example, cameras installed on the buildings for surveillance, cameras fitted on cars that are open to the environment for ADAS applications, camera for flight passengers to view outside scenes on the fly etc. One of the most challenging problems in such scenarios is that the dust particles may easily form a partially or fully occluding layer on the camera lenses and block vision. There are more challenging scenarios like the presence of wind, rain, mist, sun glare etc. which can also lead to false imaging algorithm results. The purpose of this paper is to solve this problem efficiently by detecting dirt/dust if presents on the lens. This is helpful to stop the system functioning instead of providing misleading results. This application is more essential for safety critical applications like ADAS where the accurate real time detection of objects must happen. Proposed approach has more than one algorithm like edge analysis, inter frame analysis, edge strength analysis etc. to produce accurate result for dust/dirt detection.

Keywords

Dust detection, Edge strength calculation, ADAS, camera degradation, vision blockage detection, Image Quality, Dimness, Fadedness

1. Introduction

With the rapid development of smart phones, tablet computers and other digital products, the demand for camera modules and camera-based applications is growing higher. Lens of the camera module can get easily contaminated by dust/dirt or oily material and can decrease the image quality. Therefore, there is a need to detect the presence of dust and blemish on lens automatically, in order to improve the overall quality of the system

In common, dust can be segregated into two types as per density that formed, Solid and Transparent respectively. Solid dust may have more density and shall blocks vision completely while transparent has partial or full vision blockage.

One of the biggest challenging of this problem is, in real world, dirt or dust will not have any specific shape, which make harder. There will be plenty of approaches in image processing available to detect or identify shape but unfortunately, we can't use here since dust does not have defined shape as it is generated randomly.

A simple method used to detect dust on scanners is proposed by Gray, (1st ref paper) Based on this approach, a similar way of dust detection on camera module was proposed by Doi, (2nd ref paper) The primary goal of these two approaches way to create a difference image to extract anomalous regions. After threshold and few of morphological processing, dirty area can be detected from these anomalous regions. The operation of such approaches is much simple and the ability to detect dirty spots is acceptable when the structured background is uniform. But in realistic uniform, easily separable background is unexpected. In order to reduce false positives, Krainion (3rd ref paper) proposed an efficient approach based on local gradient difference method. Anomalous image regions can be identified by comparing the gradient magnitude of pixels in the image and average gradient of neighbor region. then, dusty area from these anomalous regions can be detected by means of a set of heuristic features, including shape, size, color and visibility measures. But this method leads to high false detection rate

This paper proposes a novel and efficient method for automatic dust detection based on edge strength and inter frame (consecutive) difference calculation. Experimental results show high detection accuracy and robustness. The proposed method has been implemented for Advanced Driver Assistance System and the accuracy obtained is provided in experimental results section

Abbreviations

Table 1. Abbreviations with expansion

Abbreviation	Expansion
ADAS	Advance Driver assistance System
TP, FP	True Positive, False Positive
TN, FN	True Negative, False Negative

Definitions

True positive is an outcome where the algorithm correctly predicts the positive class.

True negative is an outcome where the algorithm correctly predicts the negative class.

False positive is an outcome where the algorithm incorrectly predicts the positive class.

False negative is an outcome where the algorithm incorrectly predicts the negative class.

positive class videos/ images having dust

negative class videos/ images having no dust

2. Problem Faced

The dust/dirt observed in real world scenarios is classified into:

- Transparent
- Solid

2.1 Transparent Dust – Properties

This type of Dust may not affect the vision information but looks unsharpened. according to amount of unsharpened edges, it may or may not allow machine vision to work. it will be further divided such Semi-transparent, Full transparent, it may hit to the camera by variant environment reason such as rain fall, grease pasting, soap form, Snow fall, plastic paper on camera. Sometimes broken / scattering surface looks dirt / dust on lens

2.2 Solid Dust – Properties

This type of dust completely occludes the vision and will not allow machine vision-based algorithms to function properly. Common forms of solid dust are dry leaves, mud paste etc. Detection of solid dust is less complex than transparent dust.

Many researchers propose algorithm like variance calculation, detecting high frequency area etc. But the problem is that the proposed approaches may suit for detecting unsharpened edges with transparent dust, but when considering solid dust it does not have any information like high/low frequency and it is very difficult to differentiate if the dust is present or not, and also the approach adopted for detecting transparent dust may fail to detect solid dust and vice versa.

As mentioned above, detecting both types of dust with single approach is a very challenging task. In this paper different approaches are proposed for different types of dirt.

The idea of this paper would be to find unsharpened edges when transparent dust exists on lens as well as to find consistent scene in consecutive frames/ images when solid dust presents



Figure 1 a. HCL Garden image (mobile) b & c HCL Garden image (mobile) with Transparent Dust



Figure 2 a. HCL Tower image (mobile) b & c HCL Tower image (mobile) with Solid Dust



Figure 3.a Rain Drops on lens [Adas] b. Ice on lens [Adas] c. Mist on lens [Adas]

3. Solution Approach / Remedial Action

Proposed framework based on Estimating unsharpened edges using edge strength calculation with sobel Edge detection and Edge difference method in inter frame analysis for dust detection on camera lens. To overcome the identified problem edge strength calculation is used for detection of Transparent Dust while other for Solid Dust, in real world scenario, system cannot expect the unsharpened edges or Dust present on entire image / lens. it might be on few parts of the image also as shown in Fig.1 – Fig.3. to identify those part, local processing is efficient comparatively global, so given image will be divided into grids,

Proposed paper divides the image into 6x6 grids, so that each grid will have a size of 341 x 180 (incase input image size: 2048x1080)

One of basic properties of dust is consistent pattern might be formed with irregular shape in consecutive frames irrespective of dust types, system can easily track pattern if no edge information (full blockage) available i.e solid dust, the same can be not be done if blockage does not affect vision / scene changes on lens i.e transparent dirt, example, if mist, fog, thin cover forms on lens it will allow vision partially wherein edge information will change as scene changes over frames so here, detecting consistent pattern is not an easy, to confirm either consistent pattern has vision or not system needs motion information (scene changes over consecutive frames)

Two approaches will be performed as shown in chart below,

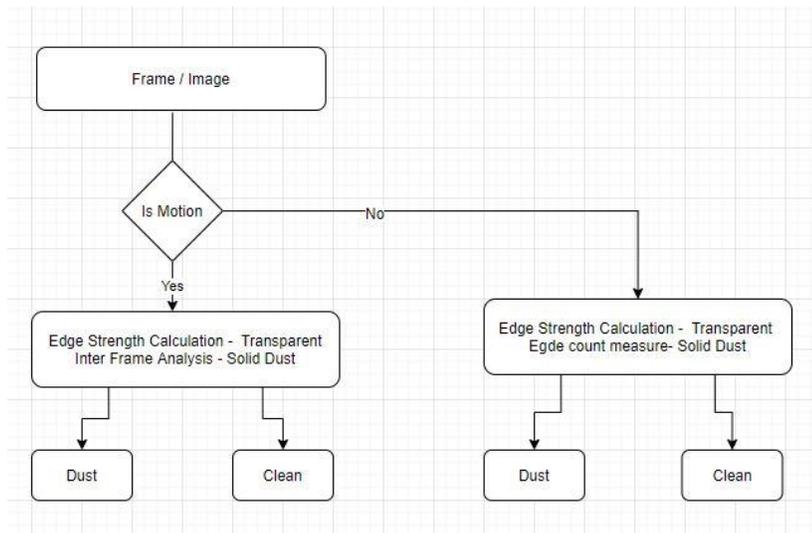


Figure 4. Overall block diagram of Dust detection

3.1 Motion Detection

To confirm either current image has motion or not system has to perform motion detection to decide the algorithm which should performed for entire image (Edge strength calculation or Inter frame analysis) as steps mentioned below,

- Capturing last N, no of frames
- Find mean image with Last N frames
- Find correlation between mean image with current image
- If correlation coefficient is greater than MinTH, image declared as stationary else moving/ has motion
- MinTH-> Threshold value is fixed and got it from elbow method to decide stationary or motion,

3.2 Edge Strength Calculation

In order to develop robust unsharpened area detection, it is required to understand the image degradation process. unsharpened will happen when each pixel in the image gets spread over the surrounding pixels. This spreading process is more often referred to as a smearing out around the neighboring pixels. Thus, dust exists area has pixels that are affected due to this smearing process. An image unsharpened is defined as a mathematical convolution between the source image and the point spread function which is known as the gaussian kernel.

3.3 Geometric structures of Edges

Based on width of edge after applying the gradient on image, we can divide the edges into 2 types, typically edge width will be high if part of image is unsharpened else very narrow if it is sharp. basic geometric structures namely as below,

- step structure edges
- smooth (Ramp) structure edges

From the above discussion we can say that the image with unsharpened i.e. place where dust is present due to rainwater droplets, mist, ice, fog etc. will have a more number of smooth structure edges and may have very a less number of step structure edges.

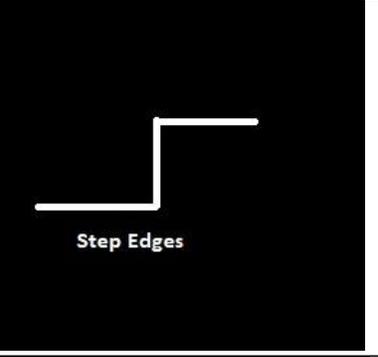
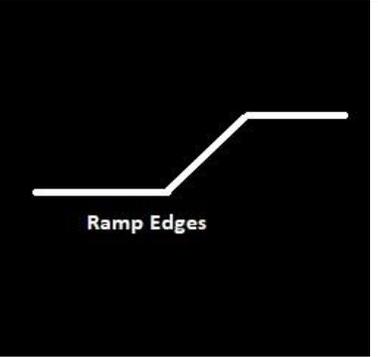
Image Example	Possible Edges can be detected	Properties explained
		<p>Normal images which does not have unsharpened pixels, it will have abrupt changes when calculates gradient, it is called step edges</p> <p>The contrast between bright and dark regions will be high</p>
		<p>When lens occluded images will like as shown in 1st column, there will be more ramp edges as it does not have sharp (step) edges i.e less abrupt changes in gradient</p> <p>The contrast between bright and dark regions will be less</p>

Figure 5. Graphic description of edge type.

The detailed algorithm to detect edge strength is listed below.

3.4 Edge Strength calculation – Algorithm Flow

Step1: Perform 3 levels of decomposition to the original image and the find edge gradient with sobel kernel for all levels

Step 2: Partition the edge maps and find local maxima in each window.

The window size in the highest scale is 2x2, the next coarser scale is 4x4, and the coarsest one is 8x8. The result is denoted as Emax1, Emax2, Emax3

In this algorithm, Emaxi represents the intensity of the edge. the larger Emaxi is, the more intense the edge is. For a given threshold, if $E_{maxi} > TH$ is labeled an edge point in the corresponding scale, otherwise it is labeled a non-edge point.

We perform algorithm on different types of edges and found that the effect is quite different. The relative intensity in different scales of different types is summarized in table below.

Emax1, Emax2, Emax3 maximum intensity of edge Map corresponding scales is mentioned in below table:

Table 2. Edge structure and corresponding max values

Edge structure	Emax1	Emax2	Emax3
<i>Step</i>	High	Middle	Low
<i>Smooth</i>	Low	Middle	High

Rule 1: If $E_{max1}(k, l) > TH$ && $E_{max2}(k, l) > TH$ && $E_{max3}(k, l) > TH$ means (k, l) is an edge point

Rule 2: If $E_{max1}(k, l) > E_{max2}(k, l) > E_{max3}(k, l)$ means (k, l) is a step-structure.

Rule 3: If $E_{max1}(k, l) < E_{max2}(k, l) < E_{max3}(k, l)$ means (k, l) is a smooth structure.

Based on the three rules obtained in the previous subsection, the detail of the scheme is given below:

Step3: Use Rule 1 to find all edge points. Let edge N be the total number of them;

Step4: Use Rule 2 to find all step structure edge points. Let edge Nst be the total number of them;

Step5: Use Rule 3 to find all smooth Structure edge points. Let Nsm be the total number of them.

Step6: Calculate the ratio of step and smooth structure to all the edges using below formula,

$$\text{Edge_Strength_Percent} = (\text{smooth Structure (Nsm)} / \text{step Structure (Nst)}) * 100$$

Step7: if Edge_Strength_Percent is less than TH1 percent and edge point N is less than TH2, the grid will be classified as “Dust ” present else as “clean”

Here, TH, TH1, TH2 value is chosen based on trial and error method for which almost 2TB of data was being used.
k, l -> pixel location of gradient image

3.5 Summary of Edge Strength calculation

- Attractive performance for the place where the transparent dust is present especially which has less or partial edges.
- May not be suitable for the dust where zero edges present,

3.6 Inter Frame Analysis Approach – Algorithm Flow

In this approach we can get properties of solid, semitransparent Dust since it is fully obstructive and will not have edge information. As it needs motion information this approach will not execute if vehicle speed is stationary,

3.6.1 Assumption

- Does not have edge content.
- It will have solid properties. It could be dark in color, smoothed surface etc.
- Dust may be present like blobs and it could be of an any shape such round, random etc.
- There is no possibility to disappear within fraction of a second once solid dust is formed on lens, so at least for 5 seconds there will be zero edges where the dust is present.

3.7 Steps involves in Inter Frame analysis approach

As we know, since solid dust will have no edge information there would be no changes during edge difference between consecutive frames. For better result we have chosen last 10 frames of interval to perform subtraction with first in first out method.

- From input video, take 2 frames of half resolution. Apply Sobel Edge detection on these images.
- As this method considers 10 frames of interval for getting difference, let's assume edge detected 1st frame as I1 and edge detected 10th frame as I10.
- Find the difference of I1 and I10 and store the result in buffer Idiff1.
- To segregate stationary and dynamic edges or portion in a current image, if any pixel is greater than 10 intensity value, 255 is placed in new buffer Ith1. it would be binary image as output.
- Similarly, Ith2 image will be created using 11th and 2nd frames from input video. (Ith3 with 3rd and 12th and so on.)
- Now, binary AND logic will be applied for Ith2 and Ith1. At any pixel, if both Ith2 and Ith1 intensities are 0 (as we changed to 0 if there is no difference between the interval), that particular pixel is made to intensity 255. Else zero.

- Similarly, the above step is repeated for Ith3 and Ith2 and so on till the end.
- This accumulation is repeated for 50 consecutive frames. Accumulation matrix size should be equal to half the size of input image
- Every location of accumulation matrix will be compared with Th (Th = 50), if it is equal to 50 corresponding locations will be confirmed as Dust. Else Clean
- Next erode the resulted threshold image to shrink un-wanted parts like dots which might be formed due to sand or other small stationary particles.
- Divide the image into 6X6 blocks.
- Count the white pixels in each block.
- If white pixels count is greater than 30% of total pixels in grid / block, the block is Dust. Else the block is Clean.

3.8 Sample results:



a. 1st frame

b. 10th Frame

c. Inter Frame difference result

Fig. 6. results of Inter Frame Analysis Approach, red color clearly shows the solid dust that present on consecutive images (Red marked area is result of Inter Frame Analysis approach when solid dust present as shown in 1st and 10th frame)

4. Results and Discussion

We evaluate our proposed dust detection method based on an image dataset with volume of 4 TB sized videos. Data captured in both rear and front camera mounted on vehicle. Algorithm is developed on Intel Core i3 processor with 8 GB RAM. For better analysis, approach has been tested for 2 different datasets wrt to TP and FP, TP videos will have dust and expected metric will be TP and FN likewise FP and TN are expected for FP videos which does not have dust and Achieved below table,

4.1 TP Results

Table 3. TP videos with accuracy metrics

Video type	Duration (Mins)	TP (%)	FN (%)
Dust videos	100	93	7

4.2 FP Results

Table 4. FP videos with accuracy metrics

Video type	Duration (Mins)	FP (%)	TN (%)
Clean videos	100	1	99

4.3 Confusion Matrix

Table 5. videos with accuracy metrics (confusion matrix)

Samples Type	Predicted No	Predicted Yes	No of samples
Actual No (clean)	TN: 95	FP: 5	100
Actual Yes (Dust)	FN: 2	TP: 98	100

Above table shows the confusion matrix results for small amount of data (200 frames).

5. Future improvements

- current algorithm may not perfectly fit for where edges are absent such smooth surface like wall, wetroad, smoothed road etc. it may handle in upcoming version
- This paper uses 10 buffers to take differentiation, it is quite high in terms of time complexity and memory management, it may handle in upcoming version
- Going forward approach may able to classify the amount of dust present on lens like 25%,50%,75%,100%

6. Conclusion

The idea of this paper is to resolve lens occlusion detection to stop its functionality that supposed to be performed, the introduced method has resolved the identified problem and been proven by shown metrics for various dataset with all environmental scenarios like rain, fog, mist etc., proposed approach uses sobel edge detection to find edge map as unsharpened area of images needs to be calculated along with nearest neighbor interpolation to downscale the images to find 3 levels of peak gradient value. Given fixed threshold values are verified with Elbow method. Since this paper uses basic image processing features such edge strength calculation, edge differences of frames proposed approach can be scale up to any of applications wherever the same problem exists even we can use it for indoor applications. Highlight of this paper is that no one steps of algorithm does not depend with features like color, size, shape etc., it may help to get good results in all the environmental condition like sunny, dusky, dark area, nighttime etc.,

7. References

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8. Biographies

Dhinakaran k has completed his Bachelor of Engineering in National college of Engg, Tirunelveli, Tamil nad, he worked on image processing applications such as Object detection, pedestrian detection, Optical character recognition for automotive especially ADAS, Aerospace, Medical, Product inspection domain. He has good knowledge on machine learning, deep learning, he has created many models for imaging applications. Also, expertise in feature engineering such HOG, SIFT, Harris corner, Bag of words etc., Currently he works in HCL Technologies as Tech lead in Bangalore India

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