Project 9: Texture Segmentation & Fault Detection in SUZUKI Car Door Fabric using Gabor Filters

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Abstract

This project provides an automated texture segmentation and fault detection system of SUZUKI car door fabric in classical image processing methods carried out as a project of Digital Image Processing course. The framework outlined by the author is based on a Gabor filter bank to represent the regular texture of car fabric and use mismatches in texture energy as the detection of defects. In contrast to the learning-based methods, the system does not need the labeled training data, but it functions in the unsupervised mode. The entire pipeline, such as fabric region extraction, Gabor energy calculation, background suppression, and defect segmentation, is built in Python with OpenCV and scikit-image and thus has an interactive user interface built in Streamlit. The experimental analysis of a small fabric images dataset given by the instructor proves that the suggested method can be expected to localize visible defects like stitching errors and texture edges in a controlled lighting environment.

I. Introduction

The inspection of texture is a highly important operation of the quality control in industry (mainly in the auto industry) in which the defects of the fabric in the interior can have influence on the aesthetics as well as on the customer satisfaction. Manual inspection is tedious, subjective and may result in human error. Hence, automated vision-based inspection system has become a popular domain of research in the area of digital image processing.

Fabric defects are difficult to detect because they are repetitive, or have different light source, and concealed defects like wrinkles, scratches, misweaves or stains. Gabor filters are one of the classical texture analysis methods that have been proven to be effective; this is because they do not only extract spatial frequency and orientation data as the human visual system does.

This project aims at identifying the presence of defects in the SUZUKI car door fabric by the use of Gabor filter-based texture segmentation. It aims to create an interpretable, lightweight, and unmonitored pipeline that can be used by academics and industries to operate when performing inspections. The project is based on the literature of common texture segmentation and realized as a working system in its entirety with Python, OpenCV, and Streamlit.

II. Theory and Background

A. Texture Analysis

The spatial arrangement of intensity variation in an image is termed as texture. The texture of fabric images is normally periodic and regular, whereas defects provide local irregularities. Inspection techniques that use the texture of the object are trying to reproduce the regularity pattern and indicate the discontinuities.

B. Gabor Filters

Gabor filters are linear filters which are sensitive to frequency and orientation. A 2D Gabor filter is a plane wave made of sinusoidal waveforms with a Gaussian envelope. Gabor filter can be mathematically written as:

[g(x,y) = (-) (2f x’)]

with (x') and (y) rotated, (f) is the frequency, (), which is the orientation, and ( ), which is the scale.

With multiple orientations and frequencies of bank of Gabor filters one can capture the predominant texture structure of fabric surfaces.

C. Texture Energy

The size of the Gabor filter reply can be interpreted as texture energy. The addition of the squared responses with respect to orientations will create a powerful texture energy map. The defective regions usually have an excess or abnormal energy than that of uniform fabric regions.

III. Proposed Methodology

This part explains the specific processing operations that have been used in our project code. The methodology will be structured in such a way as to strictly adhere to classical principles of texture segmentation and still be easy, understandable, and only fit within a course-based Digital Image Processing implementation.

The overall pipeline of the proposed system is shown below:

Fabric Image → Fabric Region Cropping → Gabor Energy Computation → Background Suppression → Thresholding → Defect Localization

A. Fabric Region Cropping

In order to prevent background interference, automatic fabric region detection is done. This is a combination of: - Entropy -based texture prior - K-means clustering HSV color space - Morphological operations.

As the region of interest (ROI), the area of the fabric that touches the image center and has a high value of the texture entropy is chosen.

B. Gabor Filter Bank

The grayscale fabric ROI is subjected to a bank of Gabor filters with a variety of orientations (usually 8) and frequencies. The central tendency of the real and imaginary response is squared to give a texture energy map.

The response is stabilized using Gaussian smoothing and noise is reduced as well.

C. Background Suppression

The background texture model is taken as a median-filtered energy map. By subtracting this background of the initial energy map, local anomalies due to defects are emphasized.

D. Defect Segmentation

The anomaly map is then normalized and thresholded through Otsu method to get a binary defect mask. Opening and closing of morphology is used to eliminate noise and bridge fragmented defect areas. Small areas less than a given area limit are eliminated.

E. Visualization

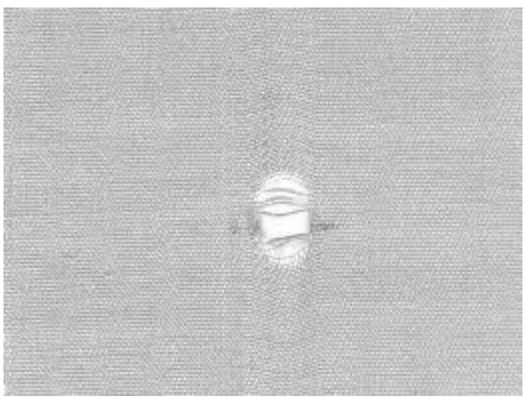
The regions of defects detected are superimposed on the original image of the fabric by red highlights and binding boxes to see them clearly.

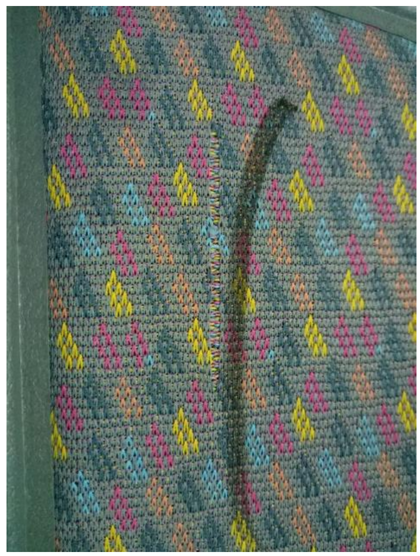
IV. Implementation Details

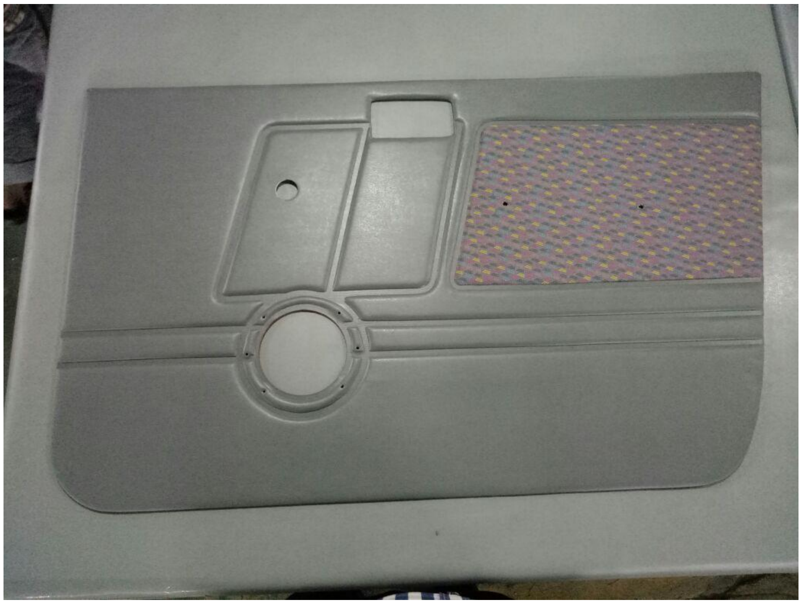
A. Dataset Description

The data set provided in this project was offered by the course instructor and it comprises of five high-resolution pictures of SUZUKI car door fabric. These pictures have areas of normal fabric and also visible defects which include irregularities in seams and distortion of surfaces. The dataset images are:

- fabric.jpg
- fabric_car1.jpeg
- fabric_car2.jpeg
- fabric_car3.jpeg
- fabric_car4.jpeg







All pictures were taken in relatively comparable lighting conditions to reduce variations in illumination and instead have texture-based defect detection as the primary objective of the picture.

B. Software and Tools

The application is done partly in Python. Image preprocessing, morphological operations, and visualization are done using the openCV. Gabor filter computation and entropy-based texture analysis is computed with scikit-image library. NumPy helps with numerical processing, whereas Streamlit is employed to create a simple graphical user interface that enables the consumer to upload images, change parameters, and view intermediate and final results.

C. Implementation Information of the user interface.

An interface based on Streamlit is created to show the entire defect detection pipeline. The UI provides the user to post images of fabrics, choose cropping behaviour and modify the count of Gabor filter orientations. The intermediate results like the cropped fabric area, Gabor energy map, anomaly map and the final defect overlay are presented on the same side to enhance easier interpretation.

Python and the following libraries are used to implement the system: - OpenCV to process images - scikit-image to process images with Gabor filters and entropy - NumPy to perform some numerical work - Streamlit to create the graphical user interface.

The application enables users to add fabric images, customize parameters like number of orientations, and cropping behavior and see intermediate results like Gabor energy maps, anomaly maps and defect overlays.

V. Results and Discussion

The suggested approach was tested in reference to the five fabrics images that were presented in the dataset. In both pictures, the system was able to detect areas in which the texture had been discontinuous with the normal cloth fabric. Specifically, seam defects and stitching anomalies were also shown in the Gabor energy anomaly map as strong responses.

To demonstrate the usefulness of each stage of processing, figures of the original fabric image, the cropped region, Gabor energy map, anomaly map, and final defect overlay are provided to visually represent the processing stages. The screenshots of the UI of the Streamlit application are also provided to present the real-time interaction and the set of parameters.

All in all, the findings show that Gabor-based texture analysis is ideally suited towards the detection of local defects on automotive fabric, particularly, when the texture of the fabric has a repetitive and directional structure.

The suggested system was applied to several SUZUKI car door fabric pictures with apparent faults. The Gabor energy-based method was able to emphasize the defective areas including texture discontinuity and surface discontinuities.

Some notable observations are: The defects are manifested in high-energy anomalies against normal fabric texture. - Auto-cropping enhances strength by eliminating irrelevant backgrounds. - The technique works better when there is homogeneous light and low levels of glare.

Though the method is not supervised and does not use labeled learned examples, it is able to generate robust localization of defects under controlled procedures of inspection.

VI. Limitations

- The quality can be compromised in high intensity light variations or shadows.
- More features may be necessary on very complex or non-repetition fabric patterns.
- The technique identifies defects and fails to categorize the type of defects.

VII. Conclusion

The project displays that Gabor filter-based texture analysis is a powerful and explainable method of detecting a defect in fabric in automotive interiors. Through texture energy modeling, background rejection, and morphological operations, the system is able to identify defects in SUZUKI car door fabric without the supervised learning.

The implementation based on Streamlit offers an all-around end-to-end solution applicable to academic demonstration and is a basis of future industrial inspection systems.

VIII. Future Work

Future research can involve: K-means texture segmentation of multivariate defects - Hybrid containers of illumination normalization plans - Deep-learning hybrid solutions - Quantitative experimentation that makes use of named defect collection objects.

References

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2. Gonzalez, R. C., & Woods, R. E. Digital Image Processing. Pearson.

3. OpenCV Documentation.

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