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Automatic forensic analysis of automotive paints using optical microscopy

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ABSTRACT

The timely identification of vehicles involved in an accident, such as a hit-and-run situation, bears great importance in forensics. To this end, procedures have been defined for analyzing car paint samples that combine techniques such as visual analysis and Fourier transform infrared spectroscopy. This work proposes a new methodology in order to automate the visual analysis using image retrieval. Specifically, color and texture information is extracted from a microscopic image of a recovered paint sample, and this information is then compared with the same features for a database of paint types, resulting in a shortlist of candidate paints. In order to demonstrate the operation of the methodology, a test database has been set up and two retrieval experiments have been performed. The first experiment quantifies the performance of the procedure for retrieving exact matches, while the second experiment emulates the real-life situation of paint samples that experience changes in color and texture over time.

1. Introduction

In forensics, automotive paint fragments are one of the most commonly recovered traces of evidence at the scene of an accident, such as a hit-and-run scene [1]. As a logical consequence, linking these traces to a matching vehicle has raised a considerable amount of attention. In recent years, multiple procedures have been defined that all aim to provide forensic experts with a well-defined, objective approach for characterizing the paint sample under study, which, in turn, can be used for identification. Such procedures often involve a combination of techniques, including macroscopic analysis, optical microscopy and spectroscopy, e.g. [2,3]. Since automotive paints typically have a complex chemical composition, consisting of multiple layers (in essence, a primer, a color coat, and a clear coat finishing), techniques that assess this composition, such as microchemical analysis and X-ray analysis as a non-destructive alternative, have been used extensively [4]. Especially with the construction of the Paint Data Query (PDQ) database, i.e. a database with information ranging from physical attributes to an infrared (IR) spectrum for every layer of each of its more than 21,000 paint samples [5], spectroscopy has found wide support. Techniques used for spectroscopic analysis include Fourier transform infrared spectroscopy (FTIR) and/or Raman spectroscopy [6–8]. Often these techniques are combined with pattern recognition methodologies, allowing automatic comparison of spectra [9,10].

However, spectroscopy typically does not provide any information on the spatial heterogeneity of the paint sample under study. In addition, changes in chemical composition, e.g. due to migration of components between layers, complicate classification [11,12]. Consequently, visual analysis of the paint sample under study, assessing its color and its morphology, remains an important step in the identification of automotive paints. This visual analysis is routinely performed manually. Unfortunately, this technique is particularly prone to inter-operator variability. Additionally, as time is of the essence in this particular type of police investigation, not only precise but also swift identification of the vehicle is of the uttermost importance. In this paper, we propose an objective and automatic approach for the visual analysis based on dark field microscopy. It is designed not only for the characterization, but also for the identification of automotive paint samples. The main aim of the new technique is to reduce the workload of the experts and the backlog of cases considerably.

In order to fully characterize a sample, the proposed method assesses both the color distribution, and the texture of the sample. The assessment of the color distribution is a particularly

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challenging step, as it does not only require proper and reproducible lab practices, but also consistency of the images themselves. To this end, a color calibration procedure is defined, together with a newly developed reflective color chart for microscopy that contains only 20 test chart colors, in order to reduce the labor intensity of the procedure. After the calibration step, the color and texture are characterized by first separating the color from the texture. This separation is only possible after transformation of the image to an uncorrelated color space, such as the CIE $L^*a^*b^*$ space. Once this separation has been done, the color distribution is assessed by calculating the color histogram of the resulting color components. Likewise, texture features are extracted from the intensity component, in the form of Gabor features. Following the extraction of these features, suitable distance measures between the image under test and each of the images in a database are selected with the aim of constructing a shortlist of matching images from this database. Such distance measures are selected for both the color histograms and for the Gabor features. Finally, in order to effectively create the aforementioned shortlist, both measures are combined in a sensible way, such that the matching images indeed reflect the highest visual resemblance to the image under test.

To validate the proposed approach, a retrieval experiment is performed in which the aim is to match several test paint samples with other instances of the same paint type in a database. Additionally, in order to demonstrate the robustness of our methodology against microscopic changes in visual appearance, as typically occurs because of wear and aging effects, a similar experiment is repeated using test paint samples that bear visual resemblance to certain database samples, but for which no instance of the same paint types is present in the database. For both of the aforementioned experiments, the effect of the color calibration step is demonstrated.

2. Material and methods

2.1. Color calibration

Color calibration of acquired images plays an important role in the reproducible and accurate extraction of color features of an image. The color calibration transforms the unknown original image RGB data to a standardized RGB color space called sRGB [14], based on a set of color chart (see Fig. 1) images acquired together with the image being investigated under exactly the same circumstances and settings. Because the sRGB color space has a known relation to the CIE colorimetric spaces like CIE XYZ and CIE $L^*a^*b^*$ it is possible to compute color features in those spaces, and use perceptual color metrics like dE^*_{76} or dE^*_{2000} to express color differences. Although frequently encountered, it is simply incorrect to transform RGB data to e.g. CIE $L^*a^*b^*$ without exact knowledge of the RGB primary colors (actually RGB is not a color space, but rather a family of color spaces which will be different, i.e. have different primaries, each time an image is acquired).

For details about the color calibration, see [15–17], but basically the color chart values as measured in the acquired images and their known colorimetric values as measured by a spectrophotometric device are used to construct a 3-dimensional transform from the original image RGB data to the desired sRGB data. This transform consists of three 1D lookup tables (LUT), combined with a 3D LUT, and the results for a set of test paint samples can be seen in Fig. 2. The camera used during the experiments was a Pixelink PL-A662 CMOS camera [18], with an Olympus BX60 microscope. The acquisition was performed using our own software in order to

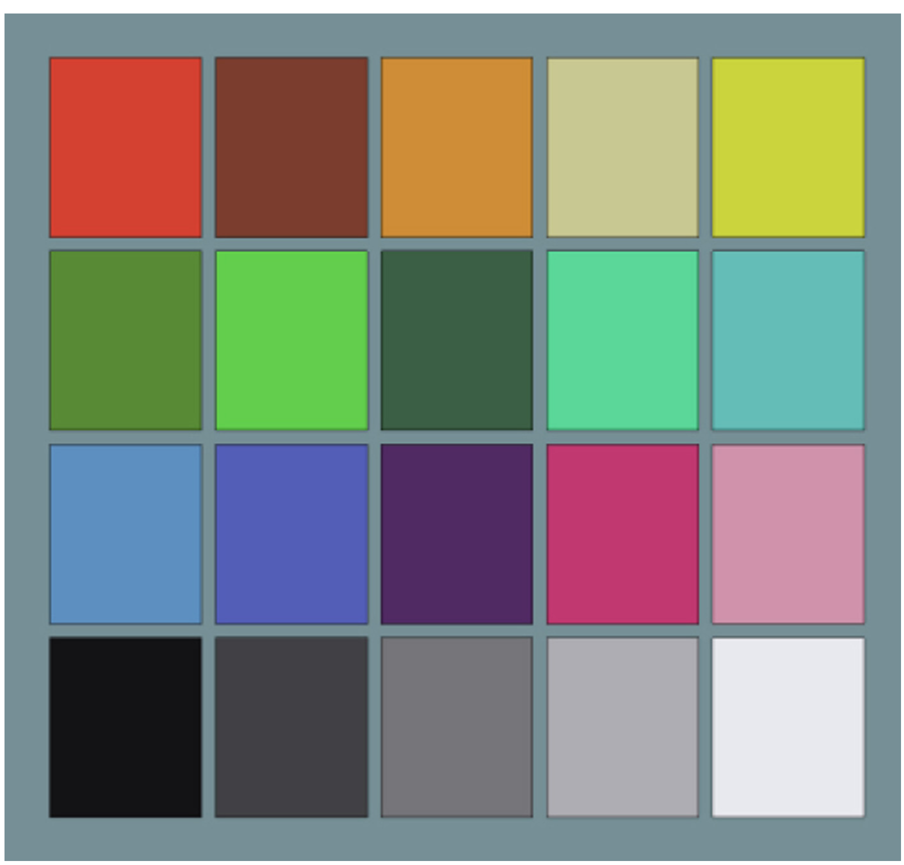

Fig. 1. The calibration chart by DSC Labs [13]. This chart has optimally placed colors for calibration.