DUST_BW: Detektion von Staub und Kratzern auf Schwarz-Weiss-Filmen durch Dunkelfeldbeleuchtung und polarisiertes Licht

DUST_BW: Detection of dust and scratches on photographic silver halide material by dark field and crossed-polarized illumination

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Zusammenfassung:
Das Projekt DUST_BW befasst sich mit der digitalen Rekonstruktion von Fotografien (Dias, Negative) und Filmen sowie deren Haltbarkeit mit Hilfe von digitaler Bildbearbeitung.
Mehrere Faktoren begrenzen die Beständigkeit von fotografischem Material. Dieses Projekt konzentriert sich auf das Problem von Staub und Kratzer. Das Projektziel ist die Entwicklung eines Systems zur Digitalisierung, welches effizient Staub und Kratzer auf jeglichem fotografischen Material (auf Farbfilm genauso wie auf schwarz-weiss Material, auf Fotografien und Film) erkennen und beim Scannen entfernen kann. Zur Unterstützung der herkömmlichen softwarebasierten Verfahren werden auch optische Verfahren zur Anwendung kommen, wie z.B. Aufnahmen mit Kreuzpolarisation und Dunkelfeldbeleuchtung. Die Kombination aller dieser Techniken zum Zweck der Bildrestaurierung ist neu.

Abstract:
The DUST_BW project pertains to digital reconstruction and permanence of photographs (slide, negative) and motion-picture films by digital image processing.
Several factors limit the permanence of photographic material: this project focuses on dust and scratches. The goal is the development of a scanning system that will efficiently detect, and subsequently remove, dust and scratches from any type of photographic material (colour as well as black-and-white, still images as well as moving images). The removal of these defects is performed through a “hardware assisted” method that uses techniques such as cross-polarization, dark field and grazing light. The combination of these techniques for this application has never been done before.

State of the Art

Different techniques are nowadays used to remove defects on photographic material, and each one has its advantages but also its limitations.
Mechanical dust removal techniques utilize pressurized air combined with electrostatic discharge and/or apply the film on a dust removal roller with a sticky surface; this is a low-budget method but the efficiency is not very high, especially when dirt is sticking to the film.
Other methods use chemical substances, like the immersion of the film into a cleaning solvent, or the so-called “WetGate” method; the main drawback of these methods is that the chemicals used are environmentally and toxicologically hazardous.
During the last years, with the strong spreading of digital imaging technologies, digital methods for restoration are replacing analogue techniques[1]. In motion picture dust can be removed automatically using the timeline. Dust has an impulse response, i.e. appears only on one frame. The comparison of a

[1] Ruth Bergman, Ron Maurer, Hila Nachlieli, Gitit Ruckenstein, Patrick Chase and Darryl Greig, "Comprehensive solutions for automatic removal of dust and scratches from images", J. Electron. Imaging 17, 013010 (Mar 26, 2008); doi:10.1117/1.2899845

movie frame with the previous and the subsequent frames allows detecting dust. Nevertheless, it is possible that image objects show the same behaviour and this may entail missed or false detections.
For still images the method mentioned above is not applicable and other techniques have to be adopted. The application of filters on digital images (e.g. median, despeckle) can be quite effective but they obliterate fine details in the image.
In the case of colour photographic films, however, *infrared cleaning* can be used. This method consists in acquiring an additional infrared channel at the same time as the visible colour channels; photographic colour film is mostly transparent to infrared radiation (no matter what is the image it contains), conversely dust and scratches are not, so they are recorded in the IR channel.
A major limitation of this technique is that it can only be used on dye-based films (colour and chromogenic black-and-white films); the image-forming silver particles in black-and-white film stocks, on the other hand, are opaque to infrared radiation, making this method inapplicable. Moreover, this technique is patented and this entails extensive additional costs.
The aim of the DUST_BW project is to define an alternative method for the automatic restoration of any kind of transparent photographic material (film, still photographs, black-and-white and colour), by providing a cost effective solution, based on an innovative combination of physical light scattering and image processing.

A novel hardware-assisted method

Digital restoration of photographic material aims at creating a digital reproduction free from the physical defects present on the surface of the material. The approach we propose accomplishes the restoration in two distinct steps: the creation of the digital reproduction and, subsequently, the removal of the defects from this reproduction. In order for the restoration to be affordable, especially for the case of movies, these operations have to be fully automatic.
The automatic digital solutions for the removal of defects, in turn, are accomplished in two stages: the detection stage, in which the defects in the digital reproduction are localized, and the reconstruction stage, in which a processing is applied to restore the pixels of the defects. The experiments described in the following are focused on the development of an effective method for the detection stage.
Dust and scratches can be considered as two different types of perturbation of the parallelism of the film surfaces: a dust grain is additional material on the film surface and, on the contrary, in a scratch the film material is missing. This fact suggest that, in order to perform the defects detection, rather than making use of the "normal" digital reproduction, another digital image (*defect-image*) can be acquired with a special optical set-up specifically designed to localize exactly irregularities present in the surface of the film. The side information acquired in this image will assist the reconstruction stage in which the defects are removed from the digital reproduction through *in-painting* techniques.
The digital restoration of a photographic motion-picture film is performed frame by frame. The experiments we are here presenting are conducted on single frames; successively, a film-transport mechanism will be involved and the results obtained with still images will be applied to the case of movies.

Optical set-ups

The optical set-up to be used to perform the defect detection has to suppress the signal related to the image impressed in the emulsion layer, thus emphasizing the signal related to the defects present on the film.
The description of the basic optical set-ups that could carry out this task is reported in the following. The scheme in Fig.1 summarizes the basic set-ups.
Cross-polarization - Dust particles and scratches may perturb the polarization of light. Therefore cross-polarized illumination can be used to obtain an image in which only the defects are visible. A polarizing filter is placed between the light source and the sample; another one is placed in front of the acquisition system. The directions of polarization of the two are orientated orthogonally. The silver grains do not perturb the polarization of light; therefore the signal related to the silver emulsion is suppressed while the signal related to the defects is maintained.

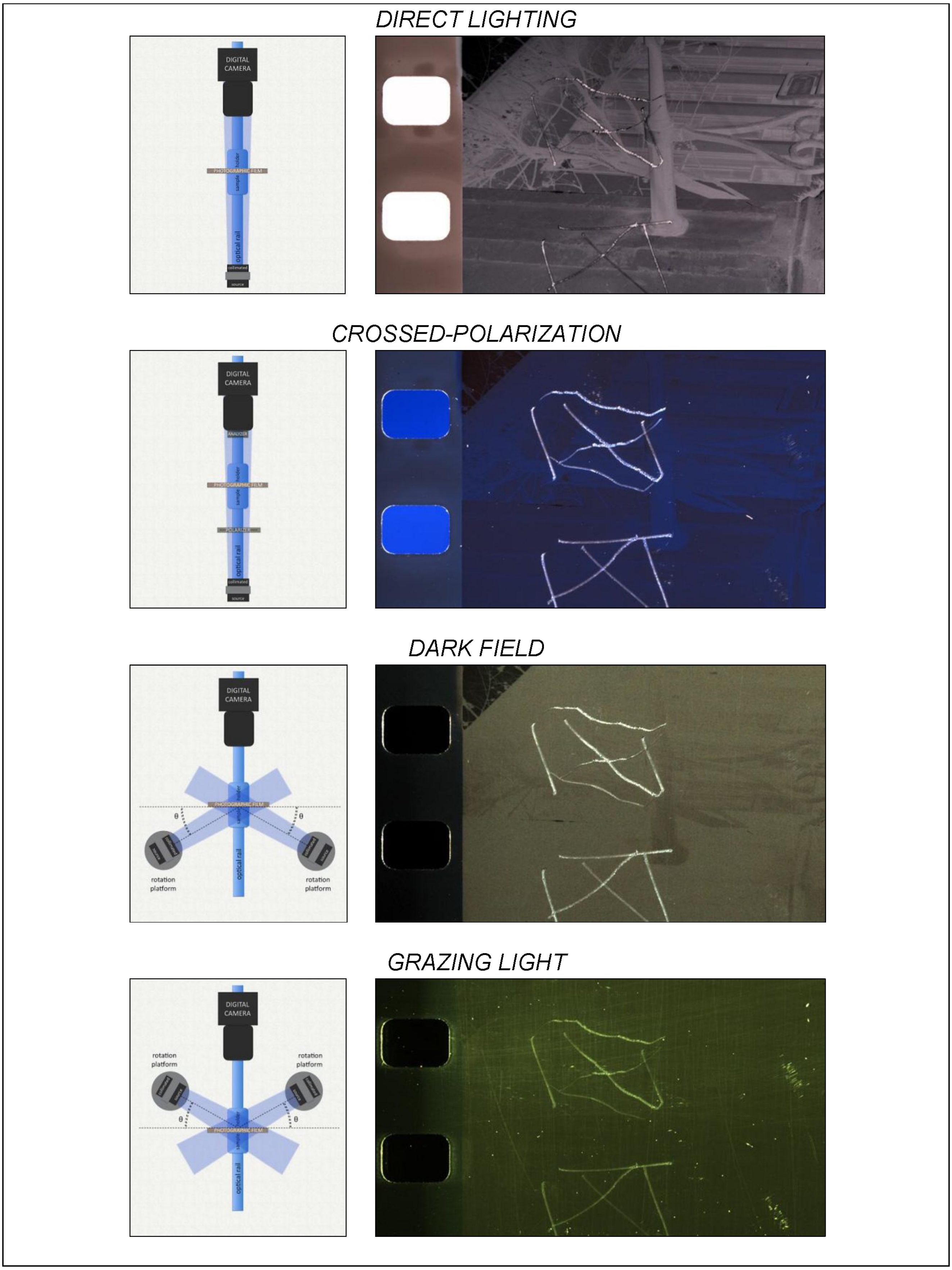

Figure 1 – Outline of the basic optical set-ups: on left the layout of the set-up, on right an example of the resulting image acquired by the camera

Dark field - The size of developed silver particles in black-and-white emulsion is < 1µm, whereas dust particles and scratches are generally much bigger. Therefore, their scattering behaviour is different. By setting an angle between the illumination and the optical axis of the acquisition device, it is possible to exclude the unscattered beam from the image. Therefore, since the silver particles and the defects scatter the visible light to a different extent, it is possible to obtain an image in which the signal related to the silver emulsion is considerably suppressed and the defects are emphasized.
Grazing light - A grazing light set-up is realized by placing high-angled light sources on the same side of the sample where the digital camera lies. The light hitting on the photographic film is mostly transmitted or absorbed; only where is there a roughness that perturbs the plain surface of the film, the light is reflected and, therefore, acquired by the camera.
This technique has the drawback that only the defects of the side facing the camera will be detected.
Combined set-ups - It is also possible to combine the basic set-ups in order to improve the results. One possibility is to add the polarizing filters to the dark field set-up (Fig.2); the analyzer can block the small amount of scattered light from the silver grains and gives the possibility to have an image in which the signal of the silver emulsion is further suppressed.

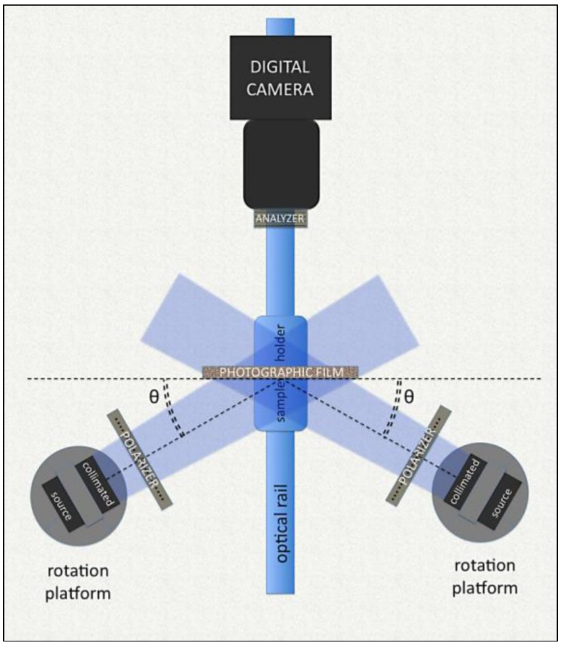

Figure 2 - Layout of the combined optical setup dark field / cross-polarization

The defect-image and the detection-mask

The experimental part has been conducted on old samples of film present at the Imaging & Media Lab and on samples created on purpose (Fig.3); all of them are 135format, black-and-white gelatine silver negatives. The frames have been then artificially scratched and/or dust has been spread on their wet surface (so the dust grains stick on the surface).
The laboratory activity is directed towards the optimization of the efficiency of the detection: hence, the variation of the efficiency with the parameters involved will be analyzed. The main parameters are the following: type of set-up (cross-polarization, dark field, grazing light, combined, etc.), the wavelength of the illumination, the angle between the beam of light and the optical axis, the type of polarization (circular, linear), the angle of the linear polarization of light with respect to the vertical direction, the characteristics of the film (such as brand, film-speed, type of development, etc.), type and characteristics of the defects (dust or scratches, type and size of dust grains, direction and depth of scratches, etc.).
A laboratory has been set up with the subsequent main elements:

- Optical Breadboard 1500 x 1250 x 25mm
- Collimated LED @ 470nm, 530nm and 625nm
- DSLR camera Nikon D3 – CMOS full frame sensor with 4256 x 2832 pixels
- Polarizing filters

As a general rule, on a 35mm movie print film the frame pitch is four times the perforation pitch; hence, the digital camera frames an area of the negative that includes four holes of the perforation in both sides (see Fig.3). This way, the area taken up by a frame (the region of interest (ROI) in Fig.3 - 19X24 mm) is completely included and the perforation can be used as spatial reference for the automatic geometrical registration (as will be explained in the following). A bellows and a UV-Nikkor 105mm f/4.5 objective have been adopted to focus on the sensor the image of this area (approximately 33X22 mm). The sampling density is therefore approximately 3300ppi.
The sensitivity is set to its minimum. The aperture is set on f/11. The shutter speed is set so the exposure is to its upper limit: saturation would occur with a 1/3 stop over.

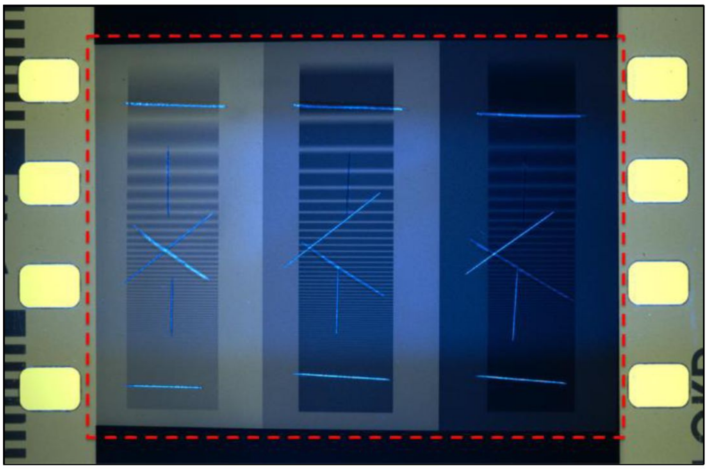

Figure 3 - The area framed with the digital camera: four holes of the perforation are included on both sides. The ROI doesn't include the perforation; it frames only the area taken up by a frame (red dashed rectangle)

The images acquired by the camera are saved as RAW images (.NEF) and then linearly converted in TIFF/16bit with the software *dcraw*[2].
In order to produce the map of the defects the defect-image will undergo processing. The simplest processing to apply is thresholding. If the proper threshold is applied, the bright pixels corresponding to the defect will be transformed into 1s and the other "healthy" pixels will be transformed into 0s. Conveniently superimposing this binary image (*detection-mask*) on the digital reproduction, it will classify its pixels in "defective" and "healthy".
The choice of the threshold value is a critical point: the higher it is, the more restrictive will be the defect detection and missed detection will be more probable.

Evaluation of the detection

In order to rate how efficiently a certain configuration of the optical set-up detected the defects on a sample, it is necessary to refer to another binary image (*reference-mask*) that provides the map of the "true" defects of the sample. The reference-mask has to be created by an operator that directly observes the frame with a magnification system and labels the pixels as normal or defective.
The pixel-to-pixel comparison between the detection-mask and the reference-mask is performed in the region of interest, providing the numerical evaluation of the defect detection. For each pixel 4 cases are possible:

Value on detection-mask	Value on reference-mask	Result
1	1	Successful detection
1	0	False detection
0	1	Missed detection
0	0	None

[2] http://www.cybercom.net/~dcoffin/dcraw/

Of course, in order for these results to be significant the two images must be geometrically registered so that their pixels exactly refer to the same point of the negative.
If we consider also the total number of 1s in the detection-mask (total number of detections) and the total number of 1s in the reference-mask (total number of "real" defects), the percentage of defects correctly detected (*SD/defects%*) and the percentage of detections that are false (*FD/detections%*) can be considered two effective indicators. The *Matthews Correlation Coefficient*[3] (*MCC*) takes into consideration these two percentages, providing a unique indicator of the performance of the detection: this number spans from -1 to 1 and, as closer it is to 1, the better is the detection.

The Scratch And Flaws detectoR and ANalyzer (SAFRAN)

A specific software platform has been realized for this project to automate the processing necessary to produce the detection-mask and the elaboration that allows the numerical evaluation of the detection.
The SAFRAN software receives as input the defect-image obtained with a certain optical set-up and performs the subsequent operations:

- Geometrical registration of the defect-image with the reference-mask
- Find and apply to the defect-image the optimal threshold to create the detection-mask
- Pixel-to-pixel comparison between the detection-mask and the reference-mask
- Calculation of the indicators of the performance of detection

Geometrical registration - The software, with the aid of the user, performs this operation semi-automatically referring to the perforation holes. In order to get a high accuracy a two-step registration algorithm was developed. The first step is based on the geometry of the reference mask, which is assumed to be known very accurately. It can thus serve as the reference frame to which the defect-image has to be registered. This is done with an *affine transformation*, which allows for the correction of rotation, translation and scaling, respectively. The implemented algorithm works with sub-pixel accuracy to minimize transformation artefacts.
Sometimes, the affine transformation fails to give the desired accuracy. In those cases the matching can be refined with the second registration method, based on the features in the images. It uses the cross-correlation in the frequency domain between the mask and the image and usually corrects for the small shift left over by the affine transformation.
Iterative thresholding - In order to define the optimal value for the threshold, an iterative operation is performed. For each iteration different threshold values are applied to the defect-image and the procedure is driven to its final result (the Matthews correlation coefficient). An algorithm identifies the threshold value that optimizes the detection, i.e. maximizes the MCC; this threshold value is then applied to produce the detection-mask.
The typical trend of the Matthews correlation coefficient with the threshold value is reported in the plot below. As can be seen the sampling outlines a well-defined maximum.

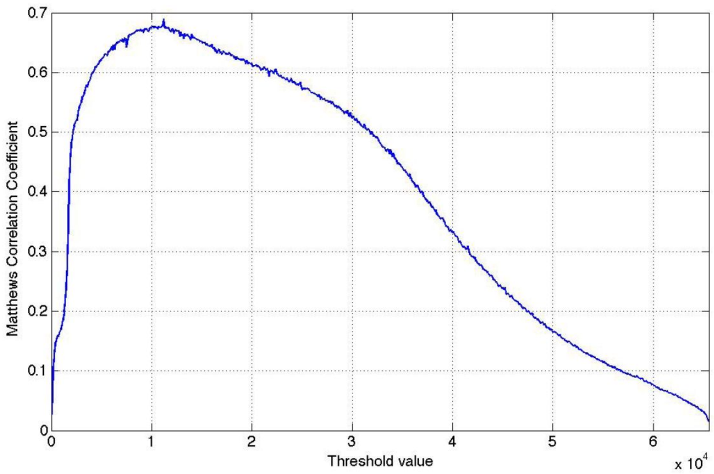

Figure 4 - Typical trend of the Matthews correlation coefficient vs. the threshold value

[3] http://en.wikipedia.org/wiki/Matthews_correlation_coefficient

Comparison of the masks - The comparison between the detection-mask and the reference-mask is performed in the ROI. A new image is then created (*detection-result*): it is indexed to have four possible values that indicate the possible results of the comparison. This image is a powerful tool to grasp information on the strengths and weakness of a certain optical set-up.

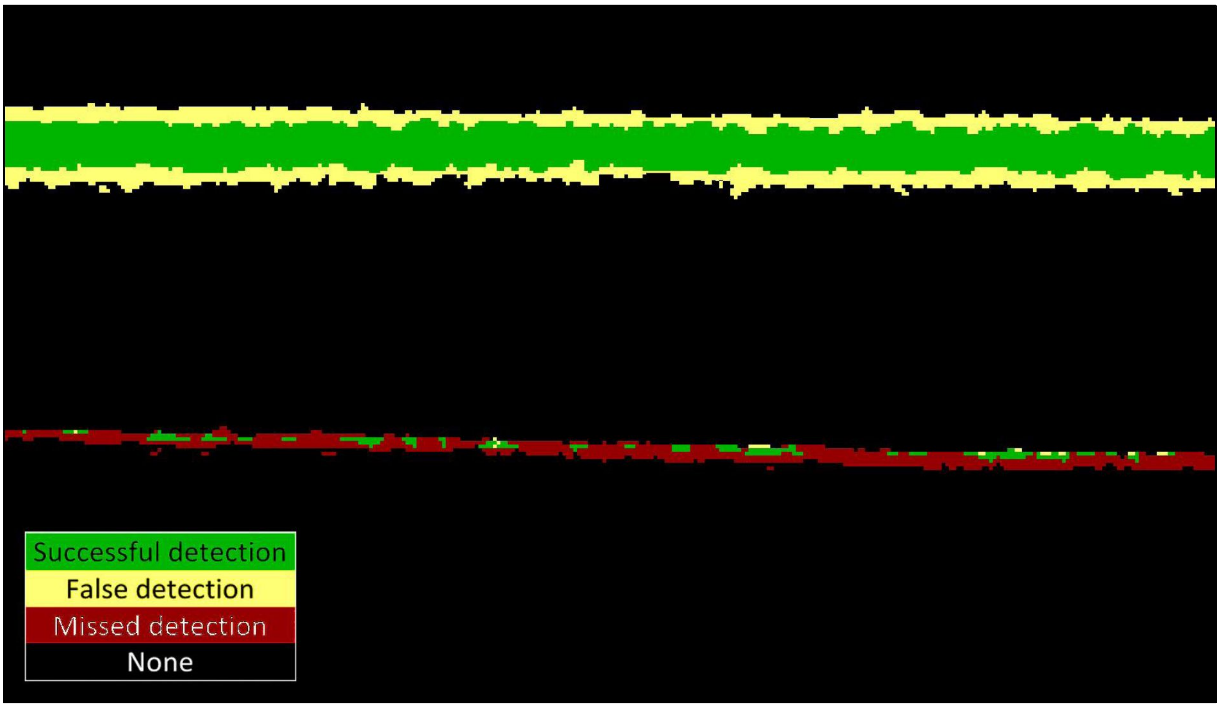

Figure 5 - The resulting image displayed by the SAFRAN software: on top an over-detected scratch, on bottom an under-detected scratch

Calculation of the indicators - Finally the software provides a set of significant values that indicate the performance of the detection (e.g. the percentage of defects correctly detected, the percentage detections that are false, the Matthews correlation coefficient).

Further developments

The SAFRAN software still needs some improvements. An adaptive thresholding will be implemented: the defect-image will be divided into regions and different threshold values will be applied in each region. Moreover, a more sophisticated thresholding will be applied on the defect-image: rather than a simple binary detection-mask, it will produce a probabilistic one.
Once those improvements will be done, systematic acquisition sessions could start in order to define the optimal optical set-up.
Afterwards, the results obtained with still images will be applied to the experimental work for moving images. A film-transport mechanism will be included and the case of motion-picture films will be handled.
At the same time, the reconstruction stage will be approached. The proper In-painting technique will be defined; the missing parts that have been detected could be replaced to obtain a digital reproduction that appears correct and natural.
The novel movie scanning system will be then ready to be designed.