Deflectometry for secure traceability

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Abstract. Secure traceability is the ability to trace the lines of products a company releases on the market, while preventing attacks on the tracing system. This can be achieved by marking the objects with complex features, difficult to replicate for potential counterfeiters. Some of us have proposed to directly extract some signature from the structure of the material composing each product instead, as a vast portion of manufactured items on the market provide naturally random structures more difficult to replicate than man-made security markers. Having developed an industrial system for diffusing materials, we present here an optical setup that could achieve the same level of security for many different types of objects with specular surfaces.

1. Introduction and definition of terms

We shall begin this paper with a few reminders and definitions which can not be avoided if the goals of our work are to be understood correctly: we are working in the field of \textit{secure traceability}, and our technology requires us to be able to work with the local properties of specular or transparent objects, which is why we are interested in \textit{deflectometry}.

\textit{Secure traceability:} According to the International Organization for Standardization, traceability is the \textit{ability to trace the history, application or location of that which is under consideration} [1]. Among other uses, it can be considered as a tool for companies or governmental agencies to fight against counterfeiting and parallel markets, or to prevent any illegal activity regarding a given range of products. In the particular case of \textit{secure traceability}, resistance against forgery or deliberate attempts to prevent the tracing is mandatory.

\textit{Deflectometry:} Deflectometry is a technique based on the measure of the way a transparent or a specular object geometrically alters the transmission or the reflection of incident light. It is generally used to measure topographical data in the case of specular materials [2], or index maps in the case of transparent ones.

† To make the following easier to read, we will only consider the reflection on a specular surface. The reasoning is similar for transmission through transparent materials.
§ Typically a ground glass screen on which sinusoidal fringes are projected [3], or simply a LCD screen.
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Figure 1. A typical deflectometry setup — a computer screen, a microscope slide used as specular test object, a camera.

Figure 2. Paper seen with white light and grazing incidence lighting. The diagonal is about 15 mm long in object space. Such acquisition parameters make it most probably impossible to find two different sheets of paper which would result in identical textures, but quite easy to acquire the same texture twice from the same zone of the same sheet of paper at different times.

 placed on the optical path of the reflection of the source by the surface of interest. It is focused between this surface and the source plane on the optical path, and records the deformation of the image of the source by the reflection on the non planar surface (see picture 1, or figure 5 on page 4 for more details).

2. Problematics

2.1. Where we come from

In secure traceability, the extraction of signatures from matter itself is a promising way to authenticate products during their market life. Instead of using complex marking techniques, our aim is to authenticate the product by extracting a unique identifier from its matter. The randomness of the latter, resulting from both the variability of its constituents and the parameters of the manufacturing process, makes every product unique (see picture 2). A signature can thus be computed for a given object from the — repeatable — random signal acquired from some previously chosen part of a product’s material. This has been achieved by some of us for diffusing materials like paper by first acquiring a portion of surface or volume data with a camera and white light illumination, and then processing the resulting image with a generic algorithm to produce an object-dependent random signature [4]. The principle is illustrated on figure 3 on the next page.

Our technical needs are the following: on the one hand, two different objects observed with the same optical setup should generate signals from which the processing will output very different signatures. This high discriminating power between objects enables us to minimise the probability that two realisations in a range of products output similar signatures. On the other hand, the signals acquired from the same object observed at different times, under reasonably similar conditions, must generate the same signature — with a small tolerance — , allowing identification. This need for a high temporal repeatability for our setup sets our
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Figure 3. Signature acquisition scheme.

tolerance for the signal recovered each time we record the same part of the object during its lifetime. Sensitivity to normal object ageing must be low for instance.

Sadly enough we do not live in a world where such specifications are sufficient. Market usage is the goal, which means that there are several other constraints we have had to fulfil. One of these is that we want to be able to work with no additional reference mark on the object — which would help us to frame the zone of interest — as the technique enables us to do it. We also need the optical setup to be lightweight and miniaturizable to allow field usage by customs officers, in commercial centres, etc. Last but not least, we wish it would integrate easily in production lines as many customers are reluctant to altering their setup. The physical constraints on the device have thus to be as light as possible, to give us room for developing usable technical solutions.

2.2. Current work

However diffusive materials are not the only ones used by the packaging industry. A far from negligible fraction of the materials are transparent and / or specular like glass, polished metals and many plastics.

The requirements for the corresponding optical setup are the same as with diffusive materials and the acquisition scheme of figure 3 still applies, but the imaging system has had to be re-worked: if we wanted to be able to simply re-use the generic algorithm mentioned in section 2.1, we had to find a technique that could generate a textured image reflecting the variability of the material structure of a specular object. Deflectometry has allowed us to acquire such images.

3. Textured image from specular random surfaces

A look at the series of pictures on the following page gives an insight of the result of lighting a glass bottle with two of the most widely used methods in image vision: diffuse (image 4a on the next page) and point source (image 4b) lighting. On a specular surface, diffuse lighting results in a contrast-less image: whatever the local height, or, more exactly, the local gradient of the surface, the same amount of light reaches the camera as the reflection coefficient does not vary much and the exitance of the source is the same on its whole surface (see figure 5 on the following page). On the contrary, a point source lighting highlights the inhomogeneities of the specular surface where it is lit, as a small variation in surface gradient can make an otherwise lit zone deflect the light away from the camera aperture, and thus, become dark. However, the brightness distribution, being highly inhomogeneous, does not allow full-field information extraction because only a limited range of local surface gradients can redirect a

∥ The packaging is a very sensitive matter in today’s brand-driven economy and the ability to protect its integrity makes a very strong commercial argument in favour of our technique…
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(a). Diffuse lighting

(b). Point source illumination

(c). Illumination with a LCD screen showing binary fringes

Figure 4. Deflectometry highlights the local randomness of a given object even in difficult conditions, like a cylindrical specular surface. Here we show several pictures of a bottle under different lighting to compare the resulting images. The image diagonal is about 25 mm long, the curvature radius of the bottle is about 30 mm, the camera is focused near the bottle surface.

Figure 5. Variation of the path of the light when rotating a flat specular object on the plane of which the camera is focused. For a given pixel, the part of the source the light comes from depends mainly on the local gradient of the surface.

Ray emitted by the small source to the aperture of the camera. This range varies continuously with field angle moreover, even for a flat surface…

Image 4c can thus be seen as the best combination of the two: the source, being wide, lights the whole field of view. Being inhomogeneous, it still provides a way to acquire contrast
Figure 6. Hamming distances between the signature of images of a given zone of a bottle, as the fringes are dephased by 1/25 period steps. With a threshold of 10% the object could be identified while dephasing remains below more or less one tenth of a period modulo half a period (as a distance of 100% would mean that the signatures are anti-correlated).

information correlated to surface gradient variations. For now we have only worked with binary fringes on the source, but many other patterns, providing a power or a phase variation, could be used on the source plane.

Note that the absence of visible fringes in image 4c is misleading: without them, such a texture would not appear. We just chose our period short enough so that the fringes are being scattered in each other’s neighbourhood in order to get as much information as possible from each picture. Temporal phase-shifting would still be possible, even if we are not sure this is the best way to process our signal.

4. Stability concerns

Our algorithm is very sensitive to uncontrolled contrast inversions in the image (much less to local defects, like a scratch, and predictable global ones, like a lighting shift). As long as we were working only with diffusive objects, a misalignment was not disturbing; however, when a specular object is translated perpendicularly to the fringes, inversions of the observed fringe value can occur, depending on the — random — value of the local surface gradient and on the length of translation. This can prevent signature matching (see figure 6).

5. Perspectives

We have now several leads on how to improve our setup. Firstly we would like to minimise its sensitivity to environmental conditions, and to find the optimum set of parameters to use this technique (distances between elements, fringes period, etc.).

To achieve this, we are making many experiments with test objects on the one hand, while changing the main parameters. On the other hand, we are trying to find the simplest model that can reproduce the properties of our images, to enable further study and optimisation while reducing the time needed to study a new parameter.

But we would also like to evaluate the potential of this technique regarding how much information we can extract from a given surface, without making the experimental setup too hard to tune: an assessment of the quality of the identifiers has to be done, in terms of
We could also eventually develop image processing tools directly adapted to the signal instead of using our algorithm directly, to make it less sensitive to source misalignments.

References

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