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Microscopic paper fingerprinting

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The natural randomness of microscopic paper texture is used to extract a unique signature for a region of paper.

Financial systems, health care, governance, and other related markets use paper as the primary medium of communication. Therefore, verifying the authenticity of a piece of paper or document is of paramount importance. Counterfeiting and forgery of paper documents are a massive problem worldwide, with losses ranging in billions of dollars. We have developed a low-cost microscope system to authenticate paper that works across a wide variety of scenarios.

Research efforts in the area of paper fingerprinting range from techniques that try to understand the fiber structure[1] or the randomness of ink splatters made by a printer to extract a unique sign,[2] to mid-range scanners to model the 3D fiber structure,[3] or lasers to model surface scattering.[4] However, these approaches are either expensive, insufficiently robust, or cater to a limited set of applications. Our work differs from these approaches in two fundamental ways. First, the physical property that we use to fingerprint the paper is very different from existing solutions and superior because it is robust to tampering and environmental effects. Second, in contrast to bulky equipment such as scanners and laser surface authentication devices, we use a portable, handheld microscope to obtain a speckle pattern suited to a variety of scenarios. For instance, it can be used to authenticate paper checks and legal documents in a low-cost manner. Our system works both on a desktop/laptop and a cell phone.

The concept of laser speckles has been around since the 1970s and is used in profiling objects.[5] The 'PaperSpeckle' system we have developed is based on texture speckles.[6] When light falls onto an object, it is scattered by the object's texture and underlying physical non-uniformities. When projected onto a screen, this light produces unique bright and dark regions (see Figure 1).

We use two types of devices to capture texture speckles. One is a handheld digital microscope with inbuilt partially coherent light sources (LEDs) and an imaging system that is attached to a desktop/laptop. The other device is a microscope that fits to the camera of a cell phone using a custom-built attachment. The light from the source is focused on the paper and the scattered light is captured by the imaging system. Once the image has been obtained at a microscopic granularity, it is analyzed and processed using algorithms that provide a fingerprint of the texture speckle pattern corresponding to the region of interest.

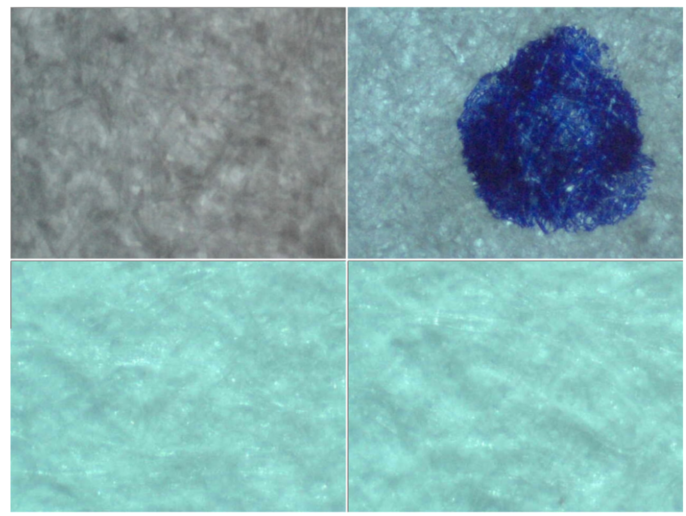

Figure 1. *Four different types of texture speckle patterns.*

We use a wavelet-based transformation such as Gabor transforms to convert the image into a bit representation. Gabor transforms are ideally suited to analyze the texture image because they are insensitive to changes in global illumination and minor modifications. Moreover, any two speckle images can be distinguished using the Hamming distance. Once the speckle has been converted to Gabor bit sequences, we decompose them to obtain the singular values. These singular values are unique, and the largest 64 or 128 values are extracted to form the fingerprints of the speckle pattern. We also examine the singular value perturbation across a large number of Gabor bit sequences and show how we can clearly distinguish between speckles of the same and different regions.

We evaluated our system across a large number (1500) of different types of paper under both ideal and non-ideal conditions. Figure 2 shows, in ideal conditions, the difference in Euclidean distance of fingerprint pairs from the same region (the distribution in black in the bottom left corner) and the difference in

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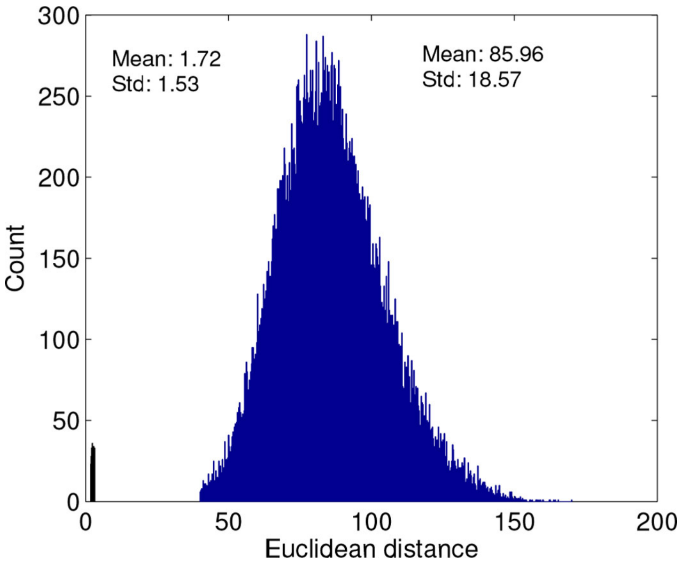

Figure 2. The difference in Euclidean distance between the pairs of texture speckle images of the same regions (left, in black) and different regions (right, in blue)

Euclidean distance of fingerprint pairs from different regions (the blue distribution). The two distributions are well separated, and a reasonable value for the Euclidean distance can be used as a threshold to match the fingerprints with no false positives. Under non-ideal conditions such as crumpling, printing, soaking, and aging, the distributions of Euclidean distance differences are also well separated, thereby providing no false positives or false negatives.

PaperSpeckle is a low-cost, robust, portable paper fingerprinting system based on fundamental principles of light scattering. It has broad application for detecting paper counterfeiting and forgery. We are now planning to extend this technique to fingerprint a variety of other materials, such as fabric, metal, glass, wood, and alloys.

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