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EMPIRICAL CHARACTERIZATION OF WOOD SURFACES BY MEANS OF ITERATIVE AUTOCORRELATION OF LASER SPECKLE PATTERNS

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Abstract—A simple and inexpensive method for the qualitative characterization of wood surfaces is presented. It is based on the iterative autocorrelation of laser speckle patterns produced by diffuse laser illumination of the wood surfaces. The method exploits the high spatial frequency content of speckle images. A similar approach with raw conventional photographs taken with ordinary light would be very difficult. A few iterations of the algorithm are necessary, typically three or four, in order to visualize the most important periodic features of the surface. The processed patterns help in the study of surface parameters, to design new scattering models and to classify the wood species.

1. INTRODUCTION

The use of speckle patterns to study important properties of surfaces is well known. Typically, interferometric techniques like ESPI (Electronic Speckle Pattern Interferometry) are used. The literature about ESPI and related techniques is abundant [1, 10]. It is not our aim to review recent progress in ESPI, but to develop an alternative, even more cost effective technique, for certain problems related with the classification of biological tissues, wood surfaces in the present case. ESPI is mainly used in mechanical engineering for detecting defects in surfaces under diverse types of stresses.

Much less effort has devoted to the use of speckle patterns for classifying biological tissues. In biomedical imaging, speckle is considered noise and several techniques has been developed to reduce it. However, speckle can be used to extract interesting periodicity patterns from biological surfaces. In many cases, these periodicities are exclusive of the surface under study, so that they can be used as classification patterns.

Wood is an ideal tissue to test classification techniques based on speckle patterns. Wood surfaces can be very complex and their roughness depends on many natural and artificial factors. However, the underlying anatomical features are relatively simple. Generally, the microscopic properties of wood samples are simpler than the properties exhibited by human tissues, for example.

In order to extract the periodicity patterns hidden in speckle images we have developed a very simple mathematical technique derived from iterative autocorrelations of laser illuminated wood images. In each successive iteration, the less prominent periodic features are automatically filtered. Typically, only three or four iterations are enough to reconstruct a very clear pattern of the surface.

This iterative procedure serves as an information extracting filter. Only the most salient features of the surface are preserved. This is a necessary step in order to classify the wood by their species. Determining the species of different wood samples is a very time consuming task which demands costly equipment, usually optical and scanning electronic microscopes, and very skilled wood anatomists. Even in such case, many wood species cannot be determined by visual or microscopic inspection and only expensive DNA analyses can resolve the situation.

A serious problem in biological tissue classification, specially in the wood case, is the greater variability among individuals of the same species, even among samples from the same individual, than among samples from different species. This phenomenon is clearly studied in this work comparing the results of our imaging technique. Finally some solutions to this variability problem are suggested.

2. EXPERIMENTAL SETUP

The experimental setup was extremely simple. A set of standardized wood samples was used. Every sample was dried, cut and sanded with the same machines. The wood was in raw form, without any added chemicals. More than forty different wood species were analyzed.

A defocussed, low cost, commercial red diode laser was used as coherent light source. No lenses were placed after the emitting diode in order to minimize any optical aberration outside the photographic camera. The laser was carefully controlled by a stabilized current source, previously calibrated. The voltage and current was continuously monitored by digital multimeters. Very good laser output stability was recorded.

The wood sample was placed vertically in front of the laser. The angle between the wood surface and the laser beam, 30 degrees, was kept constant by means of a protractor placed on a dedicated table. A pair of rules with millimeter accuracy were fixed for both the laser source and the photographic camera in order to assure the same light intensity and focusing for every sample.

A simple black opaque box was used to eliminate any external light contribution. Besides this box, the laboratory was kept in dark during the photographic session.

The speckle images were taken with a commercial digital camera able to store the photographs in an uncompressed TIFF format. All the image processing was performed with the excellent free and open source ImageJ software [11].

3. THEORETICAL BACKGROUND

Our technique is inspired by stellar speckle interferometry, but in a much more qualitative fashion. Several rigorous and complete descriptions of stellar speckle interferometry can be found in the literature. A classic one is in the Goodman's textbook [12].

Analyzing the tissue classification problem, we are interested only in the most salient pattern features of the image. A clear measure of the underlying periodic structure of wood surfaces can be described by the bidimensional autocorrelation function of the image. Iterating this function, we construct a convenient filter which reinforces the most contributing frequencies of the structure under study.

Autocorrelation is related with the power spectral density via the Fourier transform. It is generally used to detect periodic information under high noise. In our case the presence of speckle noise is a highly desirable property of the wood images because it allows the convergence of the iterative autocorrelation sequences. This is due to the high frequency content of the speckle images.

If a similar procedure were tried for photographs of wood illuminated with conventional light, the result after one iteration would be a high centered peak of autocorrelation intensity over an almost completely blurred background. The presence of speckle patterns changes this situation completely, allowing so the detection of periodic features which would be very difficult to observe and filter with conventional images.

The advantages of this simple image processing approach are manifold. Autocorrelation can be calculated with ease and highly optimized libraries based on FFT are available. Besides, the autocorrelation patterns converge very quickly and a multiscale analysis of different surface features can be performed.

We could develop an approximate scattering theory for the wood surface considering it a rough surface [13–19]. However, these periodic patterns are a better starting point to model the scattering of coherent light by biological tissues, because the iterated images prove that they are not entirely random. Detailed simulations performed with the information provided by iterated speckle patterns will be performed in future works. With such simulations, more powerful approaches to electromagnetic inverse problems will be possible. As a direct application, the development of these techniques in human tissues can be very useful as a medical tool to improve the early detection of pathologies.

4. EXPERIMENTAL RESULTS

More than forty wood species were imaged and analyzed. A few examples will be presented here in order to illustrate our technique. More detailed statistical studies will be reported in future works.

The images were stored in uncompressed TIFF format in order to preserve all the speckle information. The images were of high quality and resolution. The complete photographs were 3072 × 2304 pixels large. The images were processed in 128 × 128 sections, resampled to 512 × 512, in order to compare several patterns from the same sample in different localizations.

Raw images show the typical elliptical pattern produced by the scattering of coherent light by an almost perfect Lambertian diffuser. Ellipsometric studies and estimates of mean values of the refractive index will be the subject of future works.

A first study shows that iterated autocorrelation speckle patterns can notably differ even in several sections of the same sample. This variability was confirmed by previous studies of other physical properties of wood like density, electrical conductivity and capacitance. On the positive side, such variability proves the very high sensibility and accuracy of this technique.

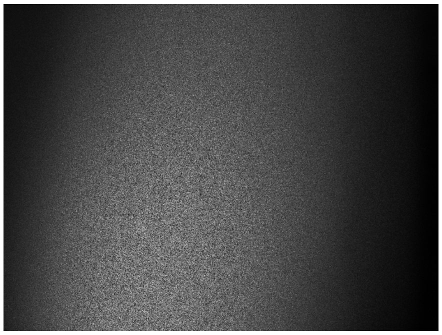

Figure 1. Raw image of the speckle image produced by a wood surface illuminated with an unfocused laser beam. The original size has been reduced to keep a reasonable image size.

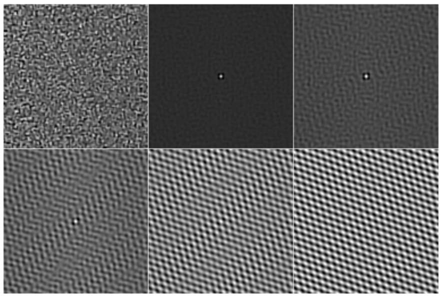

Figure 2. Sequence of the first six iterations of the autocorrelation of the speckle image of a wood surface. It is clearly observed how the noise frequencies are quickly filtered. Only the most regular patterns are preserved.

Figure 2 represents a very clear illustration of the iterative process. In the first subimage only apparent random speckle noise is observed. The first and second iterations of the autocorrelation exhibit a high intensity central peak, typical result of the autocorrelation operation. In fact, if the image were perfect white noise, the autocorrelation would reduce to a Dirac delta distribution. The fourth subimage presents an interesting regular pattern with a fairly uniform intensity, although the main peak is still clearly visible. The last iterations are much more regular, but they reduce considerably the information about possible subpatterns. Optimal compromise is achieved with the fourth or fifth iteration in most cases.

As a curious note, it should be commented that many of the wood samples produced considerably pretty patterns, specially if a pseudocolor intensity mapping was used. In fact, several people, who did not know the origin of the iterative patterns, showed interest of using such images as design patterns for clothes, curtains or fabric, for example.

Figures 3 and 4 show the result of the fourth iteration of two different wood samples. The original speckle image is presented before as comparison. It is easily observed that the original speckle images are hardly useful to analyze the underlying periodic properties of the wood surfaces. In particular, direct comparison of the speckle images does not add any information about possible different species.

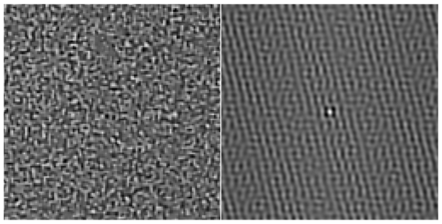

Figure 3. Original and fourth iteration of the autocorrelated image of one wood sample. Regular features of the surface are clearly observed.

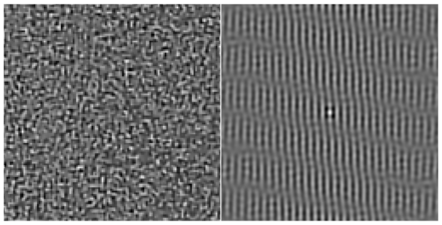

Figure 4. Original and fourth iteration of another wood sample from a different species. The iterated pattern is clearly distinct from Figure 3.

In sharp contrast with the previous observation, the fourth iteration of the autocorrelation shows rich and very detailed regular patterns in every case. Both wood samples are clearly distinguished by a simple visual inspection. In Figure 3, a predominantly linear structure with superimposed curled vortex-like substructures is produced. The iteration pattern of Figure 4 is very different. It is formed by at least two clear almost orthogonal periodic structures.

In Figure 5 two different patterns from the same sample are compared. As in the previous case, the original speckle images are

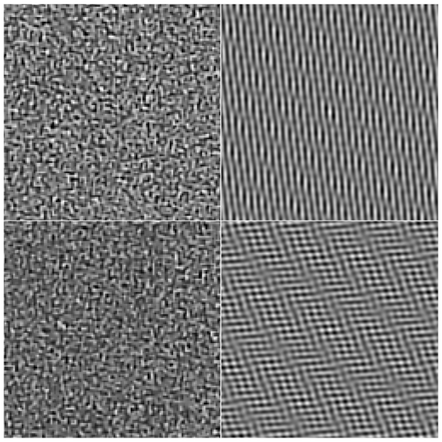

Figure 5. Tracing of different fiber orientation in two locations of the same sample. Both the raw speckle image and the iterated autocorrelation pattern are shown for comparison purposes.

almost indistinguishable. The iterated autocorrelation patterns, on the contrary, show plenty of details. Several periodic structures can be observed with different space scales. The main periods in both figures are similar, as they correspond to samples of the same species. However, the direction of the principal lines is different and indicates a change in the orientation and angle of the wood fibers. In fact, this is the case, because both images were taken from different areas of the same sample with a clear twist in fiber orientation.

These results suggest the use of autocorrelated speckle patterns for tracing and verifying fiber properties of wood, like their direction. Macroscopic fiber direction, at present, can only reliably measured by stylus based devices. It can be observed that the autocorrelated patterns contains a much richer bidimensional information.

5. ANALYSIS OF THE EXPERIMENTAL RESULTS

Autocorrelated images clearly show that useful structural information can be extracted from simple speckle images of biological tissues. The high frequency content, in the sense of spatial frequencies, of the images of scattered laser light allows autocorrelation patterns to converge to filtered images with a increasing regular structure. These regular structures are related with the underlying periodic nature of the constituents of the tissues under study.

An evident limitation of this simple technique is the impossibility of spatial location of the periodic elements of the structure. This is due to the mathematical fact that there is no exact mapping between the autocorrelation images and the original one in the spatial domain.

A striking feature of the autocorrelation patterns was the great variability of the periodic structures among the same sample of wood. This is a desirable result from the point of view of fiber tracing applications, but it turns the species classification problem into a very complex one.

Further research must be done in order to discover convenient image processing algorithms to aid in the classification process. Traditional methods like principal value decomposition, clustering and pattern matching techniques have proven very limited success in this case. This is due to the high dynamical nature of the tissue formation processes. The problem is very difficult from a complete geometric point of view and surely topological multiscale analyses will be necessary to extract significant classifying mathematical parameters.

As an example, a principal component analysis of six images of different locations of the same wood sample is shown in Figures 6, 7 and 8. The first principal component accounts for an approximately 80% of the total variance as Figure 8 reveals. This seems a very good point to try a classification algorithm. However, the comparison between the images in Figure 6 and the principal components is not clear. Due to the high variation of the iterated patterns with position, the best approach would be a large principal component analysis of selected areas of the sample. The selecting criterion should be based in the uniformity of the surface at the sampling points.

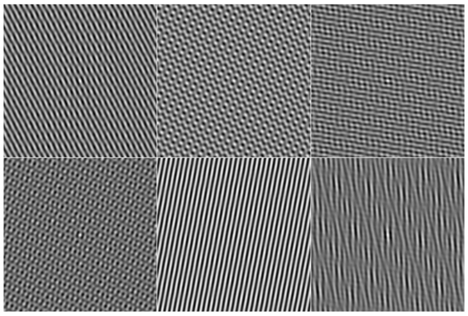

Figure 6. Iterated autocorrelation patterns of six different locations of the same wood sample.

A great step in the understanding of the relationship between autocorrelated speckle patterns and a possible wood species classification would be the study of an accurate model of laser scattering by the

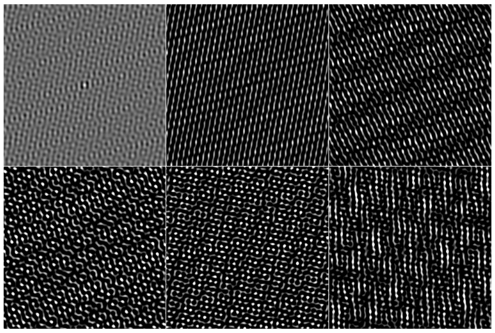

Figure 7. Principal component analysis of the images in Figure 6.

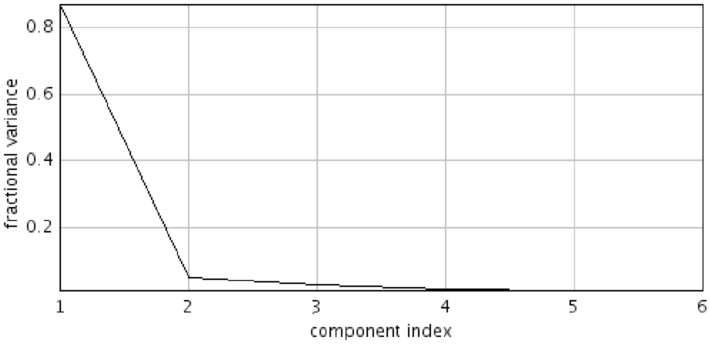

Figure 8. Relative contribution of each component in Figure 7.

wood surface.

Natural wood surfaces can be statistically approached as random or quasirandom surfaces in electromagnetic scattering theory. However, the existence of highly regular structures in the autocorrelated speckle images suggest the modeling of laser scattering as a kind of dielectric bidimensional diffraction gratings with several levels of added noise.

Simulations based on these patterns could provide more accurate results in modeling electromagnetic inverse problems. The existence of these regular patterns can also provide a firm empirical justification of some concrete analytical models used in the study of electromagnetic wave propagation in biological tissues. Analytical and reliable numerical models of electromagnetic wave propagation in biological samples are of uttermost importance in medical imaging and many other noninvasive testing procedures [20–28].

6. CONCLUSIONS

Regular properties of the structure of wood surfaces are obtained by means of a simple iterating procedure over the autocorrelation of laser speckle images. The images were taken with commercial photographic cameras from standardized wood samples illuminated with diffuse laser light. Cheap red diode lasers showed enough power and stability as light sources for the experiments. This technique is completely noninvasive. Damages of the biological tissue are negligible due to the low power and defocussing of the laser source.

The image processing algorithm is very simple. It is implemented in most image analysis software. The performance of this analysis is very good because only four iterations of the autocorrelation of the images are typically necessary. Autocorrelation is implemented efficiently via the FFT and is extremely fast for most application purposes.

First steps towards a species classification procedure are suggested. Future research will involve large statistical sampling of iterated patterns, topological approaches, direct and inverse modeling, polychromatic imaging and ellipsometry of biological samples.

The future applications of this method are manifold and important, such as a possible tissue classification scheme. An specially important use is to serve as a complementary, noninvasive and inexpensive medical imaging procedure. A promising application would be the study of possible skin lesions or melanomas. This is one of main objectives of this research. Wood tissues has been chosen as a first, less complex, testing of the experimental procedure with good results.

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