Illumination Level Independence in the Dynamic Laser Speckle Analysis

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Abstract

In this article we show an analysis of how the frequency band, of the speckle signal, influence in the light independence of the speckle index value in a dynamic laser speckle analysis. Specifically, will be studied as It is influenced the temporal speckle deviation index by the use of 3 different frequency bands of the speckle signal. Finally, It is shown as signals with high frequency values return values with more illumination level independence.

Keywords: Biospeckle laser, Biospeckle index, Biospeckle signal, Biological activity, Dynamic speckle, Backscattering.

1. Introduction

In the literature we can found a work [1] that show as some speckle indexes have a frequency filter behavior; by example, we have the AVD [2] and IM [3] index, that they filter the information like a first order high pass filter with cut-off in the middle of normalized frequency band. For this reason, It is important analyze how, the chosen frequency band, alter the result of selected index. By other side others works [cita] (acho tinha um artigo de kefir que tinha problemas de iluminacao) show the problem of made a speckle analysis with the presence of variation of illumination, because the most of biospeckle indexes in the literature are influenced in your values by the use of a determinate illumination level. Thus, the present work searches establish a relation between the frequency band used and the speckle index; specifically here will be studied the dependence of the temporal speckle deviation matrix [4] with the illumination level.

2. System description

2.1. Obtaining data packages in the test over an ink sample

The Fig. 1 shows the system diagram of the ink sample test; in It, we can see as a red laser was pointed to an ink sample, the drying process is monitored by a digital camera; the images are collected receiving two different illumination levels, because these are obtained using a neutral density lens between the ink sample and the laser, covering partially the view angle of the laser. The images in each data package are sampled with a frequency of $F_s =$[[[12.5]]] hertz, being collected $N = 400$ images by package. In total were collected 11 packages (with two different illumination levels each one) at the minutes 0, 10, 20, 30, 40, 50, 60, 75,105,120 and 150 of drying process. In each one of the 11 packages were

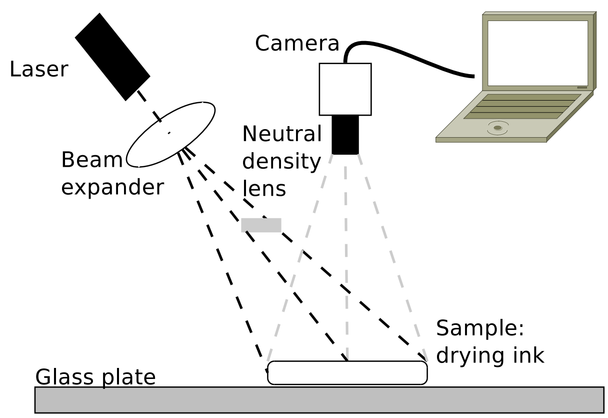


Figure 1: System description.

selected two regions, of 250×200 pixels, corresponding to the regions with two different illumination levels, as shown with black lines in the Fig. 2. In the right side of the figure we have the portion of image that was altered by the neutral density lens. The figure represents with a color bar the result of calculus the temporal speckle mean matrix (μ) according the Eq. (2) showed in the Sec. 3.2. Being this value associated in the literature with the illumination quantity in the surface of sample [4]; corresponding thus high values of μ to places with more illumination.

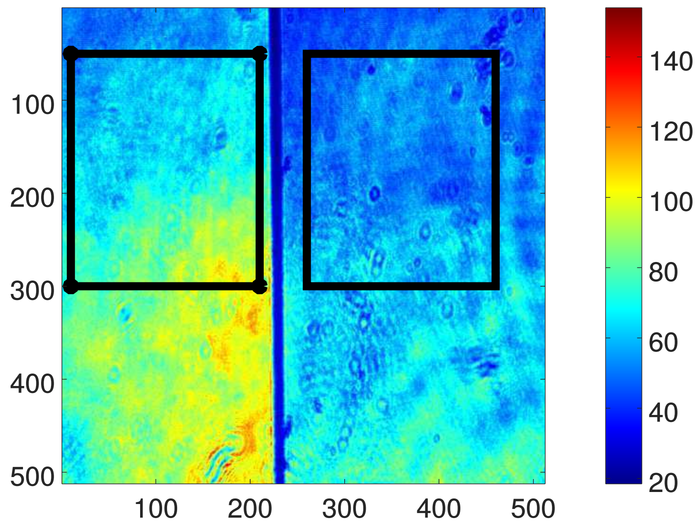


Figure 2: Selected regions and light intensity distribution in the ink drying test.

2.2. Obtaining data packages in the test over a paper piece

The test over a paper piece has a similar configuration that seen in the Fig. 1 with the difference that in the paper piece test is not used the neutral density lens; thus It is collected one data package sampled with a frequency of $F_s =$[[[12.5]]] hertz, being collected in total $N = 129$ images of $640{\times}480$ pixels. The Fig. 3 represents with a color bar the result of calculus the temporal speckle mean matrix (μ) according the Eq. (2) showed in the Sec. 3.2; thus, it is easy to see how the illumination level of laser over the paper has a elliptical form being it higher in the centroid close to the image top.

3. Numerical analysis

3.1. Data package filtering in three frequency band

Each data package or sub package (P_T) goes through of a filter bank with 4 outputs having each one a different type of processing, the first output is trivial because it leave pass the information freely, this package is called of P_T,

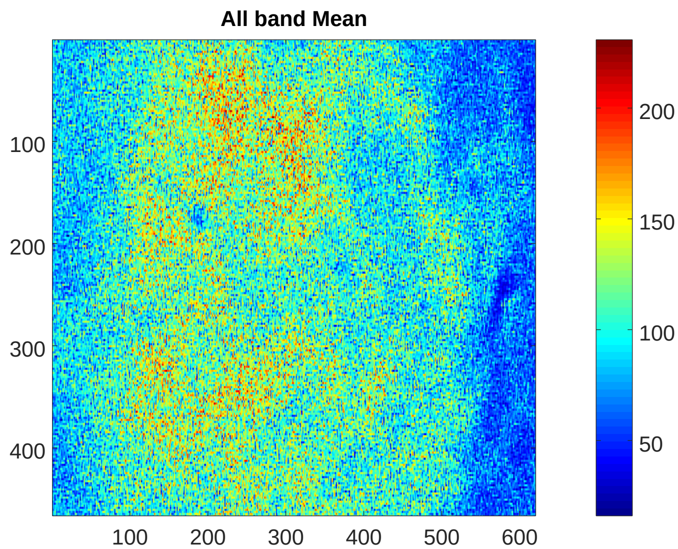


Figure 3: Light intensity distribution in the paper piece test.

the others 3 processing types return signals, filter by frequency band; thus, we have the band between $[0, \frac{1}{3}]\frac{F_s}{2}$ (low frequencies), the band between $[\frac{1}{3}, \frac{2}{3}]\frac{F_s}{2}$ (intermediate frequencies) and the band between $[\frac{2}{3}, 1]\frac{F_s}{2}$ (high frequencies); obtaining at end, the packages P_X, P_Y and P_Z, respectively; as can be seen in the Fig. 4. Internally the obtaining of the filtered packages are realized using in cascade two low pass Finite Impulse Response (FIR) filters of order 32, so that the sum of signals $P_X + P_Y + P_Z = P_T$.

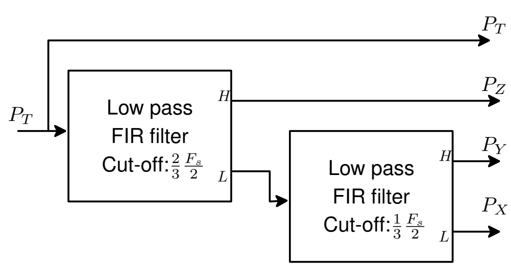


Figure 4: Filtering of data packages.

3.2. Temporal speckle deviation matrix

The calculus of the temporal speckle deviation matrix (σ) [4] uses as input, the N images of a data package. We designate to each image, in the package P, as $\mathbf{I}_k$, $1 \leq k \leq N$, being k an integer; thus, to get the value σ, it is necessary to get the matrix σ as seen in the Equation 1,

$$\sigma = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(\mathbf{I}_k - \mu)^2}, \tag{1}$$

being that, the value μ can be calculated as,

$$\mu = \frac{1}{N}\sum_{k=1}^{N}\mathbf{I}_k, \tag{2}$$

Additionally, can be defined the temporal speckle deviation index, $\bar{\sigma} =< \sigma >$, as the mean value of all elements in σ, being $< . >$ the mean spatial operator.

3.3. Datapack processing in the ink drying test

As explicated in the Sec. 2.1 we have in the ink drying test, analysis regions with two levels of illumination in each data packages; thus, we separate each package in two sub package (left and right), representing each one the regions shown in the Fig. 2. These sub packages are filtered following the process explicated in the Sec. 3.1, obtaining the packages P_T, P_X, P_Y and P_Z. Immediately

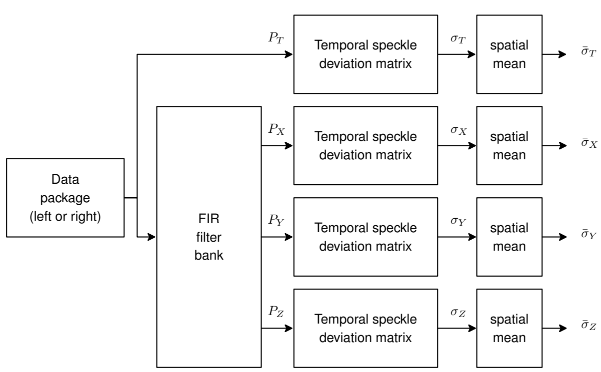


Figure 5: Filtering of data packages.

later of obtained these filtered packages, over each one of these is calculated the temporal speckle deviation matrix and in base of this result are obtained the temporal speckle deviation indexes $\bar{\sigma}_T$, $\bar{\sigma}_X$, $\bar{\sigma}_Y$ and $\bar{\sigma}_Z$. The procedure to obtain these values is explicated in the Sec. 3.2.

3.4. Statistical analysis of relation between the matrices σ and μ

We define σ_i and μ_i as the values in the $i-th$ position in the σ and μ matrices, respectively; also define μ_p as any element value in μ. And finally we define the set $S_{\mu_p} = \{\sigma_i : \mu_i \equiv \mu_p; \forall i\}$ as the set of all σ_i values given that $\mu_i \equiv \mu_p$. With all these in mint we calculate the vectors L_p, σ_p and e_p using all the μ_p values, according the next description.

- $L_p(\mu_p) = card\left(S_{\mu_p}\right)$, being $L_p(\mu_p)$ the number of elements in the set S_{μ_p} and $card(.)$ the cardinality function operator.
- $\sigma_p(\mu_p) = mean\left(S_{\mu_p}\right)$, being $\sigma_p(\mu_p)$ the mean value of elements in the set S_{μ_p} and $mean(.)$ represents the mean value function operator.
- $e_p(\mu_p) = std\left(S_{\mu_p}\right)$, being $_p(\mu_p)$ the standard deviation value of elements in the set S_{μ_p} and $std(.)$ represents the standard deviation function operator.

In the practice only will be take in count in the vectors, values of μ_p with a $L_p(\mu_p) > 200$ samples, to establish a limit to consider a set of representative samples.

3.5. Datapack processing in the paper piece test

As explicated in the Sec. 2.2, in this test we have one data package; this package is filtered following the process explicated in the Sec. 3.1, obtaining the packages P_T, P_X, P_Y and P_Z, over each one of these filtered packages are calculated the temporal speckle mean matrix and the temporal speckle deviation matrix, as can be seen in the Fig. 6.

In base of these results are made statistical analysis to obtain the vectors σ_p, μ_p, e_p to each one of bands. The procedure to obtain these values is explicated in the Sec. 3.4.

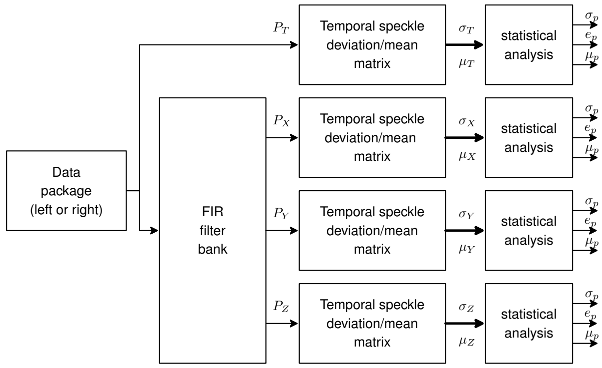
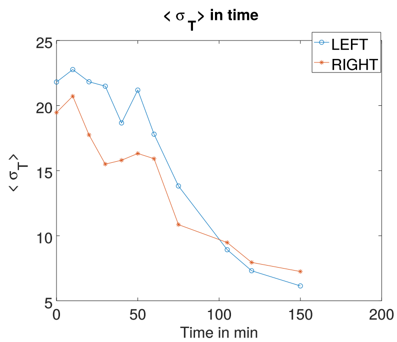


Figure 6: Filtering of data package in paper piece test.

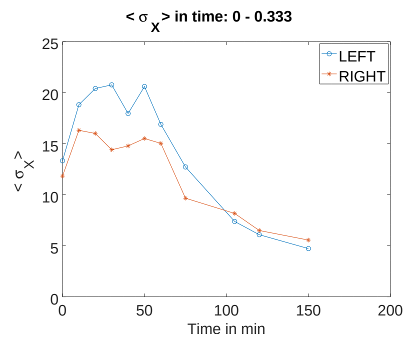
4. Numerical results

4.1. Numerical results in the ink drying test

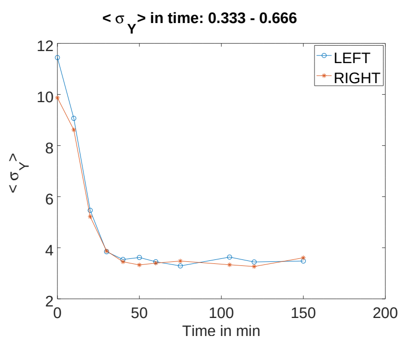
In the Fig. 7 we can see the result of data packages processing in the ink drying test. The Fig. 7a represent the $\bar{\sigma}_T$ value in two light intensity levels, It is calculates over the package P_T trough the time, and use the complete frequency band. The Fig. 7b represent the $\bar{\sigma}_X$ value in two light intensity levels, It is calculates over the package P_X trough the time, and use the frequency band between 0 and $\frac{1}{3}\frac{F_s}{2}$Hz. The Fig. 7c represent the $\bar{\sigma}_Y$ value in two light intensity levels, It is calculates over the package P_Y trough the time, and use the frequency band between $\frac{1}{3}\frac{F_s}{2}$ and $\frac{2}{3}\frac{F_s}{2}$ Hz. And the Fig. 7d represent the $\bar{\sigma}_Z$ value in two light intensity levels, It is calculates over the package P_Z trough the time, and use the frequency band between $\frac{2}{3}\frac{F_s}{2}$ and $\frac{F_s}{2}$ Hz. As can be seen, when analyze the index over the complete frequency band (Fig. 7a), we have different results to both illuminations levels, being that the index value It is major in the left side,that is the side with most illumination. This indicates a positive influence of illumination level in the index value. By other side, if we observe the figures 7b, 7c and 7d, we can perceive as the index values from different illuminations turn most similar with the grow of frequency. being greater this similarity in the frequency band between $\frac{2}{3}\frac{F_s}{2}$ and $\frac{F_s}{2}$ Hz. Thus the similarity is limit by the sampling frequency used.



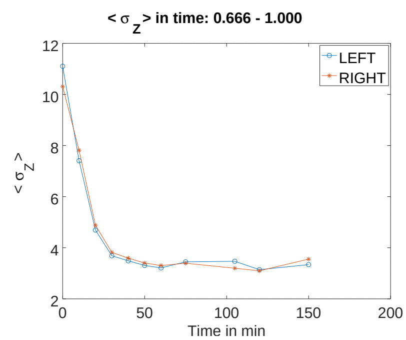
(a) $\bar{\sigma}_T$ value through the time.



(b) $\bar{\sigma}_X$ value through the time.



(c) $\bar{\sigma}_Y$ value through the time.



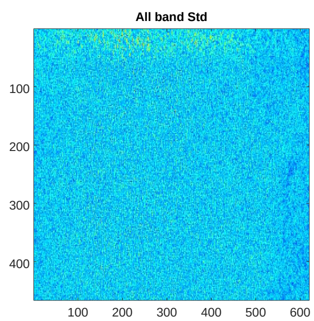
(d) $\bar{\sigma}_Z$ value through the time.

Figure 7: Numerical results in the ink drying test.

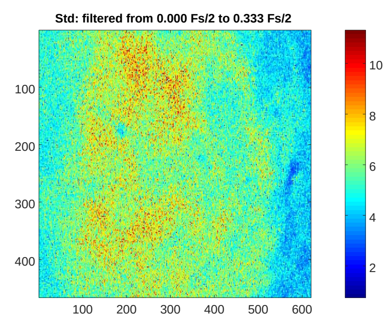
Finally It is important highlight that in an ink drying test, like the used here, It is characterized by speckle signals with high frequencies in the begin time of drying and speckle signals with low frequencies at end, being gradual this frequency transition until reach the limit of signal and to have only the noise of test. So that, when in the figures It is observe a horizontal line in the index, these data should not be use in the comparisons, even if they are similar, given that these only are show the noise of test. By example, in the Fig. 7d we filter so that only have high frequency signals; later, we know that these only happen in the begin of drying process, and in the figure this happen from 0 until the 50 minutes and later only have a similar horizontal line in both illuminations. This indicates that the comparisons of index illumination independence only should be made between these minutes because out this range we will be using the noise of test in the comparisons.

4.2. Numerical results in the paper piece test

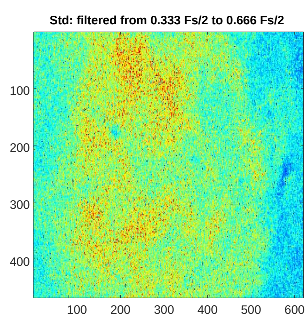
In the Fig. 8 we can see the result of the processing the data packages in the paper piece test. The Fig. 8a represent the σ_T matrix that use the complete frequency band. The Fig. 8b represent the σ_X matrix that use the frequency band between 0 and $\frac{1}{3}\frac{F_s}{2}$Hz. The Fig. 8c represent the σ_Y matrix that use the frequency band between $\frac{1}{3}\frac{F_s}{2}$ and $\frac{2}{3}\frac{F_s}{2}$ Hz. And the Fig. 8d represent the σ_Z matrix that use the frequency band between $\frac{2}{3}\frac{F_s}{2}$ and $\frac{F_s}{2}$ Hz.



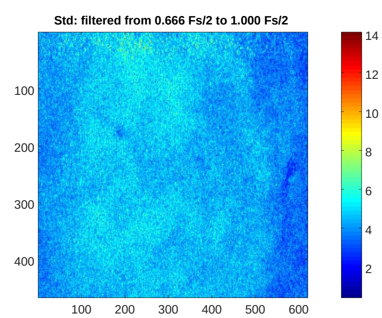
(a) σ_T matrix over the complete frequency band.



(b) σ_X matrix over the inferior third of the frequency band.



(c) σ_Y matrix over the middle third of the frequency band.



(d) σ_Z matrix over the superior third of the frequency band.

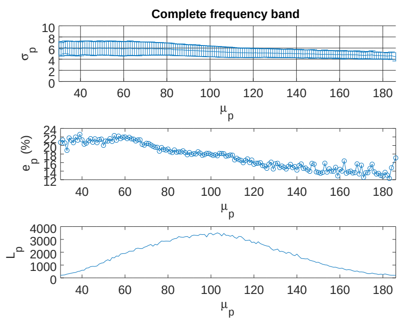
Figure 8: Temporal speckle deviation matrix of paper piece.

In the next group of graphics we analysis the relation between a value σ_p, in the σ matrix, with a value μ_p, in the μ matrix, to all frequency bands. These analysis have importance because the value μ_p is related with the illumination level in the surface of sample [4] and the color or material of sample. Thus, when we choose μ_p as reference variable in a homogeneous sample, in true we choose indirectly the illumination level in the surface. In these sense, the Figs. 9, 9b, 9c and 9d show the variables σ_p, e_p and L_p in function of μ_p, to the case of the complete frequency band, the inferior third of the frequency band, the middle third of the frequency band and the superior third of the frequency band, respectively in each sub figure. It is import to note that e_p ever is graph as percentage in the relation to the value σ_p, this means $100\frac{e_p}{\sigma_p}\%$.

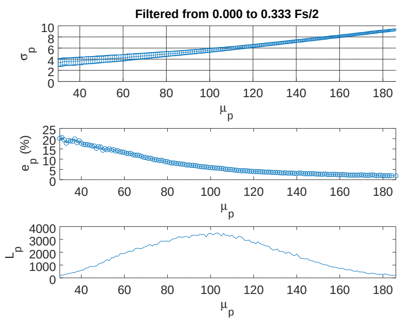
In all these results we hope see a homogeneous tend in the index values, in all spatial positions, because has been analyzed an homogeneous paper piece. Keeping this in mind, in the Fig. 8a we observe a slightly homogeneity in the values because exist a variability in the result in some regions, this is most evident if we analyze the Fig. 9a where observe as change the value σ_p in relation to the value μ_p, so that σ_p is around of 5.5 with changes that depended of illumination level μ_p, but even to a specific value μ_p exist much variability in the expected value of σ_p, having a e_p around of 12% in the best case. In other cases in the Figs. 9b, 9c and 9d. We observe a linear ascendant relation between σ_p and μ_p, being that the slope decreases with the increase of the frequency band. As can be seen in the Fig. 9d where the variations in μ_p only slightly influence to σ_p and the error e_p can be of 5% when the illumination is maximum.

5. Conclusion

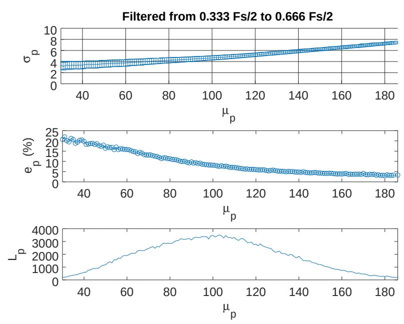
In this work were presented comparisons between the values of the temporal speckle deviation index to 3 different frequency bands of the speckle signal and different illuminations levels, in a dynamic laser speckle analysis, the results shown as the influence of illumination level over the index decreases with the use of signals with high frequency bands.



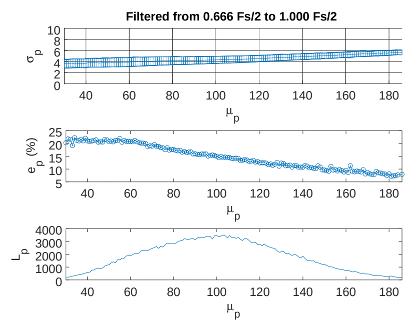
(a) Analysis in the complete frequency band.



(b) Analysis in the inferior third of the frequency band.



(c) Analysis in the middle third of the frequency band.



(d) Analysis in the superior third of the frequency band.

Figure 9: Relation between the standard deviation value and the illumination level in a paper piece.

6. Acknowledgment

We wish to acknowledge the partial financial support for this study provided by the *CAPES* scholarship *PNPD* Program, *FAPEMIG* and *CNPQ*.

7. Bibliography

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