Importance of Sampling Frequency in the Dynamic Speckle Analysis

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Abstract

In this article, we show as the variation of sampling frequency, in a dynamic speckle analysis, affect the value of some dynamic speckle index, in this case: the absolute value of the differences index, the temporal speckle standard deviation index and the temporal speckle mean index. we show that the dynamic speckle index value decrease your maximum excursion with the grow of sampling frequency because this affect directly the time integration (exposition time) of camera.

Keywords: Frequency sampling, Dynamic speckle index, Dynamic speckle index, Dynamic speckle analysis

1. Introduction

The dynamic laser speckle analysis has become in the last years an important study topic[1, 2, 3, 4, 5] to determine the activity level of biological materials. The importance of technical aspects of dynamic laser speckle analysis, as the stability of laser illumination level has been analyzed [3]; and also It was studed as indexes, as absolute values of the differences [6, 7] are affected in your values by the variation of illumination level. Thus, It is necessary analyze the effect of technical parameters that affect the perceived illumination level; In these sense we analyze the effect of sampling frequency in a dynamic laser speckle analysis.

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2. System description

2.1. Exposure time of the camera

The acquisition time, frame per seconds (fps) or sampling frequency (F_s), in the camera Marlin F-033 will be calculated in the Table 1, where we can see, the shutter register value ($Shutter$), time base register value ($Base$), exposure time ($Exposure$), exposure time offset ($Offset$) and effective exposure time (E); so that

$$Exposure = Shutter \times Base, \tag{1}$$

$$\frac{1}{F_s} = E = Exposure + Offset. \tag{2}$$

Where, F_s is calculated in relation to the E; being that, the $Exposure$ represent the photography integration time and E the effective time between photographs; the difference between these two exposures arise from $Offset$ time, that is the time between end and start of a photography.

$Shutter$	$Base$ [μs]	$Offset$ [μs]	E [ms]	F_s [fps]
3332	20	12	66.652	15.003
1665	20	12	33.312	30.019
1110	20	12	22.212	45.021
832	20	12	16.652	60.053

Table 1: Exposition time and sampling frequency

2.2. Data packages in the ink drying process

This data package analyze a drying ink process, where images data packages are taken at the times {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10} min. In each time, the package has 512 images of 147 pixels of height and 166 pixels of width. They were use 4 different sampling frequencies to the images in each package, being these frequencies 15, 30, 45 and 60 hz.

2.3. Data package of the activity analysis in corn seed

This data package analyze the activity of a corn seed with 3 days of germination. In this point, They are taken 4 image data packages with different sampling frequencies to each package, being these frequencies 15, 30, 45 and 60 hz. Each package has 512 images of 15 pixels of height and 15 pixels of width.

2.4. Test 1: ink drying process

The Fig. 1 represents the data analysis method, acquired at a sampling frequency of F_s, with the characteristic seen in the Section 2.2, where, $P(t)$ is

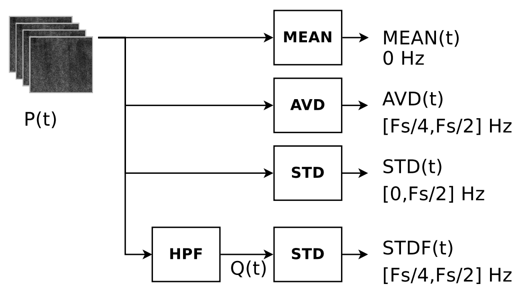


Figure 1: Data analysis of the ink drying process test.

an image data package at the time t minutes, being that this package has N images and M pixels, where $P_{n,m}(t)$ define the n-th image and m-th pixel, for all $1 \leq n \leq N$, $1 \leq m \leq M$. The $MEAN$ block represents the calculus of a temporal speckle mean index from the package $P(t)$, returning the value $MEAN(t)$, as exposed in the Section 3.1. The AVD block represents the calculus of an absolute values of the differences index from the package $P(t)$, returning the value $AVD(t)$, as exposed in the Section 3.2. The STD block represents the calculus of a temporal speckle standard deviation index from the package $P(t)$, returning the value $STD(t)$, as exposed in the Section 3.3. And finally, the block HPF represents a digital finite impulse response "high-pass filter" with order 40 and cut-off at $0.25F_s$ and this block filter the $P(t)$ package and return $Q(t)$, that causes to have at end of path the $STDF(t)$ index value. According the information of the data packages, we will have speckle indexes values, for each minute during 10 minutes.

2.5. Test 2: Activity analysis in corn seed

The activity analysis of a corn seed, uses the information of data package seen in the Section 2.3. We analyze this information of similar way to the seen in the Section 2.4, with the difference that is taken an data package at the time t (3 days of germination) and a sampling frequency F_s.

2.6. Test 3: Frequency band activity analysis

The Fig. 2 represents the frequency band analysis method of data package P, acquired with a sampling frequency of F_s. This package pass through the BPF block described in the Sec 3.5, with a frequency band pass between $f_1(l)$ and $f_2(l)$, according the Eq. 10, where l represent the band so that $1 \leq l \leq L$, being L the quantity of analysis frequency bands; thus, we obtaining the R package (a filtered version of P). Later, It is processed a σ block, where It is calculate the σ_m value to each pixel in the package R, as described in the Sec 3.3. Finally, an image is obtained and It is designed with the variable $STDB$.

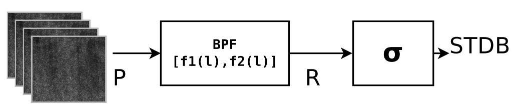


Figure 2: Frequency band analysis of a data package.

3. Theoretical definitions

In the next subsections we use the variable P to define $P(t)$ in any time t.

3.1. MEAN index

The temporal speckle mean index (μ_m) [8] calculates the mean value of the illumination level to the m-th pixel in the package P, It is implemented with the Eq. 3,

$$\mu_m = \sum_{n=1}^{N} \frac{P_{n,m}}{N}. \tag{3}$$

Finally, the $MEAN$ index is the mean value of all μ_m results, as can be viewed in the Eq. 4,

$$MEAN = \sum_{m=1}^{M} \frac{\mu_m}{M}. \tag{4}$$

3.2. AVD index

The Absolute Values of the Differences (AVD_m) [6, 7] calculates the mean value of the absolute differences in the illumination level of the m-th pixel in the package P, It is implemented with the Eq. 5,

$$AVD_m = \sum_{n=2}^{N} \frac{|P_{n,m} - P_{n-1,m}|}{N}. \tag{5}$$

Finally, the AVD index is the mean value of all AVD_m results, as can be viewed in the Eq. 6,

$$AVD = \sum_{m=1}^{M} \frac{AVD_m}{M} \tag{6}$$

3.3. STD index

The temporal speckle standard deviation index (σ_m) [8] calculates the standard deviation value of the illumination level to the m-th pixel in the package P, It is implemented with the Eq. 7,

$$\sigma_m^2 = \sum_{n=1}^{N} \frac{(P_{n,m} - \mu_m)^2}{N}. \tag{7}$$

Finally, the STD index is the mean value of all σ_m results, as can be viewed in the Eq. 8,

$$STD = \sum_{m=1}^{M} \frac{\sigma_m}{M} \tag{8}$$

3.4. HPF block

The high-pass filter (HPF) block It is implemented with a finite impulse response (FIR)[9] filter of order 40 and cut-off at $0.25F_s$. The 41 values in the filter are represented with $h(i)$, for all $0 \leq i \leq 40$ and zero in others cases, so that if we send a data package P through the HPF block we obtain a data package Q, as can be seen in the Eq. 9,

$$Q_{n,m} = \sum_{k=1}^{N} P_{k,m} h(n-k+20). \tag{9}$$

3.5. BPF block

The band-pass filter (BPF) block, It is implemented similarly as the see in Sec. 3.4, with a FIR filter of order 40 but with a cut-off in $f_1(l)$ and $f_2(l)$,

$$[f_1(l),\ f_2(l)] = \left[\frac{(l-1)}{L},\ \frac{l}{L}\right]\frac{F_s}{2}, \tag{10}$$

representing l, for all $1 \leq l \leq L$, the l-th band of L parts; so that each band has $\frac{F_s}{2L}$ Hz. The filter is represented with $g(i)$, for all $0 \leq i \leq 40$ and zero in others cases, so that if we send a data package P through the BPF block we obtain a data package R, as can be seen in the Eq. 11,

$$R_{n,m} = \sum_{k=1}^{N} P_{k,m}\ g(n-k+20). \tag{11}$$

4. Numerical results

4.1. Result of test 1

This test shows the analyze result of an ink drying process, across 10 minutes, with the sampling frequency: 15, 30, 45 and 60Hz.

The Figure 3 analyze the $MEAN(t)$ index, in the test showed in the Section 2.4, to each time t for 4 sampling frequencies. It easy to see as the value of index has a monotonous behavior over time. By other side the values in the curves decreases in proportion with the grow of sampling frequency.

The Figure 4 shows the result of analysis explained in the Section 2.4 about the $AVD(t)$ index. The Figure 4a shows the $AVD(t)$ index, in each time t, to 4 sampling frequencies, showing a different behavior across time in each sampling frequency, so that, the value of the index in all the curve decreases in proportion with the grow of sampling frequency. By other side, the Figure 4b shows a normalized version of $AVD(t)$ index, so that the maximum value of

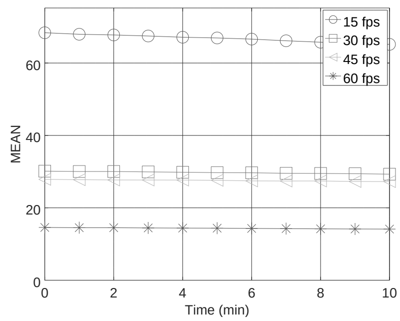


Figure 3: $MEAN$ index value.

(a) AVD index value.

(b) Normalized AVD index value.

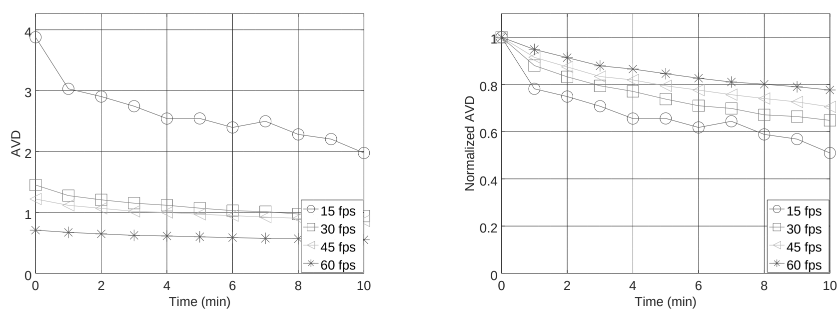


Figure 4: AVD index anaysis.

curves have an unit value; thus, It is easy to see that the maximum excursion of the curve is greater when decrease the sampling frequency. Remembering that this index use information in a frequency band between $F_s/4$ until $F_s/2$ Hz, as seen in Section 3.2.

The Figure 5 analyze the $STD(t)$ index in the test showed in the Section 2.4. The Figure 5a shows the behavior of $STD(t)$ index, in each time t, to 4 different sampling frequencies. Remembering that this index uses information in a frequency band between 0 until $F_s/2$ Hz, as seen in Section 3.3. This index shows a different behavior across time to each sampling frequency, so that, the value of the index in each time of curve decreases in proportion with the grow of

(a) STD index value. (b) Normalized STD index value.

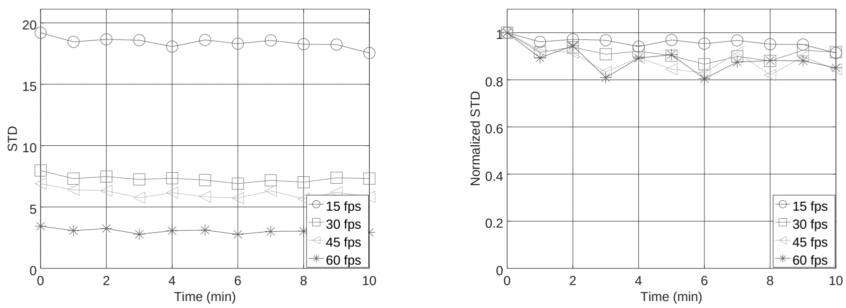


Figure 5: STD index anaysis.

sampling frequency. By other side, the Figure 5b shows a normalized version of $STD(t)$ index; being the unit, the maximum value of curves; thus, It is easy to see that exist a small difference between the maximum excursion of the curves with different sampling frequency; even so, It is possible to observe a decrease of the maximum excursion in the curve with the grow of the sampling frequency.

The Figure 6, analyze the $STDF(t)$ index, in the test showed in the Section 2.4. The Figure 6a shows the behavior $STDF(t)$ index, in each time t, to

(a) $STDF$ index value. (b) Normalized $STDF$ index value.

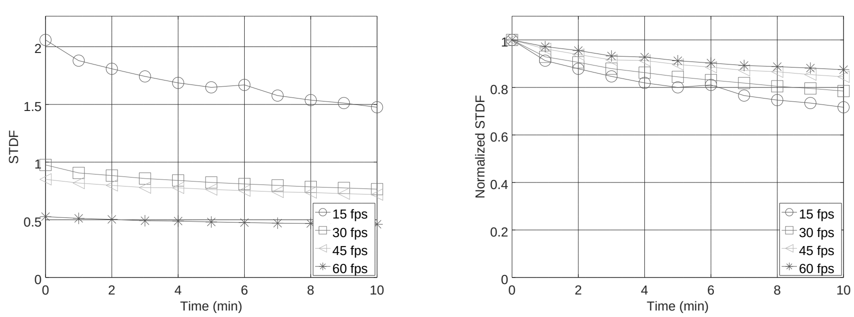


Figure 6: $STDF$ index anaysis.

4 different sampling frequencies. Remembering that this index uses filtered information of datapack, so that your frequency band is between $F_s/4$ and $F_s/2$ Hz, of similar way of $AVD(t)$ index but with different order filter, as seen in Section 3.4. This index shows monotone decreasing behavior in time, where we observe a different behavior across time to each different sampling frequency; so that, the value of the index in each time of curve decreases in proportion with the grow of sampling frequency. By other side, the Figure 6b shows a normalized version of $STDF(t)$ index; being the unit, the maximum value of curves; thus, It is easy to see that exist a considerable difference between the maximum excursion of the curves with the use of sampling frequency; so, It is possible to observe a grow of the maximum excursion with the grow of the sampling frequency.

4.2. Result of test 2

This test shows the analyze result of a corn seed with 3 days of germination, with the sampling frequencies: 15, 30, 45 and 60Hz.

The Figure 7 shows the $MEAN(t)$ index, in the test described in the Section 2.5; The figure shows as the index decrease your value, with the increment of

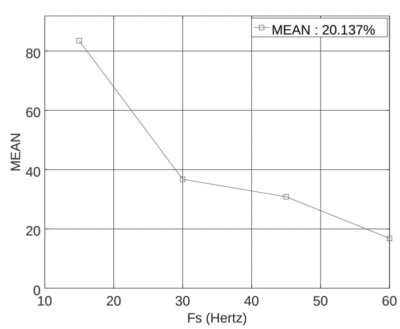


Figure 7: $MEAN$ index value in the germinated corn seed.

sampling frequency in the datapack, so that between 15 Hz until 60 Hz, the index value reaches the 20.137% of your value.

The Figure 8 shows the $AVD(t)$, $STD(t)$ and $STDF(t)$ indexes, in the test described in the Section 2.5; The similar way that in the Figure 7, the index

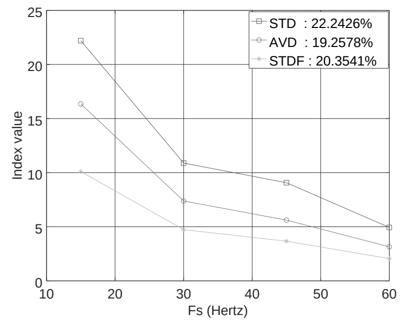


Figure 8: $AVD(t)$, $STD(t)$ and $STDF(t)$ indexes values in the germinated corn seed.

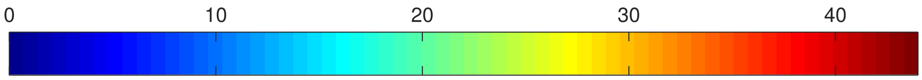
decrease your value with the grow of F_s, so that the indexes, $AVD(t)$, $STD(t)$ and $STDF(t)$, reaches the 22.2426%, 19.2578% and 20.3541% of your values, respectively.

4.3. Result of test 3

The Table 2 shows the result of calculating the $STDB$ image in different frequency bands over a package P, see Sec. 2.6, The package represents a corn seed as in the Section 2.3; where, we have packages sampled with the frequencies: 15, 30, 45 and 60 Hz, as can be seen in the first column of table.

In the other columns we can see the results of until 8 frequency bands of package P, these bands are represented in the first line of table, were l indicates the position of frequency band in crescent order relative to the frequency components. Thus, we have these frequency bands limited on: 0, 3.75, 7.5, 11.25, 15, 18.75, 22.5, 26.25 and 30Hz. So that, the package sampled in 15hz was divided in $L = 2$ frequency bands, in 30hz was divided in $L = 4$ frequency bands, in 45hz was divided in $L = 6$ frequency bands and finally in 60hz was divided in $L = 8$ frequency bands.

The matrices $STDB$ are represented using a color palette, that goes from dark blue to dark red color, representing of ascendant way the values in each pixel in all matrices. It is evident how the index values decreases with the



l	1	2	3	4	5	6	7	8
	0	3.75	7.5	11.25	15	18.75	22.5	26.25
F_S	3.75	7.5	11.25	15	18.75	22.5	26.25	30
15								
30								
45								
60								

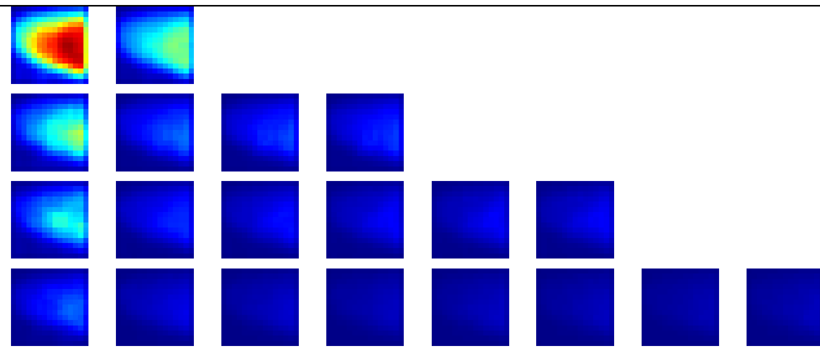


Table 2: frequency band analysis

increment of frequency sampling F_s in each one of 8 frequency bands, the index values also decrease with the increment of the position of frequency band, being the best analysis case, in the sense of differentiating better places of lower and higher index, to a frequency sampling of 15 hz and a frequency band between 0 Hz and 3.75 Hz.

5. Analysis results

In the results seen in Section 4, we can observe in the Figure 3 and 7, that the indexes show a relation between the value of curve and the sampling frequency of datapack. How is known [8], the temporal speckle mean index is related to the observed illumination level in the surface of study material and correspond to zero frequency of the signal (datapack). Thus, we can conclude that the level of illumination, perceived by the camera, decrease with the increment of sampling frequency. This is because that the exposition time is modified with the alteration of sampling frequency, see Section 2.1, so that less lighting is used to take the picture and consequently the temporal speckle mean index decrease in your value. In this sense, It is important have careful in to choose a sampling frequency that give us an index value superior to noise level of test or the quantization level of the camera.

The modification of exposition time also affect and limit other indexes, remember that we have a quantization level between 0 and 255 in the camera. We can see this interference in the Figures 4, 5, 6 and 8, where the $AVD(t)$, $STD(t)$ and $STDF(t)$ indexes decrease your values in concordance with the decrease of exposition time. Other way in that the sampling frequency affect the values of indexes, It is that, it limits the frequency band of analyzed signal; for example, a sampling frequency F_s, by the Nyquist theorem [10, 11], causes that the frequency band of analyzed signal (datapack) will be between $0Hz$ and $F_s/2\ Hz$. Thus, in this context we have an index as $STD(t)$ that uses information between $\langle 0, F_s/2]\, Hz$, and be other side we have indexes as the $AVD(t)$ and the $STDF(t)$ index, that use information of half frequency band, this is between $[F_s/4, F_s/2]\, Hz$. In the comparison between $STD(t)$ vs $\{\ STDF(t)$ and $AVD(t)\ \}$, we can see how the use of half, of entire frequency band, causes the decrease in the values of the curves, but give us considerably good values in the maximum excursion of the curve. By other side, in the case of ink drying process, the use of complete frequency band, It returns low values of maximum excursion in the curves. The importance of excursion in this test, It is due the necessity of to have significant differences en the values of two states, when the sample start or end the ink drying process.

It is necessary to highlight the importance of to choose the least value of sampling frequency F_s; so that, the frequency band of signal contain the frequency components with the information that you want to analyze; so that, the values of indexes have the greatest values and consequently a good excursion, when compared with an inert part of sample; By example, in the Table. 2 is analyzed a corn seed, we can see as the major values of indexes are obtained to a $F_s = 15$ Hz, analyzing frequency component between 0 hz and 7.5 Hz. At this point, an additionally result is evident, when we ask ourselves, What is the best frequency band? where according with the test, we see that for all frequency bands, the best frequency band, to the case of corn seed, is the one with the components with less frequency.

6. Conclusion

In this work were presented comparisons of behavior of three dynamic laser speckle indexes subject to different values of sampling frequency, thus we concluded that: It is important to know to choose an appropriate sampling frequency, being recommendable to use the minimal sampling frequency possible to get an acceptable maximum excursion, so that the phenomenon under study to be in the analyzed frequency band. Finally, we show that the digitization of speckle signal imply a restriction of frequency band of signal and consequently this affect the result of an speckle analysis.

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