New Nonlinearities Interpolation Approach Applied to Surface EMG Signal

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Abstract: One of the main problems that arise in many scientific engineering applications is the estimation of the missing data in a sequence of a series. A new technique is proposed in this work to handle such a problem. An implementation of a feedback for missing process in the surface of electromyography signal has been carried out by developing a robust forecasting formula on the basis of nonlinearities interpolation technique (NIT). Extracted electromyography signal from a Biceps Brachii muscle of one subject aged 35 years has been studied when muscle on tension under normal and fatigue conditions. A pair of gold-coated stainless steel bipolar electrodes have been used for the detection of the electromyography. The damaged signals are derived from the actual signals, with the amount of damage of about 80%. With a processing time of 50 msec, results show a conformity of the interpolated signals to those of the real electromyography signals, with a high degree of accuracy among the values of interpolated and of the real signals.

1 INTRODUCTION

With electrodes mounted on the skin surface of the muscle, an electric signal is detected when a muscle contracts, known as the surface EMG. This noise like signal is an interference pattern which is the temporal and the spatial sum of action potentials from all motor units in the region of the detecting electrodes (Harba & Ibrahim, 1986). Raw EMG can range between +/- 5000 microvolts and typically the frequency contents ranges between 6 and 500 Hz, having most frequency power between ~ 20 and 150 Hz (Konrad, 2005).

The digital interpolating technique has been used by Zheng Y. and Jan V. der Spiegel to predict the analog signal before it is converted by using analog to digital converter. Algorithms are derived from the spline theory. Such converters are expected to have reduced complexity in their analog circuitry and can be easily implemented using digital filter (Yang & Spiegel, 2005).

The estimates of missing data in a sequence of series is considered as one of the main problems that arise in many scientific and engineering problems. In most applications, these sequences converge very slowly, and this makes their direct use to approximate limits an expensive proposition. However, there are important applications in which they may even diverge. In such cases, the direct use of the infinite sequences to approximate their so called "antilimits" would be impossible. "Antilimits" can be interpreted in approximate ways depending on the nature of the infinite sequence. One of these ways is the interpolation, which has been recognized by Richardson and Aiken (Sidi, 2003).

The aim of this work is to predict missing samples. The available and missed samples are impartial in planning, monitoring, and system evaluation. In order to estimate the missed samples, special normality assumption is imposed along with constraining the interpolation process within the data range.

In this work a Kolmogrov-Smirnov Z statistics is applied to measure the goodness of fit (distribution test) to the real and interpolated signals.

A mean square error (MSE) is also applied.

2 THE PROPOSED TECHNIQUE

Suppose an observed sample $\{y_t\}$ consist of two components which are, $\{x_t\}$ representing by the core

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process in addition to irregular outliers, $\{v_t\}$ then;

$$y_t = x_t + v_t \quad (1)$$

Applying the robust filtering technique for the contaminated data that were used by (Al-Naqeep, 1997) accompanied by a sequential least square method for autoregressive coefficients, the forecasted data are obtained as:

$$\widetilde{x}_t = \sum_{j=1}^{p} \emptyset_j^p \, . \hat{x}_{t-j} \quad (2)$$

Where; $\{\hat{x}_{t-j}\}$ represents the regret core process, $\emptyset_j^p$ represents autoregressive coefficient, and (P) represents the order of the autoregressive equation in time series based on (Akaike, 1969).

A weighted estimation is required here (Davis & Jones, 1968), which is;

$$w_t = W\,\{(y_t - \tilde{x}_t)/\sigma_p\} \quad (3)$$

Where;
W is an even function, more ever,
$W(0) = 1$,
$W(\infty) = 0$,
$\sigma_p$represent the positive square error.
$\{\hat{x}_t\}$can be determined by adding the average observed weight and the forecasted one, where,

$$\hat{x}_t = w_t y_t + (1 - w_t)\tilde{x}_t \quad (4)$$

or;

$$\hat{x}_t = w_t(y_t - \tilde{x}_t) + \tilde{x}_t \quad (5)$$

and,

$$\hat{x}_t = \hat{\sigma}_p \varphi(u) + \tilde{x}_t \quad (6)$$

Where; $\varphi\ (u)$ is an active function and;

$$u = \frac{y_t - \hat{x}_{t-1}^T \hat{\emptyset}}{c\,\hat{\sigma}_p} \quad (7)$$

c is an efficiency constant (Thomson, 1977).

The proposed method maintains the observed data when errors are scared and the forecasted data for large error.

The whole process is nonlinearities, and to prevent complications in the EMG signal, an affected function needs to be selected. The selection is to guarantee no effects of large error in the spectrum contents of the EMG signal.

The missed signal values are obtained using a nonlinearities interpolation formula. This formula supposes outlier values, Known as an upper outlier. In order to obtain a symmetric distribution, the distribution shall be in accordance with a standard accumulative density function *w (u)* for extreme value distribution. The density function is;

$$w(u) = exp\big(-ex\,p\big(-q(|u| - q)\big)\big) \quad (8)$$

Where;
q: Represents a constant value that is defined through the cumulative of the standard normal distribution function $\Phi_{\mathbf{N(0,1)}}$.
u: Represents the random variable of Gumbel distribution function of type one.

Then, in some way, the linear interpolation formula is (Hintze & Kaysville, 2007);

$$\hat{x}_t = \frac{O.\hat{x}_{t+i} \ - \ M.k.\hat{x}_{t-i'}}{\hat{x}_{t+i'} \ - \hat{x}_{t-i}} \quad (9)$$

Where; $i \le i'$
O and M are defined the two extreme points that the ordered of the interpolation's ranks induced to the backward and forward observations
$\hat{x}_{t-i'}$ and $\hat{x}_{t+i}$ repectively.

A constant weighted logarithmic relation is used to process of extreme values for forecast ones. The weighting is done in order to obtain the highest efficiency possible. This is done empirically, and a weighting factor (k) of, k=3, was found to be more suitable for the best signal reconstruction. The weighted, nonlinearities logarithmic relation used in this work related to the equation (1) is;

$$\hat{x}_t = \frac{O.\hat{x}_{t+i} - M.k.\log_e \hat{x}_{t+i'}}{\hat{x}_{t+i'} - \hat{x}_{t-i}} \quad (10)$$

To obtain reliable and new estimates of the parameters $\{\emptyset\}$ and then the estimates of the sequence$\{\hat{\sigma}_p\}$, the sequence $\{\hat{x}_t\}$ will be used instead of $\{y_t\}$ in the autoregressive accordance model. Sequences $\{\hat{\emptyset}\}$ are used consequently, to obtain the new estimation in order to get the final$\{\hat{x}_t\}$. This means that the value of $\{\hat{\sigma}_p\}$ in the previous session is equal to or less than that variable in the previous session. The filtering operation will be completed and the forecasting processes of the missing values of the signal are obtained. Figure 1 shows a flowchart of the proposed method algorithm.

3 DATA ACQUISITION SYSTEM

The Biceps Brachii of one subject aged 35 years was studied when muscle on tension. A weight of 5 Kg was held in the palm of the subject with arm outstretched and supported on the elbow, for five minutes to ensure that the muscle is in the fatigue state. A pair of bipolar electrodes was used for the detection of the EMG. The electrodes are dry surface, gold-coated stainless steel the electrode separation being 20 mm. The pre-amplifiers are similar to those in (Miller & Reed, 1977). They have a high common mode rejection ratio (CMRR >80 dB) at the main power frequency, and high differential gain (≈ 60 dB). The EMG is passed to a laptop via an 8-Bit A/D converter with a sampling

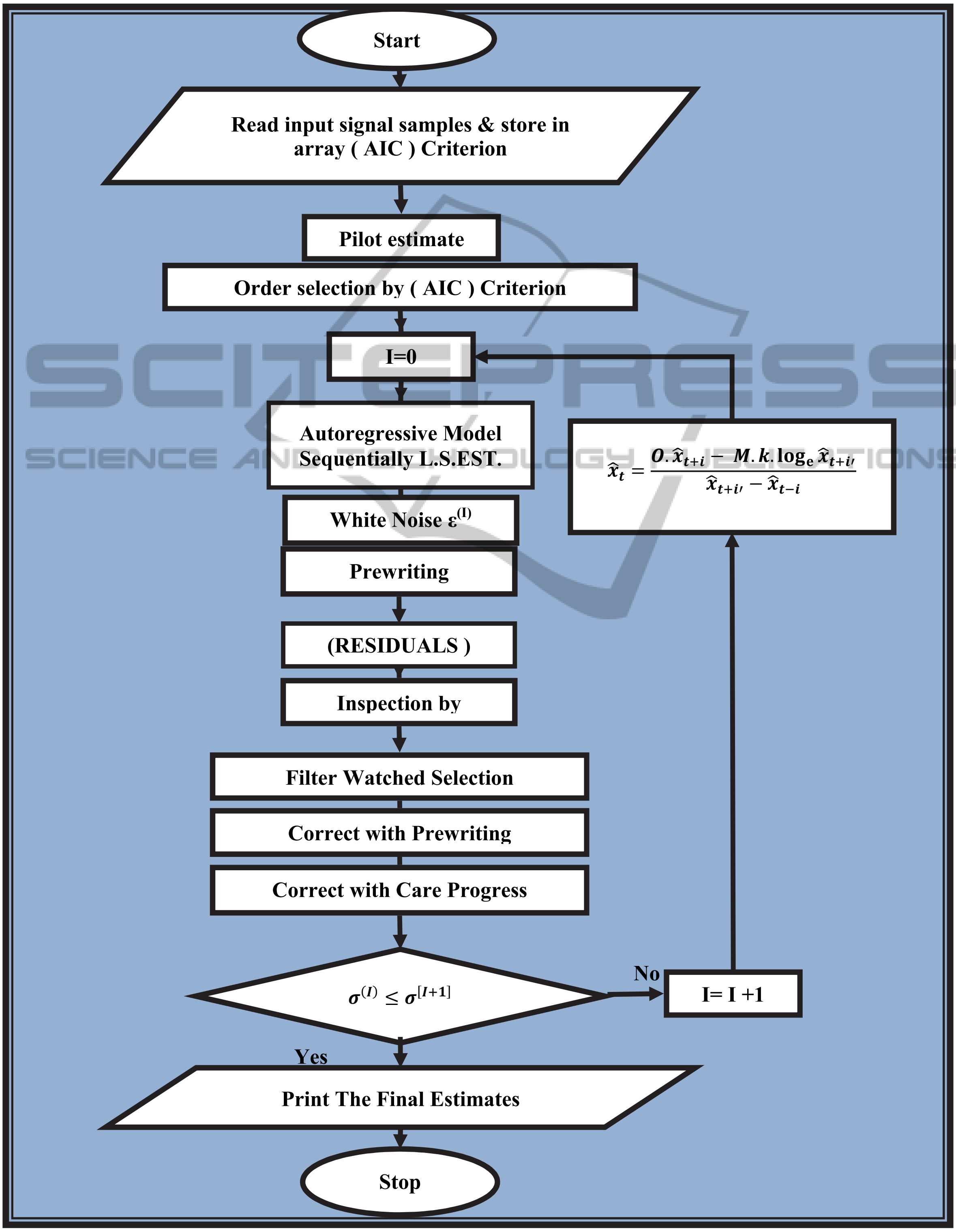

Figure 1: Shows a flowchart of the proposed formula.

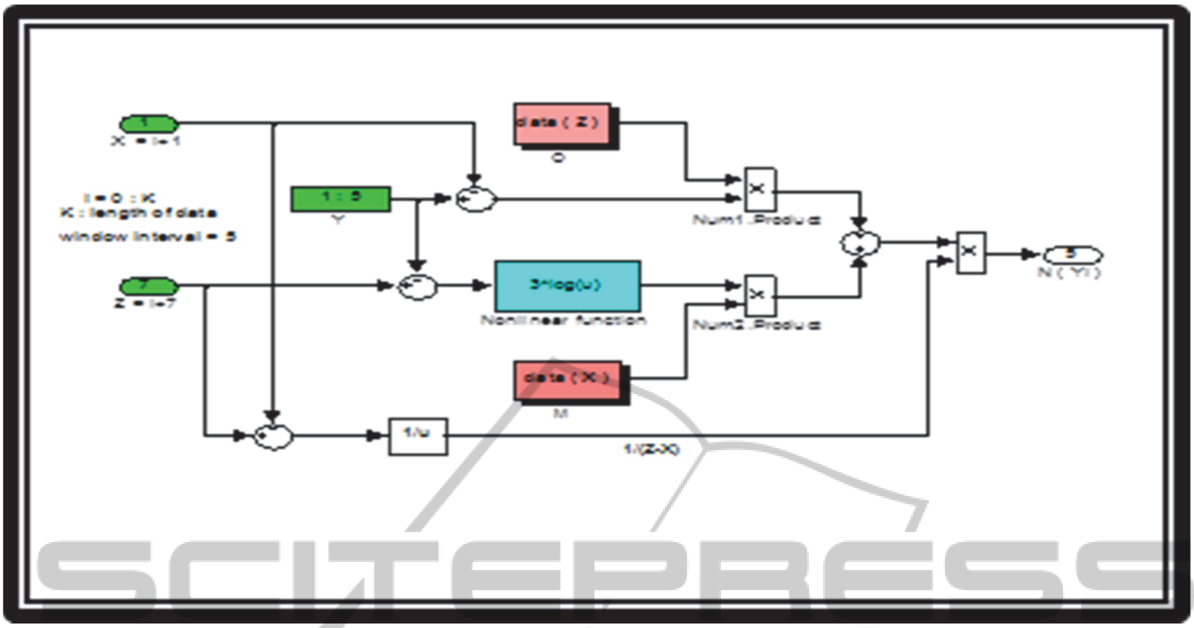

Figure 2: Proposed nonlinearities interpolation formula structure.

frequency of 8 KHz. The digital output is a positive integer numbers lying between 0 and 255. The use of the laptop is preferred instead of PC for the complete isolation between the subject and the main power lines, and also to reduce interference and for the same reasons, the power of the amplifier is supplied by batteries (Adriano, Andrade, Slawomir, Nasuto, Kyderd, 2007). A series of (twenty fifth) data files, each with a time interval of 1 sec. are stored in the computer . A selective time windows of the recorded signals from the Biceps Brachii of the subject have been chosen (*R5, R1, R15, R20, R25*) in this work. The damaged signals have been derived from the real's signals, with the amount of damage of about 80%.

Figure 2 shows a Simulink representation of proposed nonlinear interpolation for 5 missing ascended data (i.e. with total interval process equal to 7 data samples), where X and Z are the outer loop counters and Y is the inner counter. The process of interpolation needs the actual values of the ascended damage vector with each band of evaluation. The output values of the interpolated missing data had been done using nonlinear logarithmic function weighted with a constant equal to 3 derived from many trials and error which fulfill minimum error between actual and interpolated signals.

4 EVALUATION OF THE PROPOSED TECHNIQUE

In order to build a robust system, a Kolmogorov-Smirnov - Z statistics test is applied to measure the goodness of fit (i.e. Fitness of the distribution shape test) to the real and interpolated signals. This test for normality is based on the maximum difference between the observed distribution and expected cumulative-normal distribution. The results in table1 show high evidence to reject the statistical hypothesis of normal distribution function assumption for all of the studied real and linearity interpolated to form of EMG signals. That invited to searching for a suitable nonlinear interpolated formula that capable for estimation and reparation of missing part that might be occurred for the signal due to different reasons.

MSE has been reported through applying the Analysis Of Variance (ANOVA) for regressive analysis between the real signal as an independent interpolated signal as a dependent variable.

Table 2 shows that MSE for the Nonlinear Interpolated to real EMG is less than MSE of the Linear Interpolated to real EMG.

Figures 3 illustrates a normalized amplitudes of damaged, real with nonlinear interpolated EMG signals with total processing time period of50 msec., under normal muscle condition with *R5* and *X5* window case. Where processing time of 50 msec. is

Table 1: Normal distribution function Goodness of fit testing hypothesis for real and interpolated EMG signals for selected time windows.

One-Sample Kolmogrov-Sminove Test										
Signal Windows	*R5*	*X5*	*R10*	*X10*	*R15*	*X15*	*R20*	*X20*	*R25*	*X25*
No. of samples	397	397	397	397	397	397	397	397	397	397
Kolmogorov-Smirnov Z	2.728	2.273	2.104	1.916	3.774	3.5	2.066	1.696	1.906	1.447
Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.006	0.001	0.030

Table 2: (MSE) of regression analysis of variance for linear and nonlinear Interpolated EMG signals.

Window interval	Nonlinear interpolated to real EMG	Linearly interpolated to real EMG
Window-5	0.04777 e-3	0.06382 e-3
Window-10	0.00932 e-3	0.01624 e-3
Window-15	0.04784 e-3	0.07734 e-3
Window-20	0.19470 e-3	0.22840 e-3
Window-25	0.15380 e-3	0.29480 e-3

suitable for EMG signal processing and applications (Harba & Lynn, 1981). It is clear that, there is a dramatic tracking of the interpolating signal with the real one for the whole period, but the robustness of tracking changed due to the fluctuation level with different parts of the test period. However, it can be divided into two main regions due to fluctuating levels; first one between 0-18 msec. and the second one between 18-45 msec. approximately. First period shows a low fluctuating level which leads to make high tracking robustness processing, while in the second period 18-45 msec., the fluctuation level increases gradually. In the other word, if the rate of change is being very large, the interpolation will lose some of tracking robustness due to small drift presentation which increases the error between the two signals.

Regardless the value and the number of the missing samples and due to the error values, the test period can be divided into two regions as well. However, while the rate of change is low, minimum error can be sensed. In contrast, as the rate of change is high caused by increasing of the fluctuation level, the interpolation will lose some of tracking robustness due to small drift presentation which increases the error between the two signals.

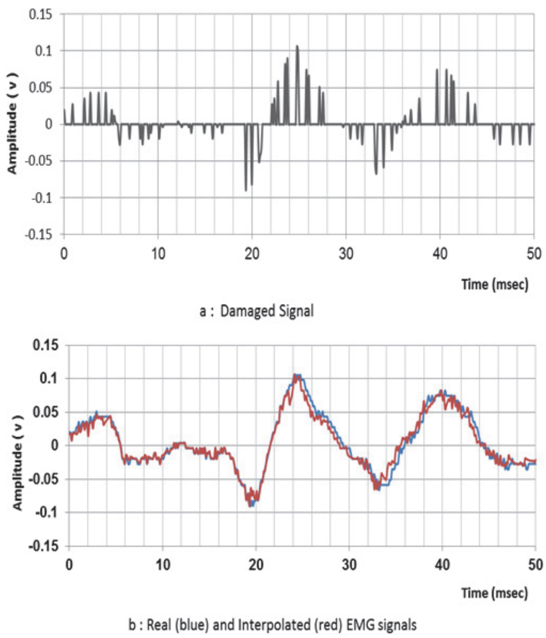

Figure 3: a): damaged signal; b): real and nonlinear interpolated EMG signals) during time period of 50 msec. under normal condition with *R5* window case.

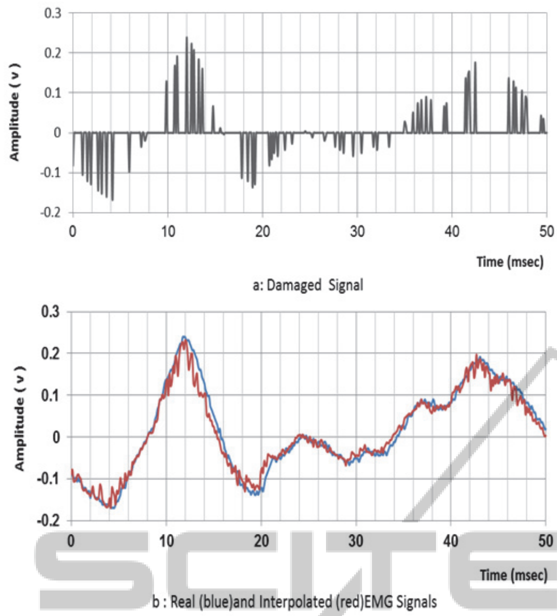

Figure 4: a): damaged signal; b): real and nonlinear interpolated EMG signals; during time period of 50 msec. under fatigue condition with *R25* window case.

Similarly, figure 4 illustrates similar normalized axes with different sets of data measurement test number under fatigue muscle condition with *R25* and *X25* window case during 50 msec. time period. Although the real EMG signal is changed with test number, the sharp rate of change (severe fluctuation) in the data still has the major effect on the proposed interpolation method. As shown in the period from 5 msec. to 22 msec., there is an error. In other word, low robustness for interpolation. In contrast, between 22 msec. and 40 msec. The proposed nonlinear interpolation recovers it's high tracking robustness process, when the envelop of the real signal being low fluctuated and error is reduced.

During time period 40 msec. to 50 msec. The drift occurs again due to the increasing rate of change and this leads to decreased interpolation robustness slightly to produce increasing in error.

Figures 5 and 6 show the power spectral densities of real, nonlinear interpolated and damaged EMG signals subjected to normal and fatigue states respectively using Fast Fourier Transform (FFT) calculation. It is clear that the nonlinear interpolated signals have recovered most energy spectrum of the real signals compared to the spectrum of the damaged signals, also the shift of the EMG power spectrum towards lower frequencies give as an index for a fatigue (Deluca, 1997; Gozalez-Izal, Malanda, Navarro-Amezqueta, Gorostiaga, Mallor, Ibanez, Izquierdo, 2010). Therefore, the fatigue of muscles can be detected efficiently by using power spectrum of the nonlinear interpolated signals to give fatigue alarming case. While due to the confused spectrum of the damaged signals, we cannot get useful information as an index for fatigue.

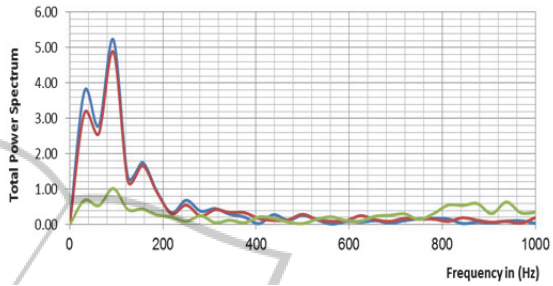

Figure 5: The spectral densities of the real (blue) interpolated (red), and damaged (green), signals under normal condition with *R5* window case.

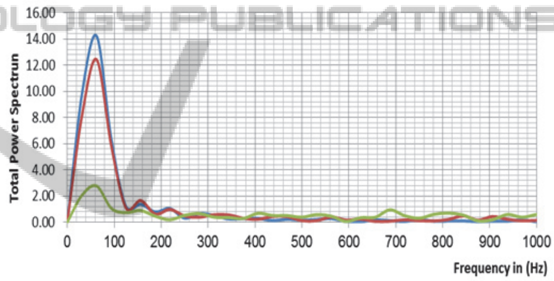

Figure 6: The spectral densities of the real (blue) interpolated (red), and damaged (green), signals under normal condition with *R25* window case.

5 CONCLUSIONS

A new nonlinearities (logarithm function) interpolation technique has been implemented on the EMG signal as a result of a highly evidence to reject the statistical hypothesis of normal distribution function assumption for all of the studied real and linearized interpolated to form of EMG signals.

Eventually, the time responses mentioned in Figure 3 and 4 described two main issues; tracking robustness of interpolation and the amount of sudden rate of change in the real measured EMG signal. Despite of small drifts and regardless of the value and the number of the missing samples, it can be concluded that the proposed interpolation method is very efficient and can be applied for other type's bio-medical signals.

The results of the proposed formula of nonlinear interpolation, that deals with non-normal shape of signal distribution function, which belongs to the non-convergence property, is approaching from the results of the conventional method in the case of non-contaminated distributions, and that results are better than the results of the conventional method in the case of dealing with contaminated distributions (I: e known Robust formula).

We can conclude that the nonlinear interpolation signal may resemble the real signal in terms of shape, spectrum and the capability to recover energy of the real signal.

In addition to that, the suggested formula represents highest grades of accuracy between real and interpolated signals whatever a difference between the conventional state (with and without stress).

One of the most important recommendations is to explore the essence of the lost part of the studied signal through residual values. Furthermore, it is recommended that the proposed technique can be applied to physical body's properties such as (MUAC, trunk length related to abdomen center).

Due to data compression technique, the proposed algorithm has the same orientation, where the number of data has been compressed to about 20% from the actual size of data (which is called the damaged signal). Therefore, it can be extracted again using the proposed algorithm.

Despite the fact that the application was for one subject only, but, the results are very promising to be applied to many for getting better reliable algorithm.

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