The application of Wavelet method for the analysis of static force exertion process during snap-fit assembly

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Abstract. The investigation of static force exertion is one of the most important issues in ergonomics. The common methods are often based on average or maximum amount of data .So, the whole process of force exertion has not been efficiently studied in the literature. The Wavelet method, which is always used in the signal processing such as EMG (Electromyography) and EEG (Electroencephalography), can also be used for the processing of static force exertion. This paper will use the Wavelet methodology for the analysis of the whole process of combined force exertion during snap fit assembly including the grasping and insertion forces. Also we will discuss the advantages of this method compared to the classic methods.

Keywords. Wavelet method, static force exertion, snap-fit assembly

1. Introduction

Today, snap-fits have found extensive application in the assembly industry. Especially in the automobile assembly industry the lightness and high speed of these connections have made them increasingly popular (Landau et al. 2009). However, the desirable technical features of these connections should not cause their ergonomic requirements not to be studied. Hence, several studies have been done in this field (Potvin et al. 2006, Salmanzadeh et al. 2010a, Salmanzadeh et al. 2010 b, Salmanzadeh & Rasouli 2015). A part of the ergonomic issues during the assembly of this type of connections is related to the study of exertive forces such is Insertion or Grasp force. These forces due to high volume and repetition sometimes cause RSI(repetitive strain injury)disorders in hands and fingers (Landau 2008). Hence, the process of exerting force in the montage of snap fits has turned in to an attractive subject of study for many researchers, and it must be studied in practice as well. In theory the process of exerting isometric force (Ideal type) has a chart as shown in figure 1. However, in practice we face the following form as shown in figure 2.

The difference with real world, which we will consider as noise, is created because of a position and direction of force exertion, type of grasp, etc. Hence, a real world process of force exertion has two components of the main process and noise, whose analysis can be very practical. However, most researchers only work with the maximum or their average, and do not consider the entire process (Salmanzadeh & Landau 2014, Schaub et al. 2010).

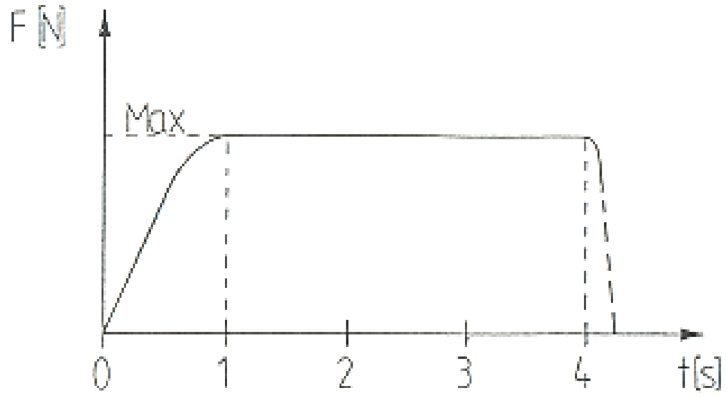

Figure 1. Ideal type of isometric force exertion process according the Rohmert et al.1992

Here we want to achieve this by using basic mathematical tools such as short time fourier transform (STFT). The fourier transform is appropriate for functions with static alternation in frequency. The fourier transform is not applicable when there are sharp spikes or there is a significant change in frequency. Short time fourier transform is more practical than fourier resolution in terms of time and frequency analysis. Also for the analysis of sharp spikes, STFT is more acceptable than other methods. Recently wavelet bases are used in signal analyses which have a more acceptable resolution compared to STFT. These transformations can be used in the analysis of signals from the force exertion process to achieve the following:

1. Better estimation of the force exertion process function
2. Reduction of the dimension in order to facilitate analysis based on wavelet coefficients
3. Noise analysis in practical process

Hence, in section 2 we will briefly discuss wavelet transformations. In section 3 we will use some examples to show the practical aspects of the Wavelet transformations.

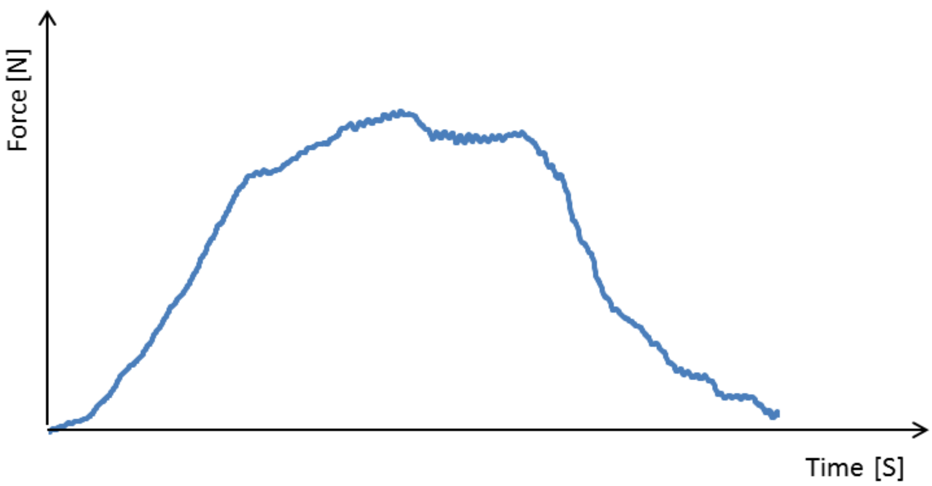

Figure 2. Real type of isometric force exertion process

2. A brief introduction of Wavelet transformation

Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. In the other hand, wavelet transform is one of a best tools for us to determine where the low frequency area and high frequency area are. Wavelet transforms have become one of the most important and powerful tool of signal representation. Nowadays, it has been used in image processing, data compression, and signal processing.

Basic wavelet function (Mother wavelet) makes it possible to be able to decompose a function $f(x)$ as.

$$f(t) = \sum_{k=1}^{N} a_k \psi_k(t),$$

where $\psi_k(t)$ is the mother wavelet and a_k's are related coefficients. In general, continuous wavelet transformation (CWT) of signal process $x(t)$ based on basic wavelet ψ is

$$\Psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{s}} \int x(t)\psi\left(\frac{t-\tau}{s}\right) dt =< x(t), \psi_{\tau,s}(t) >, \tag{1}$$

where τ and s are respectively transform and dilation parameters, and wavelet function $\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right)$ is a real number function such that satisfies the following,

$$\int_{-\infty}^{\infty} \frac{|\widehat{\Psi}(s)|}{|s|} ds < \infty,$$

where $\widehat{\Psi}$ is Fourier transformation of wavelet function. In relation (1), $\Psi_x^{\psi}(\tau, s)$ is coefficient of $x(t)$ related to wavelet basic $\psi(t)$. Also, it is clear from the above formula that the basic wavelet is scaled, translated and convolved with the signal to compute the transform. The translation corresponds to moving the window over the time signal, and the scaling corresponds to the filter frequency bandwidth scaling.

If we have these coefficients, then we can write

$$f(t) = \sum_{k=1}^{N} < f(t), \psi_k(t) > \psi_k(t),$$

and signal $x(t)$ as

$$x(t) = \int_{0}^{\infty} \int_{-\infty}^{\infty} \Psi_x^{\psi}(\tau, s) \frac{\psi_{\tau,s}(t)}{s^2} d\tau ds. \tag{2}$$

The Haar wavelet function is a famous basic. It prepares a orthogonal basic, but is discontinuous and hence not derivable. Meyer (1992) and Daubechies (1988, 1992) presented orthogonal bases that are continuous and derivable. Because of the nice features that belong to the orthogonal basis only, we use them.

3. Application of wavelet in Analysis with Example

Generally for the filtering of force exertion noises, smoothing is used. Smoothing is the average of adjacent points. A similar result can be achieved by using the Haar wavelet basic function. However, since the function resulted from Haar transformations is not continuous and differentiable, the trend of force exertion changes cannot be evaluated. Hence, we suggest that in wavelet transformations the basic functions of Daubechies and Meyer be used. In wavelet transformation for coefficient generation the number of coefficients must be determined in advance. For instance, if the sample number used in the evaluation of the process of force exertion is n, then in order to determine the number of coefficients, k must be selected in a way such that $\max_{k}(2^k) < n$.This way the number of possible coefficients will be 2^k.

Consider the vector $\mathbf{X}_\mathrm{i} = (\mathrm{x}_{\mathrm{i}1}, \dots, \mathrm{x}_{\mathrm{im}_\mathrm{i}})$ which contains the recorded numbers of the force exertion process of the i-th person in the sample ($i = 1, \dots, n$). Notice that it is not necessary that the number of recorded data be the same for each person and it only suffices that a process has been performed. If we want to perform an imaginary test for comparison purposes, for example, the difference between the force exertion process between men and women. Since the recorded values of people are not necessarily the same (i.e. m_i's are not the same), and the number these values is larger than the samples (m_i> n) for each person, a scientific (statistical) method does not exist. To resolve this issue the wavelet coefficients from the force exertion vector for each person can be easily used with the number of coefficients determined earlier 2^k. Hence, software packages like Matlab are used and based on the recorded observation of each person for formula 1 we estimate

$$\widehat{\Psi}^{\psi}_{\mathbf{X}_\mathrm{i}}(\tau, \mathrm{k}) = \frac{1}{\sqrt{2^\mathrm{k}}} \sum_{\mathrm{j}=1}^{\mathrm{m}_\mathrm{i}} \mathrm{x}_{\mathrm{ij}}\, \psi\left(\frac{\mathrm{t}_\mathrm{j} - \tau}{2^k}\right), \qquad (3)$$

The number of such estimation obtain the same for each person. Meaning, at the end for each person we will have wavelet coefficient vector with similar dimensions. The similarly-dimensioned vectors make tests such as multivariate method like MANOVA possible.

For example, the data used by Salmanzadeh et al. 2014 evaluate the difference of maximum points for three grasp points. Now if we want to compare the entire force exertion process resulted from these three points; because of the high volume of the

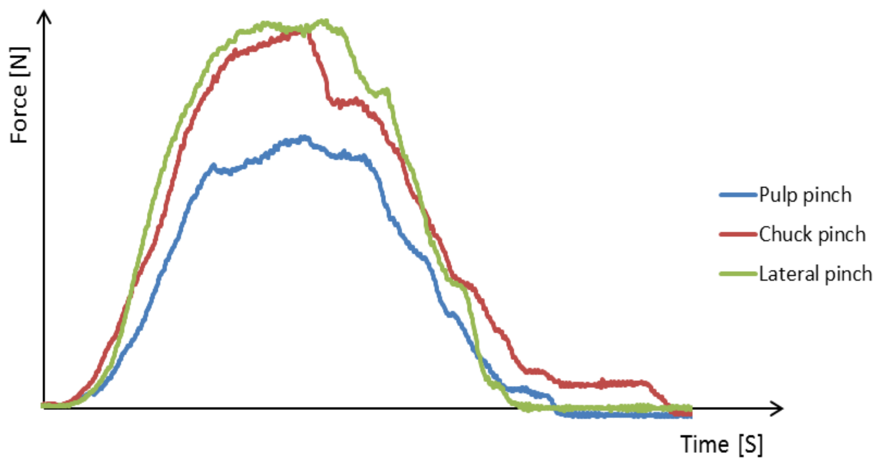

Figure 3. Real type of isometric force exertion process for three different grasp types of snap-fits

recorded points (1000 records) for 26 people, it is not possible to use multivariate methods. Hence, we used the Meyer wavelet transformation. The curves resulted from the real recorded values and estimated coefficients are shown in Figure 3 and 4 respectively.

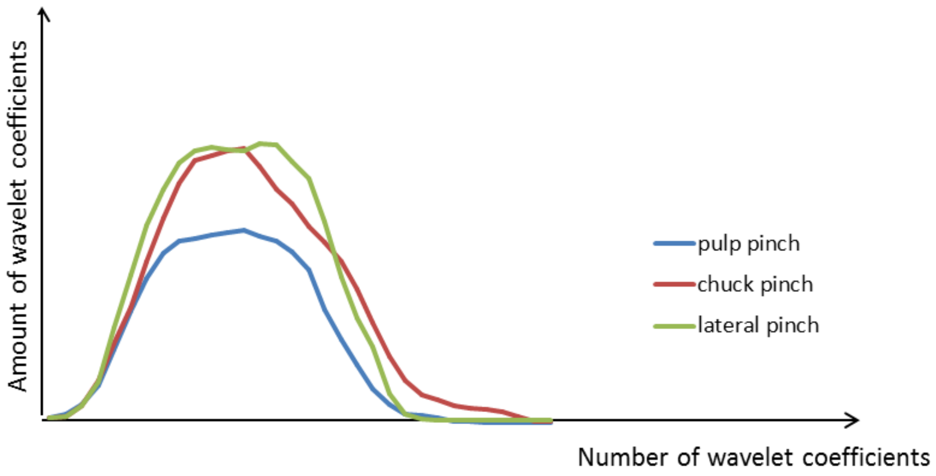

Figure 4. Wavelet curves of isometric force exertion for three different grasp types of snap-fits

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