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The Stamp method for processing of high noise data from infrared sensor in harsh environment

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ABSTRACT

This article presents a new digital method, called Stamp method, for elimination of undesired noise data from a periodic IR signal. The Stamp method is a useful tool for statistical analysis of changes which appear in a noised input signal. One stamp is a statistical image of several consequence periods from a raw input signal. The Stamp method is a combination of equidistant transversal and differential filters, where useful output data is produced by subtraction of neighboring stamps. The corresponding digital Stamp filter formulation is provided with the Z-transform formalism. An application of the statistical Stamp method is presented on temperature changes extraction from a real noised IR (infra-red) raw signal from turning shaft in a power plant. The moving average and impulse-response filters were applied for final cleaning up of the data. The MATLAB short source code of stamp implementation is in the Appendix A.

1. Introduction

There are a lot of methods for analysis of changes in periodic signals of different nature – sounds, mechanical vibrations, alternating electromagnetic processes, etc. [1]. A similar problem is solved when two or more signals of different natures are mixed together. However, the problem becomes more complicated in cases when the signal is mixed with thermal, random non-Gaussian or other noise [2–5]. This can occur in a case when a useful measured signal is at a same level or lower than a noise or other parasitic signal, which cannot be removed by a hardware method – by shielding, for example. The measured signal should be separated and the useful signal should be extracted by data processing in this case. When a useful signal is mixed with random noise, a statistical approach is one of the successful methods for data processing [6,7].

In this article a new statistical Stamp method for raw periodical data processing is presented for solving the problems described. The Stamp method basics are presented with the mathematical approach and practical application of the method. A statistical approach plays a key role in the Stamp method. It does not provide an absolute value of the useful signal but it is focused on changes of the useful signal. Despite this limitation, the method is useful in a lot of cases where absolute values are not important, but possible changes of a useful signal can be an important factor and should be analyzed.

An example is a weak signal of an infrared (IR) sensor from a pulsed source demonstrated by a rotating shaft of a hydroelectric power plant generator with a temperature gradient or hot spots, where the useful signal is temperature variation and it is mixed with a high power electromagnetic emission. The measured signal is represented by the dotted line in Fig. 1. The amplitude of the electromagnetic field noise and undesired periodical signal is ten times bigger than useful signal, obtained by classical methods. Period of the undesired signal is equal to the period of the useful signal. Thus, classical methods, like the Butterworth passband signal processing filter, frequency response functions (FRF) with a fast Fourier transform (FFT), and a moving average filter (introduced by the "smooth" function in MATLAB, for example) [1,8–11] are not strong enough for noise removal and cleaning up the raw measured data. An additional disadvantage of the frequency dependent methods mentioned is the necessity of a priori known characteristic of the useful signal for correct adjustment for filters. The data after processing using the described filters are shown in Fig. 1 by the solid line. The first quarter of the periods in the cleaned signal contains overlapped peaks and it is difficult to identify their nature: result of imperfections of the filters mentioned or real form of the useful signal. These results show that it is not easy to determine the position and size of temperature peaks from this evaluation. It is also not possible to determine the character of the changes in the useful signal: constant value or increasing from period to period and whether the increase is linear or exponential. To retrieve this information, the new method should be used for the data processing.

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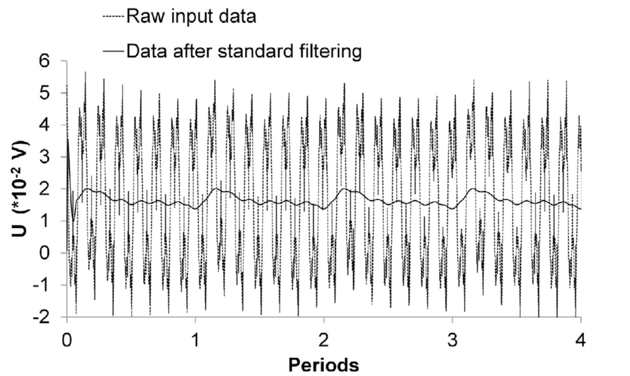

Fig. 1. Real signal from IR sensor, which contains noise and an undesired periodic signal from a powerful electromagnetic field. Dotted line – raw data with signals from several sources with different natures. Solid line – data about temperature of object after applying Butterworth filter, FRF and smooth function for the noised IR signal.

2. Stamp method

2.1. Basic description

The Stamp method is an evolution of subtraction algorithms with recursive logic. Subtraction algorithms are naturally used for cleaning up raw data from CCD matrices, video streams and statistical analyses of images [12–14]. A subtraction method is also used in measurement in a fusion plasma environment [15]. The subtraction algorithms are a good processing method for data, where an evaluation is not focused on absolute values of the data, but on local changes in a series of the data [16]. This method has more advantages when the undesired signal has a clean harmonic character and random noise, but the useful one has a more complex form. The new feature of the Stamp method is its statistical character. The fundamental idea of the Stamp method is based on two basic assumptions:

I – the mean value of undesired signals and noise is the same in the whole studied region;

II – the useful signal is phase sensitive, but the random noise and the mentioned imperfections of mathematical methods are not phase sensitive.

The first assumption is acceptable in the case when undesired signals and noise are the same through whole processed region of the input data. In the case when the raw signal contains additional undesired signals or noise, which are changing by some function, then it is needed to apply special techniques, for example group analyses of the raw data [17]. The second assumption only underlines the fact, that influence of measurement system, imperfection of hardware or software, does not contain any information about period of measured signal. The application of these two assumptions of the Stamp method can be explained with the help of the logical scheme in Fig. 2. It is necessary to create one first stamp vector of incoming data as the first step. This stamp vector is formatted from N periods from the first selected area of the raw signal (Fig. 2, Area 0). In this case the period value is a known constant, but in the other cases it is possible to use an autocorrelation function for period optimization (for example by maximal-minimal set-of). A M° sequence of the periods from this selected area is collected as the next step into the matrix:

$$M^0 = \begin{bmatrix} P^0_{1,1} & \cdots & P^0_{1,K} \\ \cdots & P^0_{i,j} & \cdots \\ P^0_{N,1} & \cdots & P^0_{N,K} \end{bmatrix} \tag{1}$$

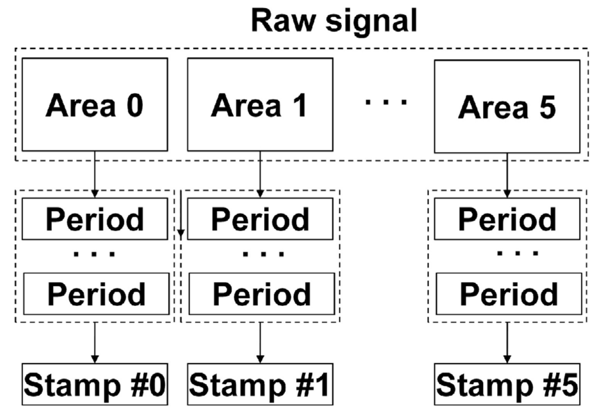

Fig. 2. Scheme of stamp gathering from six areas with 10 periods in each area.

where $P^0_{i,j}$ is the value of the signal in period number i in the data area 0 at the position j from the beginning of this period; N is the full number of periods in the selected area; K is the full count of samples in one period. The full number of periods in the selected area N has a limitation such that the abmodality should be smaller than 1% between the first and last period in the area. After the matrix M° is assembled, the statistical stamp S° is built as a vector, which contains the mean values of the data in columns of matrix M°:

$$S^0 = N^{-1} \cdot \left[\sum_{i=1}^{N} P^0_{i,1}, \sum_{i=1}^{N} P^0_{i,2}, \ldots, \sum_{i=1}^{N} P^0_{i,K} \right] \tag{2}$$

This equation represents the statistical stamp S° from the first area in the input signal. This starting stamp S° plays a key role in the presented method for providing the subtraction algorithm. The next stamp S^1 should be prepared from the next selected area from the raw signal in the same way. The resulting output of the stamp method returns only statistical image about changes of the signal in data region and regression of the noise stay to be unfinished. For full finished stamp method processing it is needed to apply additional classical methods, as Butterworth filter [11] and smooth function [1].

2.2. Digital filter stamp

The convolution of input data in the one output value of the stamp is provided by a summation of all equidistant values from the input signal:

$$y(j) = N^{-1} \cdot (x(j) + x(j-1\cdot K) + \ldots + x(j - N\cdot K)) = N^{-1} \cdot \sum_{n=0}^{N} x(j - n\cdot K) \tag{3}$$

where $y(j)$ is the output data in the stamp and $x(j)$ is the input data value. In this way, every sample of the stamp is a statistical image of the equidistant samples from the whole area. This is a basic difference between the presented Stamp method and corresponding transversal digital filters. The next step of the Stamp method is providing subtraction between two neighbor stamps:

$$y_s(j) = N^{-1} \cdot \left(\sum_{n=0}^{N} x(j - n\cdot K) - \sum_{n=0}^{N} x(j - N\cdot K - (n+1)\cdot K) \right) \tag{4}$$

Here the impulse response of the system is H^{-1}. The system is stable, because the N is not zero and is not infinite. One period contains more than one sample [18,p. 174]. The subtraction procedure, which is presented in Eq. (4), returns data about changes of the signal between two wide areas. These extended areas contain several periods, and as a result, the output data has a statistical character.

The block diagram of the subtraction algorithm with Z-transform indexes is shown in Fig. 3. On this diagram, the process of