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STATISTICAL RESEARCH SPACE OF MEASURES OF VIBRATION ENERGY IN MACHINES

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Abstract: *This work presents computer procedures for technical systems multidimensional monitoring. They include; MATLAB program for constructing a Symptoms Matrix starting from experimental measurement, development of: a software tool to read and export .unv format files, OPTIMUM computer algorithm, Singular Values Decomposition analysis (SVD) computer algorithm and MATLAB program to analyse matrix using MAC theory.*

Keywords: vibration symptoms, research, statistic, monitoring of the state

1. Technical systems state analysis

The state of analysis technical systems is a compound for a set of mathematical procedures that can be related to each other, to develop analysis of superior order and to find relationships between procedures and states in different systems. The procedures can be classified according to the analysis stage, in which they are executed: pre-processing, processing, and post-processing.

There are many relationships that can be possible because of those procedures; in this work there are proposed only a few chosen relations. Of course, it is possible to formulate other relations of procedures to make another kind of methodologies or analysis (Fig. 1).

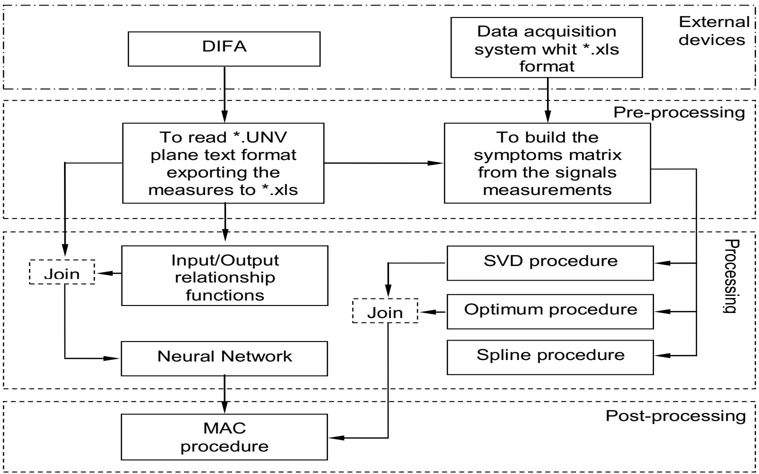

Fig. 1: Flow diagram of the technical systems state analysis

2. Basic research methodology

2.1. Import *.UNV format

The universal file format (unv) is a set of ASCII file formats widely used to exchange analysis and test data. These files are text archives of data set from experimental tests and are available to the public domain.

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The data set can come from data acquisition systems with different sources as acceleration, displacements, temperature, noise, etc. the data are in the dynamic time domain t.

Starting from .unv files, the measures matrix, M_{mtx}, could be made with the q observation vectors; the observation vectors have p observations, that means (a):

(a)

$$Mmtx = \overbrace{\begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1q} \\ m_{21} & m_{22} & \cdots & m_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ m_{p1} & m_{p2} & \cdots & m_{pq} \end{bmatrix}}^{Measures} \begin{matrix} \rightarrow Observation_1 \\ \rightarrow Observation_2 \\ \vdots \\ \rightarrow Observation_p \end{matrix}$$

(b)

$$\begin{array}{c} S_j \\ \downarrow \end{array}$$

$$Smtx = \begin{bmatrix} s_{11} & \cdots & s_{1j} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots & & \vdots \\ s_{i1} & \cdots & s_{ij} & \cdots & s_{in} \\ \vdots & & \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mj} & \cdots & s_{mn} \end{bmatrix} \begin{matrix} \rightarrow State\ q_1 \\ \vdots \\ \rightarrow State\ q_i \\ \vdots \\ \rightarrow State\ q_m \end{matrix}$$

2.2. Symptom matrix

The symptoms result from a measures matrix, M_{mtx}, are separated into two classes, according to the relation between the signals:

- single signals analysis,
- related signal analysis.

These distinctions are due to the mathematical differences procedures, and generate a classification of symptoms. The symptom matrix is developed starting from the chosen symptoms $S_{mtx} = \{S_1, S_2, \ldots, S_j, \ldots, S_n\}$, where S_j represents the j symptom vector in the life time of the system q, that means (b).

2.3. OPTIMUM method

Given a set of n data, $S_{mtx} = \{S_1, S_2, \ldots, S_j, \ldots, S_{n-1}, S_n\}$, where symptom vector $S_j \in {s_i}^n$ a multidimensional space and contain m stages in the time domain q, time of system life. The approach is focused to realize an analysis of the symptomatic space with statistical criteria.

OPTIMUM establish the variation coefficient as the parameter $f1_j$:

$$f1_j = \frac{s_j}{\bar{S}_j}, \tag{1}$$

where s_j is the standard deviation and $\bar{S}_j$ is the average, of the *j-th* symptomatic vector.

The parameter $f2_j$ can be calculate to three different ways:

- coefficient correlation,
- symptoms sensitivity,
- the Modal Assurance Criterion (MAC).

A time vector is created as $f2_j$ in the correlation coefficient. The time frame Θ represents the existent connectivity between the states q. Θ is a linearly spaced and increase vector, it is mean a degradation linearly progressive between the states $\{q_1,\ldots,q_j,\ldots,q_m\}$ is assumed; when q_1 is the first stage of fault, q_2 is the second stage of fault and consecutively.

Then the correlation coefficient is defined as:

$$f2_j^1 = \frac{C(\Theta, S_j)}{\sqrt{C(\Theta,\Theta) \cdot C(S_j, S_j)}} \tag{2}$$

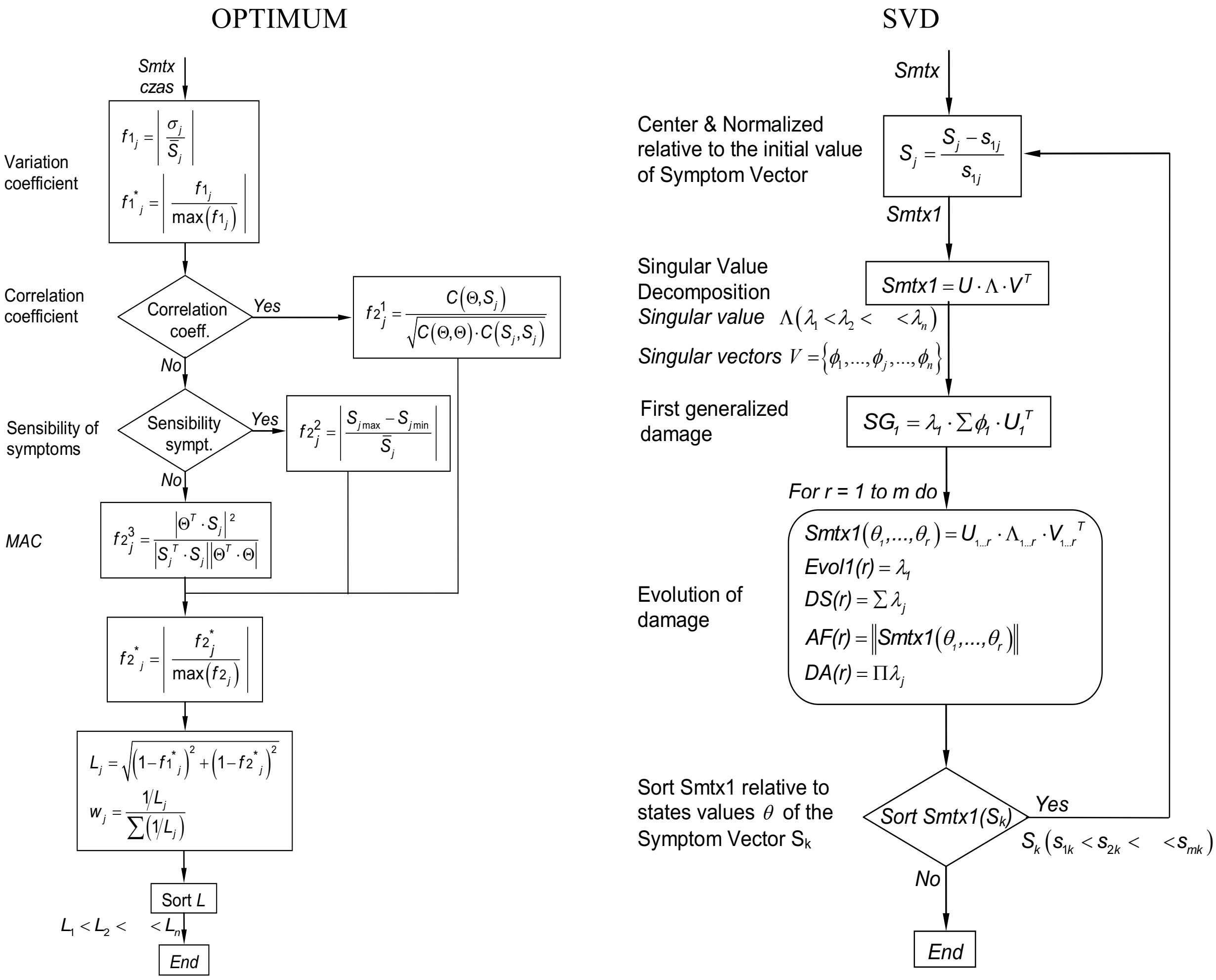

Fig. 2: Flow diagrams of OPTIMUM and SVD

C is the variance of the vector elements and its expression is:

$$C(\Theta, S_j) = E\left[(\Theta - m_\Theta)(S_j - m_{S_j})\right] \tag{3}$$

where E is the mathematical expectation and $m_{S_j} = ES_j$

The calculation of the symptoms sensitivity has similar expression to the variation coefficiency in the parameter $f1_j$, therefore exist a relationship strongly linear. The expression of sensitivity of symptoms is:

$$f2_j = \left| \frac{S_{j\max} - S_{j\min}}{\bar{S}_j} \right|. \tag{4}$$

MAC procedure uses the time frame Θ defined in correlation coefficiency to realize the calculus, then MAC assumes equal considerations in the stages characteristics q. MAC expression has the form:

$$f2_j = \frac{\left|\Theta^T \cdot S_j\right|^2}{\left|\Theta^T \cdot \Theta\right| \cdot \left|S_j^T \cdot S_j\right|}. \tag{5}$$

To carry out the maximization of the parameters f_i, a normalization of each element of them relative to the maximum value is executed:

$$fi_j^* = \frac{fi_j}{\max(fi_j)} \quad i = 1,2 \tag{6}$$

where fi^* represents the statistical behaviour of each symptom performance, which later on will permit to mark the coordinates of ideal point.

It is possible to get an index to quantify the relationship between each symptom's performance fi^* and the ideal performance. This relationship is established through trigonometric focus, the calculus of the existing norm L_j between the statistical symptoms performance points $\left(x = f1_j^*, y = f2_j^*\right)$ to the ideal point $\left(x = 1, y = 1\right)$.

$$L_j = \sqrt{\left(1 - f1_j^*\right)^2 + \left(1 - f2_j^*\right)^2} \quad (7)$$

Then L_j are converted weight expressions w_j (coefficients) to have better interpretation of results:

$$w_j = \frac{1/L_j}{\sum_{j=1}^{n}\left(1/L_j\right)} \quad (8)$$

it is requisite $\sum w_j = 1$. The global OPTIMUM is described in Fig. 2 (left).

2.4. SVD procedure

Given a set of n data, $S_{mtx} = \{S_1, S_2, \ldots, S_j, \ldots, S_{n-1}, S_n\}$, where symptom's vector $S_j \in s_i^n$ a multidimensional space, and contain m stages in the time domain q. The approach is focused to realize a linear analysis of the symptomatic space. A *singular value* and corresponding *singular vectors* of the matrix S_{mtx} are a scalar s and a pair of vectors u and v that satisfy:

$$Smtx \cdot v = s \cdot u$$
$$Smtx^T \cdot u = s \cdot v \quad (9)$$

With the *singular values* on the diagonal of the matrix Λ and the corresponding *singular vectors* forming the columns of two orthogonal matrices U and V, it is obtain

$$Smtx \cdot V = U \cdot \Lambda$$
$$Smtx^T \cdot U = V \cdot \Lambda \quad (10)$$

Since U and V are orthogonal, this becomes the singular value decomposition.

The SVD of an m by n in S_{mtx} matrix that involves an m by m in U, and an n by n in V. In other words, U and V are both square. If S_{mtx} is square, symmetric, and positive definite, then its eigenvalues and singular value decompositions are the same. But, as S_{mtx} departs from symmetry and positive definiteness, the difference between the two decompositions increases.

The singular value decomposition is the appropriate tool for analysing a mapping from one vector space into another vector space, possibly with a different dimension. The procedure calculates the first generalized damage *GS1*, and evolution of damage.

3. Conclusions

A set of computer algorithms was developed and called Technical Systems of State Analysis (TESSA). It contains computer tools that enable to make a technical state analysis. TESSA integrates eight modules and each module analysis a procedure. The modules are the following: import *unv format, to build symptoms matrix, SVD procedure, OPTIMUM procedure, Input/Output relationship function, optimization, Neuronal Network and MAC procedure.

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