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Recognition of thermal images of synchronous motor with the application of 2-D discrete wavelet transform and GSDM

***Abstract**. Technological progress and decreasing prices of thermovision cameras make profitable their application to monitoring and assessing a technical state of machines. This article discusses the recognition method of imminent failure conditions of synchronous motor. The proposed approach is based on a study of thermal images of the rotor. Extraction of relevant diagnostic information coded in thermal images is important for diagnosing of machine. It can be performed with the use of selected methods of image processing, analysis and recognition. Studies were carried out for three conditions of motor with the application of two-dimensional wavelet analysis and Genetic Sparse Distributed Memory. The experiments show that the method can be useful for protection of synchronous motor. Moreover, this method can be used to diagnose machines in steelworks and industrial plants.*

***Streszczenie.** Postęp technologiczny wraz ze spadkiem kosztów kamer termowizyjnych sprawiają, że ich zastosowanie do monitorowania i oceny stanu technicznego maszyn jest opłacalne. W artykule omówiono metodę rozpoznawania stanów przedawaryjnych silnika synchronicznego. Proponowane podejście jest oparte na badaniu obrazów cieplnych wirnika. Ekstrakcja istotnej informacji diagnostycznej zakodowanej w obrazie cieplnym jest ważna dla diagnozowania maszyny. Może być ona wykonana z użyciem wybranych metod obróbki, analizy i rozpoznawania obrazów. Przeprowadzono badania dla trzech stanów silnika z zastosowaniem dwuwymiarowej analizy falkowej i Genetycznie Rozrzedzonej Pamięci Rozproszonej. Eksperymenty pokazują, że metoda może być przydatna do ochrony silników synchronicznych. Ponadto metoda może być stosowana do diagnozowania maszyn w hutach i zakładach przemysłowych (**Rozpoznawanie obrazów cieplnych silnika synchronicznego z zastosowaniem dwuwymiarowej dyskretnej transformacji falkowej i GSDM**).*

Keywords: Diagnostics, Wavelet analysis, Thermal images, Synchronous motor, Genetic Sparse Distributed Memory
Słowa kluczowe: Diagnostyka, Analiza falkowa, Obrazy cieplne, Silnik synchroniczny, Genetycznie Rozrzedzona Pamięć Rozproszona

Introduction

The discrete wavelet transform (DWT) is a useful tool for image processing, especially in multi-resolution representation. I. Daubechies introduced the concept of compactly supported wavelets and the theory of frames. S. Mallat introduced a multi-resolution signal decomposition of the DWT and provided the foundation for its implementation [1]. Wavelets can be used in image processing. Image processing is very important for thermography, which is a non-invasive, safe and modern technique of thermal visualisation. Every object on the earth emits thermal radiation. Thermovision camera is able to detect this type of radiation, even small changes in temperature can be accurately monitored. Afterwards recorded data are computer-processed and shown in the form of temperature maps that provide for a detailed analysis of the temperature field. Thermovision camera measures the thermal radiation emitted from an object. This camera shows an image of these temperature differences. The darker areas are those that radiate less thermal radiation. Radiation is emitted from the surroundings and is reflected by the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere. These effects can be compensated by thermovision camera. The thermographic techniques have found many applications, for example in industry, police, building, energetics, veterinary medicine. Moreover, there is possibility to use 3D visualization for thermography [2], [3].

In animals or humans, changes in vascular circulation result in an increase or decrease in their tissue temperature. This process is used to evaluate the situation in that area. For example, heat generated by inflammation is transmitted to the overlying skin via increased capillary blood flow, and is dissipated as thermal energy. Similarly thermovision camera and special system can measure thermal radiation. Advantage of this technique is that it does not need physical contact with the object. It allows for measurement of temperature distribution on its surface. There are also some limitations for thermography. Thermal images should be taken for the objects which are free of dirt and moisture. The investigated object should be out of direct sunlight and wind currents.

Many methods for fault diagnosis were described in the literature. Most of them are based on a study of electric currents [4-9]. Some studies have been conducted using infrared thermography [10-11]. Infrared thermography is used in diagnostics of electrical machines [11]. These electrical machines are constructed of steel elements, which conduct electricity. Material properties of steel elements were investigated in the literature [12-15].

The article describes the method of diagnosis of a synchronous motor. This approach is based on recognition of thermal images of the rotor.

Recognition process of thermal image of synchronous motor

Recognition process of thermal images consists of two phases. First of them is pattern creation process (Fig. 1). Second phase is identification process. These phases include methods used in image processing. At the beginning of pattern creation process movie is recorded in the computer memory. After that movie is converted into thermal images. Next 2-D wavelet analysis is used. In next step sum of pixels values is calculated. Each sample which is used in pattern creation process gives us one sum of pixels values. This sum of pixels creates feature vector. Next all sums are used to writing (training) of GSDM (Genetic Sparse Distributed Memory). Steps of identification process are similar as for pattern creation process.

Significant change occurs in the classification. In this step GSDM is used to identify (read) feature vector.

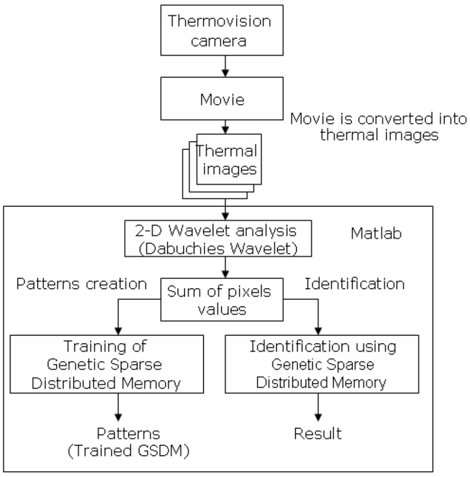

Fig.1. Recognition process of thermal image of synchronous motor with the use of 2-D Wavelet analysis (Dabuchies Wavelet) and Genetic Sparse Distributed Memory

Video recording

All objects emit a certain amount of thermal radiation as a function of their temperatures. Generally the higher an object's temperature is, the higher is its emission. Thermovision camera can measure this radiation. It can also work in darkness because it does not need an external light. Thermovision camera used in experiments was installed 0.25m above rotor of synchronous motor. It recorded images at a resolution of 640 × 480 pixels in grayscale with a resolution of 8 bits (values 0-255). Next recorded video was transferred to a PC and stored in permanent memory in AVI (Audio Video Interleave) format.

Acquisition of thermal images

Every second of movie contains 24 monochrome thermal images. To extract a single thermal image from the movie, a program in a Perl scripting language was implemented. This program uses *mplayer* library. As a result, monochrome thermal images are obtained. Each of them has resolution of 640 × 480 pixels. In identification process, thermal image is acquired directly from camera sensor, in order to achieve real-time processing.

Two-dimensional wavelet analysis

Proposed approach of 2-D DWT is based on separable orthogonal mother wavelets. At every iteration of the DWT, the lines of the input image (obtained at the end of the previous iteration) are low-pass filtered with a filter having the impulse response m_0 and high-pass filtered with the filter m_1. Next the lines of the two images obtained at the output of the two filters are decimated with a factor of 2. After that, the columns of the two images obtained are low-pass filtered with m_0 and high-pass filtered with m_1. The columns of those four images are also decimated with a factor of 2. Four new sub-images (representing the result of the current iteration) are generated. The first one, obtained after two low-pass filterings, is named approximation sub-image (or LL image). The others three are named detail sub-images: LH, HL and HH. The LL image represents the input for the next iteration. In the following, the coefficients of the DWT will be noted with ${}_{x}D_{m}^{k}$ where *x* represents the image for which DWT is computed, *m* represents the iteration index (the resolution level) and *k* = 1, for the HH image, *k* = 2, for the HL image, *k* = 3, for the LH image and *k* = 4, for the LL image.

More about 2D Discrete Wavelet Transform is presented in literature [16], [17], [18]. Monochrome thermal images of rotor of synchronous motor were presented in figures 2-4.

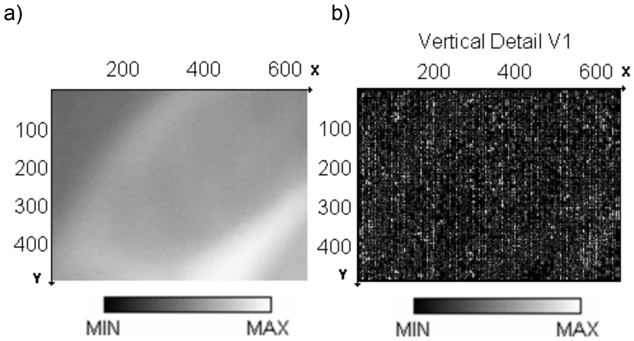

Fig. 2. a) Monochrome thermal image of rotor of faultless synchronous motor, b) Monochrome thermal image of rotor of faultless synchronous motor after 2-D wavelet decomposition using db2 (Dabuchies wavelet)

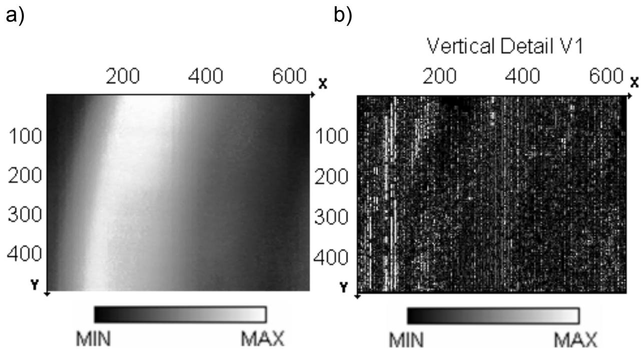

Fig. 3. a) Monochrome thermal image of rotor of synchronous motor with faulty ring of squirrel-cage, b) Monochrome thermal image of rotor of synchronous motor with faulty ring of squirrel-cage after 2-D wavelet decomposition using db2 (Dabuchies wavelet)

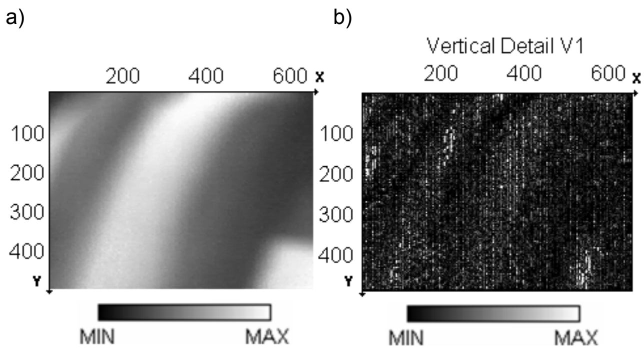

Fig. 4. a) Monochrome thermal image of rotor of synchronous motor with one faulty rotor bar, b) Monochrome thermal image of rotor of synchronous motor with one faulty rotor bar after 2-D wavelet decomposition using db2 (Dabuchies wavelet)

Selection of features

Thermal image contains 640 × 480 pixels. Each pixel has a value from range 0-5 (0 – black pixel, 5 – white pixel). Feature of thermal image is the sum of all pixels values. Therefore, the feature vector will contain one feature (Fig. 5). This feature vector will be used in classification.

Genetic Sparse Distributed Memory

Genetic Algorithms are very useful in a practical problems of pattern recognition. They are usually used whenever there is a large search space, and no efficient algorithm, for trimming it. Sparse Distributed Memory (SDM) is an associative memory model invented by Kanerva. SDM has a vast binary space of possible addresses in the semantic space. Moreover, when we consider any practical application only a very small portion of this space can actually exist. This makes SDM a perfect match for genetic algorithms search. Having so many possibilities for assignment of actual locations to addresses motivates the use of genetic algorithms. Genetic algorithms proved to be much more superior to the random initialization method that is widely used [19]. Fan and Wang proposed GSDM in 1997. They used SDM and initialized the locations based upon the data set. This can serve to reduce the memory requirement. GSDM uses the mutation and crossover genetic operators to allow for change or noise in the assigned addresses. Reading operation of GSDM is the same as that of SDM. The main difference is that an effective writing operation guided by genetic algorithms is added. GSDM has a finite number of storage locations N with empty addresses and contents. The address **p** of a training pair (**p**, **d**) is sent into memory to get selected storage locations by calculating the Hamming distance. More about GSDM algorithm is described in literature [19], [20], [21], [22].

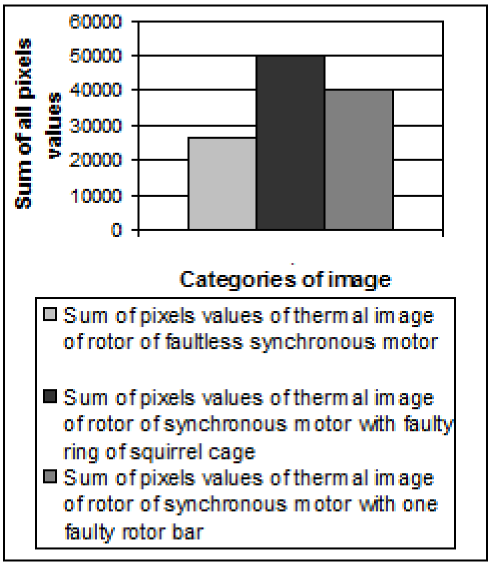

Fig. 5. Sums of pixels values for three categories of thermal image

Results of thermal image recognition of synchronous motor

Investigations were carried out for two different failures of synchronous motor. They are denoted as follows: synchronous motor with faulty (broken) ring of squirrel-cage, synchronous motor with one faulty (broken) rotor bar (Fig. 6). These failures did not cause the destruction of the machine.

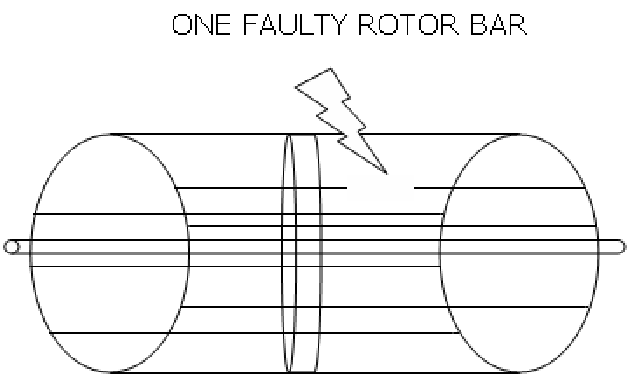

Fig. 6. Synchronous motor with one faulty rotor bar

Synchronous motor had following supply conditions: faultless synchronous motor, $U = 300$ V, $I = 21.5$ A, synchronous motor with faulty ring of squirrel-cage, $U = 300$ V, $I = 77$ A, synchronous motor with one faulty rotor bar, $U = 300$ V, $I = 21$ A, where: U – supply voltage, I – current of one motor phase.

Thermovision camera recorded three movies of one motor operating in laboratory conditions. These movies contained thermal images of faultless synchronous motor, synchronous motor with faulty ring of squirrel-cage, synchronous motor with one faulty rotor bar.

The process of pattern creation was carried out for 30 monochrome thermal images. Identification process was carried out for 120 monochrome thermal images. Efficiency of thermal image recognition is defined as:

$$T = \frac{K_1}{K}, \tag{3}$$

where: T – thermal image recognition efficiency, K_1 – number of correctly identified samples, K – number of all samples.

Efficiency of thermal image recognition of synchronous motor depending on Hamming distance was presented in Fig. 7. The best efficiency of thermal image recognition was obtained for Hamming distance equal 22. Efficiency of thermal image recognition of faultless synchronous motor was 100%. Efficiency of thermal image recognition of synchronous motor with faulty ring of squirrel-cage was 100%. Efficiency of thermal image recognition of synchronous motor with one faulty rotor bar was 75%.

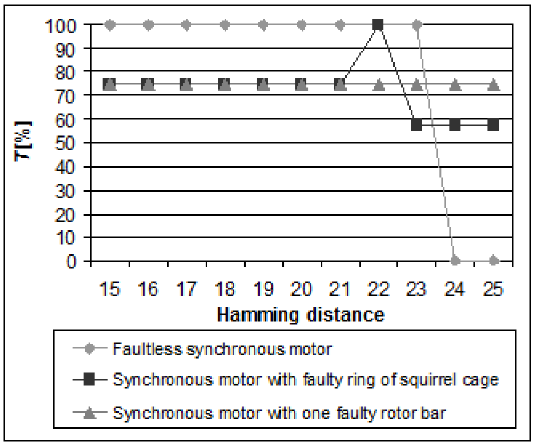

Fig. 7. Efficiency of thermal image recognition of synchronous motor depending on Hamming distance

Conclusions

Technological progress and decreasing prices of thermovision cameras make their application to monitoring and assessing a technical state of machines profitable. Thermography can generate important information where the possibilities of conventional diagnostic techniques have been exhausted. Extraction of relevant diagnostic information coded in thermal images is important for diagnosing of synchronous motors. It can be performed with the use of selected methods of image processing, analysis and recognition. Researches involving the use of image processing methods to thermovision diagnostics has been carried out for synchronous motor. Results of thermal image recognition were good for 2D wavelet analysis and GSDM. Further researches should be continued to examine other failures of electrical machines and metallurgical equipment.

Moreover applying 2-D Wavelet analysis and GSDM for diagnostics can be useful for machines in steelworks and industrial plants.

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