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Recognition of Color Thermograms of Synchronous Motor with the Application of Image Cross-Section and Linear Perceptron Classifier

***Abstract**. The article presents the diagnostic method for fault recognition of the synchronous motor. The decision on the condition of the motor is based on an analysis of thermal images. Thermal monitoring can quickly, accurately and safely locate problems, indicated by thermal anomalies. Studies were carried out for four conditions of motor with the application of image cross-section and Linear perceptron classifier. Pattern creation process used 60 color thermal images. Identification process was carried out for 200 color thermal images. Analysis of the effectiveness of the proposed recognition algorithms shows that the method can be used for diagnosis of industrial motors.*

***Streszczenie.** Artykuł ten przedstawia metodę diagnostyczną do rozpoznawania uszkodzenia silnika synchronicznego. Decyzja o stanie silnika jest podejmowana na podstawie analizy zdjęć termowizyjnych. Monitorowanie podczerwieni może szybko, dokładnie i bezpiecznie zlokalizować problemy, wskazane przez anomalie termiczne. Przeprowadzono badania dla czterech stanów silnika z zastosowaniem przekroju obrazu i klasyfikatora liniowego perceptronu. Proces tworzenia wzorców do rozpoznawania został przeprowadzony dla 60 kolorowych zdjęć termowizyjnych. Proces identyfikacji wykorzystywał 200 kolorowych zdjęć termowizyjnych. Analiza skuteczności rozpoznawania proponowanych algorytmów pokazuje, że metoda może być stosowana do diagnozowania silników przemysłowych. (**Rozpoznawanie kolorowych termogramów silnika synchronicznego z zastosowaniem przekroju obrazu i klasyfikatora liniowego perceptronu**)*

Keywords: Diagnostics, Recognition, Thermal images, Synchronous motor, Linear perceptron classifier.
Słowa kluczowe: Diagnostyka, Rozpoznawanie, Zdjęcia termowizyjne, Silnik synchroniczny, Klasyfikator liniowego perceptronu.

Introduction

Infrared sensors detect electromagnetic radiation emitted from an object. It should be noticed that all objects with a temperature above absolute zero emit radiation, even cold substances like liquid nitrogen (77 K). The higher object's temperature, the greater energy is released. Infrared light is not visible because its wavelength is too long to be detected by the human eye. For this purpose, infrared cameras are needed. These cameras render images of infrared radiation that provides non-contact temperature measurement capabilities. They are also cost-effective diagnostic tools in many diverse applications because many objects gets hot before failure. Hot elements can cause many electrical problems. Thermography can be applied to solve some of such cases. Part of infrared radiation from objects is focused by special optics onto an thermal sensor. Next the measured values are passed to sensor electronics for image processing. After that the signal processing circuitry converts the thermal detector data into a thermogram that can be viewed on a video monitor. Thermography let us see in the dark and enhance our ability to detect objects at critical moments when they are heating up due to some malfunction. Warmer parts of the engine stand out from other objects [1].

Faulty elements of the electric motors have the highest temperature. Typically, these elements are made of steel. Properties of steel alloys were examined in the literature [2], [3], [4]. Fault diagnostics is important for electrical industry [5], [6]. The article provides the diagnostic method for fault recognition of the synchronous motor. This method uses infrared pictures and data processing algorithms.

Process of recognition of infrared images of synchronous motor

The process of recognition of infrared images contains two phases. First of them is pattern creation process (Fig. 1). Second is identification process. These phases include algorithms used in image processing. At the beginning of pattern creation process movie is recorded on the memory in computer. After that movie is converted into infrared images. Next image cross-section is used. In next step Linear perceptron classifier is applied. Each sample which is used in pattern creation process gives us pixel values (red, green, blue). Next these pixel values create feature vector. Each feature vector belongs to the class of patterns. Next perceptron is trained depending on input data. After that identification process is executed. Phases of identification process are the same as for pattern creation process. Significant change occurs in the classification. In this step linear perceptron classifier identifies infrared pictures.

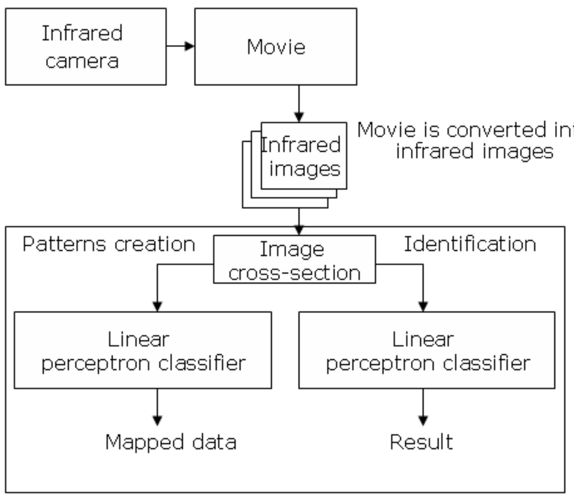

Fig.1. Process of recognition of infrared image of synchronous motor with the use of image cross-section and Linear perceptron classifier

Video recording and acquisition of thermal images

A thermal camera is a non-contact device that detects infrared energy and converts it into an electronic signal. Next this signal is processed to produce a thermogram on a video monitor [1]. Thermal camera used in investigations was installed 0.25m from rotor of synchronous motor. It recorded images at a resolution of 640 × 480 pixels in 24-bit coded color. Color thermal images were stored in AVI (Audio Video Interleave) format on an external personal computer. Every second of movie contained 24 frames (color infrared images). To extract a single frame from the movie, a program in a Perl scripting language was implemented. For proper operation of the script, the mplayer library was needed. Next each frame was saved in JPEG format.

Image cross-section

Image cross-section is the intersection of a picture with a line. Knowing it, we can cut an image into slices and we can obtain many parallel image cross-sections. These cross sections contain some pixels. As we mentioned each pixel uses 24-bit. It allows 8 bits per component (Red, Green, Blue). Next we can use 0-255 values to each component. We have 3 values (Red 0-255, Green 0-255, Blue 0-255), when one pixel is considered. During the researches the number of pixels will be selected. Moreover these pixel values will create feature vectors.

Linear perceptron classifier

Engineers have described a lot of data analysis algorithms [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. The perceptron is a type of artificial neural network (a linear classifier). The weighted sum of the inputs and the bias are first summed and then processed by a step function to yield the output. In the training process, the weights (inputs and bias) are adjusted so that input data is mapped to one of the two classes. The perceptron can be trained to solve any two-class classification problem where the classes are *linearly separable.* In two-dimensional problems (where x is a two-component row vector), the classes may be separated by a straight line, and in higher-dimensional problems it means that the classes are separable by a hyperplane. The perceptron maps its input x to an output value [17], [18]. The output $f(x)$ can take values of 0 or 1:

(1) $$f(x)=\begin{cases}1 & if \quad w\bullet x+b>0 \\ 0 & if \quad w\bullet x+b\le 0\end{cases},$$

where: w is a vector of real-valued weights, $w\bullet x$ is the dot product, and b is a constant. The value of $f(x)$ is used to classify new input x on the basis of mapped data.

Results of thermal image recognition of synchronous motor

Researches were conducted for three different failures of synchronous motor. They are defined as follows: synchronous motor with faulty ring of squirrel cage, synchronous motor with one faulty rotor bar (Fig. 3), synchronous motor with two faulty rotor bars. These failures did not cause the destruction of the machine. Synchronous motor had following operation parameters: 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, synchronous motor with two faulty rotor bars, U = 300 V, I = 20 A,
where U – supply voltage, I – current of one motor phase.

Thermal camera recorded four movies. These movies contained thermograms of faultless synchronous motor and synchronous motors with failure (Figs. 2a, 2b, 3a, 3b).

a) b)

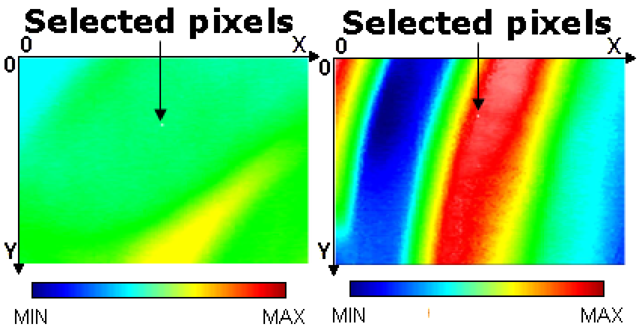

Fig.2. a) Color thermal image of rotor of faultless synchronous motor b) Color thermal image of rotor of synchronous motor with faulty ring of squirrel cage

a) b)

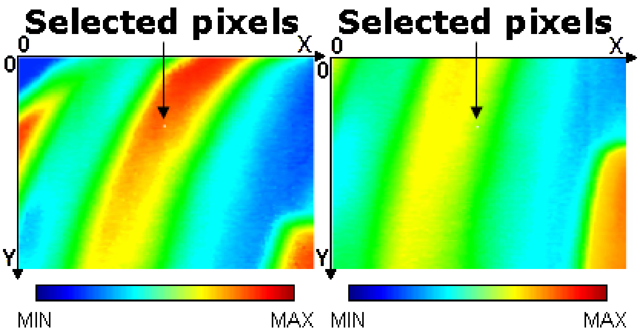

Fig.3. a) Color thermal image of rotor of synchronous motor with one faulty rotor bar b) Color thermal image of rotor of synchronous motor with two faulty rotor bars

Image cross-section was the line between points X1=315, Y1=150, X2=320, Y2=150. It contained 5 pixels (15 RGB values). Next these pixels were used by the linear perceptron classifier (Figs. 4a, 4b, 5a, 5b).

a) b)

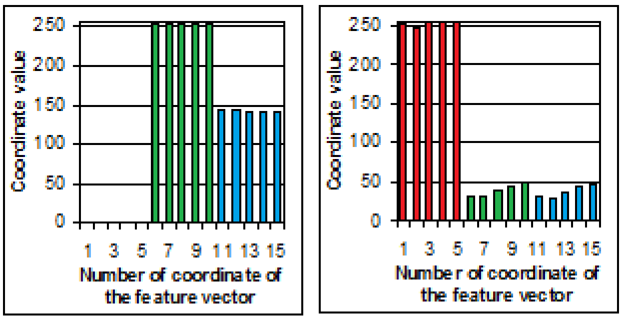

Fig.4. a) Coordinate values of thermal image of rotor of faultless synchronous motor b) Coordinate values of thermal image of rotor of synchronous motor with faulty ring of squirrel cage

a) b)

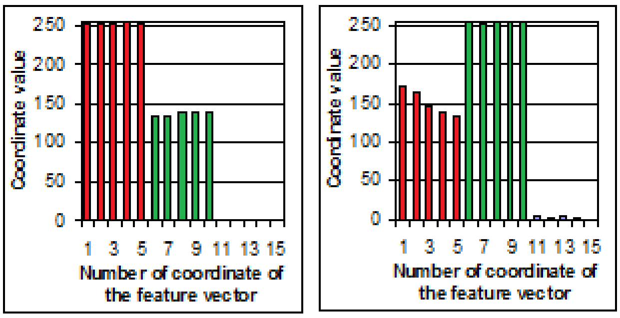

Fig.5. a) Coordinate values of thermal image of rotor of synchronous motor with one faulty rotor bar b) Coordinate values of thermal image of rotor of synchronous motor with two faulty rotor bars

The process of pattern creation used 60 color thermal images. Identification process was carried out for 200 color thermal images. Efficiency of thermal image recognition is defined as:

$$T = \frac{K_1}{K} \tag{2}$$

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

Studies have been conducted in a room without any interferences and other failures. 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 100%. Efficiency of thermal image recognition of synchronous motor with two faulty rotor bars was 100%.

Conclusions

Infrared thermography provides a tool for two-dimensional non-intrusive temperature assessment of synchronous motor. Infrared energy sensed by a detector can be measured, enabling to not only monitoring thermal performance, but also identification and evaluation of the heat problems. It should be noticed that infrared software delivers very cost-effective solutions of thermal analysis. Thermal monitoring can quickly, accurately and safely locate problems, indicated by thermal anomalies. The aim of this method is not to be a substitute for other techniques but to enhance them. Algorithms of data processing were investigated for synchronous motor. Results of color thermogram recognition were good for image cross-section and linear perceptron classifier. Efficiency of synchronous motor diagnostics was 100%. Further researches should be continued to examine other failures of electrical motors.

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