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Thermal imaging and frequency analysis

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Abstract

IR based thermology and thermal images can be used in many industrial areas of predictive maintenance. In most cases these applications concentrate on taking single samples from interesting surface temperatures which means loss of possibility for long time data recording. The use of a simple image averaging method creates image data without periodic behavior of the object in interest.

There is a lot of interest to be able to measure wide area temperature profiles from a fast moving surface (e.g. in paper machine) with track velocities like 10-20 m/s. Normal low speed line scanners typically give scanning speed of 50 Hz which in this case corresponds to 20 m/s / 50 Hz = 40 cm resolution, and thus obtained resolution is not high enough. To have more accurate vision to the surface, IR camera line scanning with line scanning frequency of 8000 Hz was proposed to be the solution which would provide a resolution of 20 m/s / 8000 Hz = 0.25 cm between surface points.

It is well-known fact that all not desired frequencies in a paper transfer system disturb the uniform paper drying process, which in some cases is the basic reason for low quality coating or even broken paper line. The possibility to detect these drying problems with thermal image frequency analysis will give a new way to control the paper drying process, and this method can be utilized in many other similar industrial processes, too. With modern IR temperature scanning equipment it is possible to have information about the temperature distribution along moving surface and then by using the well established frequency data analysis, the error estimations can be calculated. The careful analysis of this new method is given in the presentation.

1. Introduction

The IR camera used in this experiment was Inframetrics Model 740 IR Imaging Radiometer. The spatial resolution of this camera is 194 elements horizontally (50% SFR) and 240 vertically. The scanning rate is 7812 Hz horizontal and 50 Hz vertical. By using this kind of camera it is possible to detect frequencies up to 25 Hz. The fast line scan mode can be used to get more accurate vision from the inspected surface.

When set to line scan mode, the vertical scan stops at the center position, and scans of the single line occur at approximately 125 µs intervals. This means a frequency of 8000 Hz which makes theoretically possible to detect frequencies up to 4000 Hz. In practice the reasonable frequency limit is about 250 Hz achieved in laboratory tests which originates from PAL video image aspects and radiometer IR detectors dynamic properties. Temperature line scans can be recorded with normal VCR equipment for further analysis [1].

2. Theoretical aspects

The idea in Fourier transform is to convert data from time domain to frequency domain. All Fourier transforms can be reduced to the DDFT (discrete-to-discrete Fourier transform). Numerical computation of Fourier transform requires a finite list of numbers. This means that infinite signals need to be windowed and continuous-time signals sampled. When given a sampled discrete-time signal x and a finite time axis {0, T , ... , (N-1)T}, the DDFT is defined as

$$\hat{x}(kF) = T\sum_{n=0}^{N-1} x(nT)e^{-jkn/N}, \quad k \in \{0,1,\dots N-1\} \qquad (1)$$

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The direct computation of DDFT is very time-consuming, but there exists a very efficient algorithm for computing the DDFT, called Fast Fourier Transform (FFT). The most widely used method for computing FFT is Cooley-Turkey radix 2 FFT. The principle of this method, like all other FFT-methods, is to convert a single numerically intensive computation to repeated easy computations.

The goal of this experiment is to develop a system that detects frequencies from the studied surface. This is done by using fast line scan mode to get IR data accurate enough and then using FFT for transferring data from time domain to frequency domain. The final step is to develop recognition algorithms for detecting of frequencies. The implementation phase was to create image processing software for data capture and analysis with fulfilled speed properties for continuous spectral logging.

3. Experiments

In an earlier paper, a preliminary approach was made by using stroboscope light tests which gave encouraging results for further development [5]. In this phase it proved out, that it was possible to adjust normal video image synchronizing with image sampling rate up to highest Nyquist frequency of 500 Hz meaning frequency detecting of 250 Hz signal. Finally test material for field evaluation was collected from the local paper industry with prior knowledge about existing frequency disturbance causing occasional defects to the final product.

4. Analysis

Earlier, our algorithms were tested successfully with stroboscope lamp, CCD-camera, thermal camera and thermal vibrator [5]. Frequency analysis was done by using several sampling frequencies from 50 Hz to 500 Hz. Low sample frequency gives a more accurate frequency domain chart for lower frequencies and high sample frequency gives a wide-ranging chart. Both types were needed because of the need to find out - if possible - the existing frequency disturbance accurately enough and to check out that it is also possible to find it by using high sample frequencies. This was, at the same time, the method to test our system capabilities.

Figure 1 shows the frequency domain analysis of a rolling paper surface, sample frequency is 100 Hz. By using frequency analysis it is possible to see at least one frequency, that has diverging magnitude, about 43 Hz. It is also possible to see a minor alteration at the frequency of 37 Hz. This data was collected from the dry end of the paper machine.

Figure 2 is a frequency domain chart for the same spot reported in *figure 1*, but the sample frequency is 500 Hz. Again it is possible to point out the frequency of 43 Hz. Data was collected from PAL video signal, which means with a disturbance at 50 Hz and its harmonic frequencies. This can be seen in the chart : 50, 100, 150 and 200 Hz. This wide-range chart describes the distribution of frequencies. Thermal vibration is concentrated on frequencies lower than 100 Hz.

Diverging magnitudes can be found also in the beginning of the paper machine (wet end). *Figure 3* shows that it is still possible to detect the magnitude of 43 Hz, but it is not decisive any more. Now the magnitude of 37 Hz is more dominatsing. When looking at the magnitude, it can be seen that the vibration is much weaker at the beginning of the paper machine than at its end.

5. Conclusions

The result of this paper shows how IR measured temperature from a fast, steadily moving surface can be used to detect frequencies in drying and coating processes. In the area of paper industry there will be a challenge to find out the significance of these frequencies and the usability of this easily performed measurement method in preventive maintenance. At the same time new applications will be sought from various industrial areas where frequencies are important indicators of process quality.

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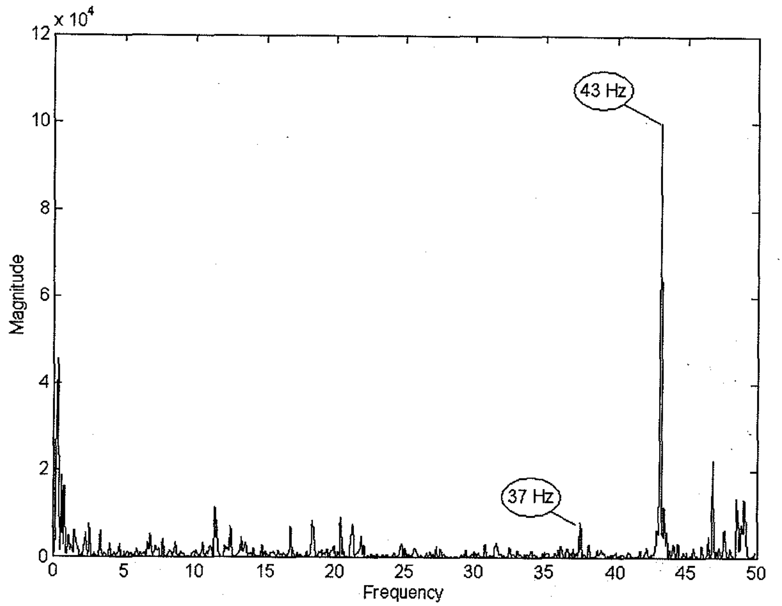

Fig. 1. Frequency analysis, dry end of paper machine

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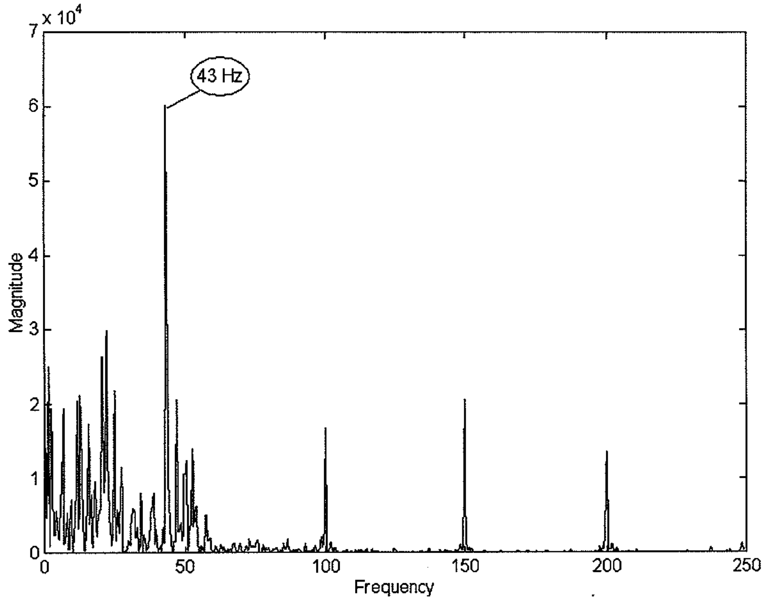

Fig. 2. Frequency analysis, dry end of paper machine, sample freq. 500 Hz

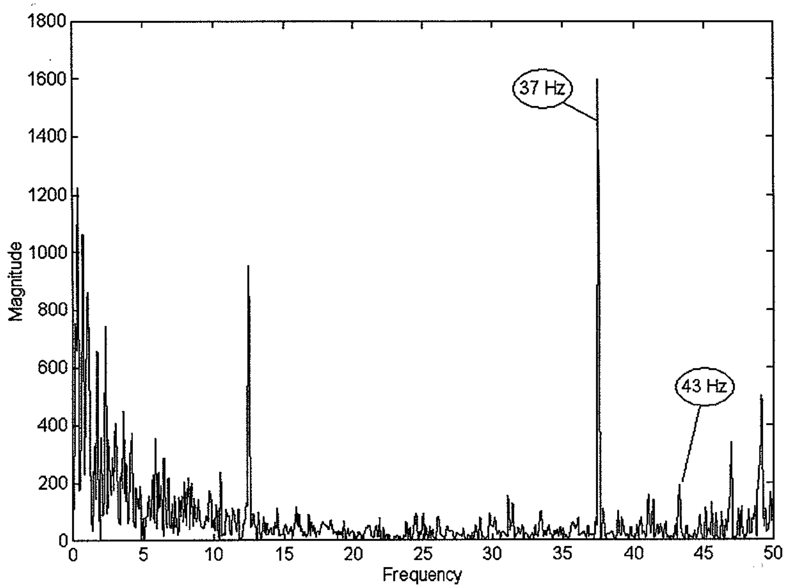

Fig. 3. Frequency analysis, wet end of paper machine