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A FAST ON LINE QUALITY CONTROL OF REFRIGERATORS BASED ON THERMAL IMAGE DETECTION AND POWER CONSUMPTION

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ABSTRACT

At the end of the production process of a refrigerator, it is necessary to verify if the refrigerator works correctly by detecting possible manufacturing and assembling defects.

Up to now, on-line quality control is based mainly on the measurement of temperatures taken inside a refrigerator that works for 30-90 minutes. This leads to a very high consumption of energy to cool the refrigerators and of space to store the refrigerators during the testing period.

The aim of this paper is to design an automatic on line system, based on thermal imaging of the condenser and the compressor, for detection of faulty refrigerators. With the thermal image approach it is possible to reduce the on line test time below 8 minutes, assuring even a higher level of accuracy in the diagnosis of defected refrigerator. This is an effective and non contact method that provides a quick thermal evaluation feasible for a 100 % on line quality control of refrigerator. Moreover using appropriate Signal Process Techniques, the collected data are analyzed and the classification, i.e. refrigerator good and faulty, is automatically performed without any operator.

INTRODUCTION

The quality control in industrial processes is more and more becoming a key part of the production process within all the household appliance domain. The classical statistical methods based on a random selection of samples at the end of the production process are being abandoned in favour of new automatized systems that are able to monitor every single sample, assuring in this way the control of 100% of the production. Another factor to take into account is the time, in fact the existing methods are time consuming. The last control test on the refrigerator completely assembled can enlarge the process up to 90 minutes, which also implies an important increment of energy consumption and space occupied.

The quality controls consisting in measuring the internal temperature of the refrigerator after a long period of functioning using temperature probes, can be substituted with a shorter test using a non contact measurement. The method here presented is based on the use of an Infrared Thermal camera that measures the emission of thermal, or infrared, radiation that the naked eye cannot detect. In fact, for given surface emittance, hotter objects emit more infrared energy, and the camera measures these differences as gray levels and displays them in varying colors through a color palette. Calibration allows the colors to be converted back to the temperature values available for a further analysis.

INSTRUMENTS AND METHODS

The testing set-up is mainly composed of:

- An Infrared Thermal camera
- A PC
- A software for the analysis and classification of the acquired images
- A temperature probe
- A power consumption measurement equipment

The infrared thermal camera output is connected to a PC that through a 16 bit frame grabber and a special software converts the color image in temperature values. In the case of the refrigerator, the attention is focused on the outside rear part of the refrigerator, in particular on the inlet and outlet tubes of the condenser and on the compressor. The thermal camera is located at a distance of 1.5 meter from the rear part of the refrigerator. An important parameter to take into account in the analysis performed with the infrared thermal camera is the emissivity. This parameter is a measure of how much radiation is emitted from the object compared to that if it was a perfect blackbody. For the condenser and the compressor surfaces, an emissivity equals to 0.94 has been used. The layout of the experimental set-up is represented in figure 1.

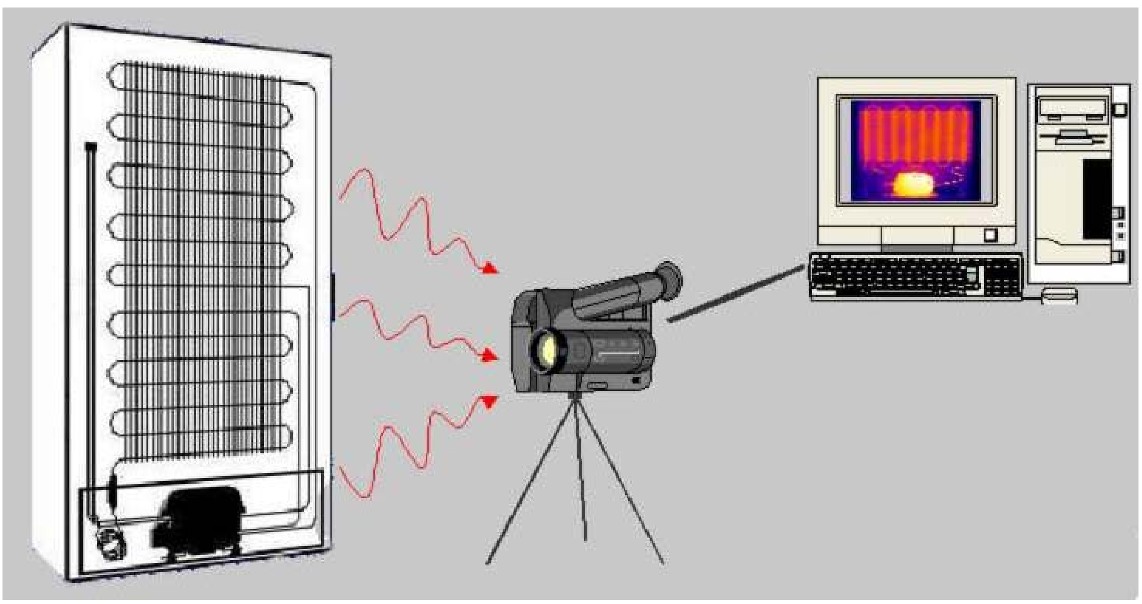


Fig. 1 Experimental set-up.

An example of the image taken from the rear part of the refrigerator is represented in Fig. 2.

It is also important to consider the influence of the ambient temperature (T_A) on the measured object temperatures not only because it may offset the surface temperatures. The ambient temperature is measured using a temperature probe positioned in the place where the refrigerator is working. In fact, the functionality of the refrigerator that operates in an environment at 15° Celsius is different from one that operates at 35° Celsius and therefore the acquired temperatures have to be adjusted based on T_A during the classification of the refrigerator as good or faulty.

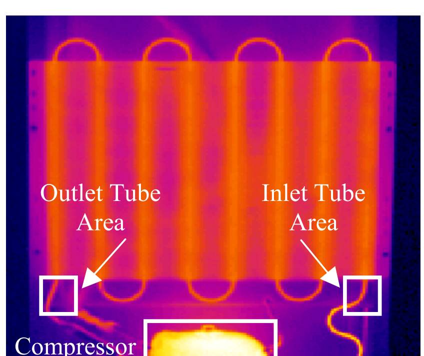


Fig. 2 Recorded Thermal Image of the refrigerator condenser and compressor.

In order to have a consistent measurement, the image acquisition has to be performed after a prefixed time elapsed from the powering of the refrigerator. In particular this test is performed after 10 - 12 minutes the refrigerator has been powered on during transient operation; this means that the inlet and outlet temperatures of the condenser and the compressor temperature are not stabilized and a small delay in the image detection could determine a variation in the read temperatures. In order to avoid this possible mistake, the circuit where the refrigerator is located before the testing area has to be under the control of a PLC that will move the refrigerator on a prefixed time base.

Installing the measurement set-up, it is also important to avoid the following aspects that could affect the measurement: environmental light reflections, directional air flow, and IR reflections from surrounding heat sources onto the object.

Once the refrigerator arrives in the testing station, the thermal image is acquired and in few seconds processed. In particular the following values are computed:

- Maximum temperature of the area located in correspondence of the condenser inlet tube (T_{IN})
- Maximum temperature of the area located in correspondence of the condenser outlet tube (T_{OUT})
- Difference between the inlet and outlet maximum temperature (Delta T)
- Mean temperature of the area located in correspondence of the compressor (T_C)

The positioning of these areas is based on the type of refrigerator to analyze and, depending on the case, it is possible to include additional areas in the rear part of the refrigerator. In the case of refrigerators with two compressors, the number of areas is doubled. Once the temperature values have been obtained, the T_A effect has to be compensated. This means that the relationships between T_A and respectively T_{IN}, T_{OUT} and T_C have to be computed in order to have the measured temperatures referenced at 20°C. The relationship has been obtained through an interpolation of the measured temperatures with the ambient temperature ranging between 15°C and 35°C.

Another important quantity to be measured in order to have a more accurate classification of the refrigerator is the compressor power consumption (W) that it is measured contemporaneously of the image detection.

All the aforementioned features, i.e. T_{IN}, T_{OUT}, Delta T, T_C and W, are the input characteristics of the Neural Network (NN) that automatically will be able to decide the state of the refrigerator [Cammarata S.]. The NN utilized by the system is the Multi Layer Perceptron

(MLP). The multilayer perceptron is a network model in which the neurons are configured in layers, whereby the neurons of a layer are generally fully linked with the neurons of the following layer. This network is able to process the input values and learns in supervised mode, employing the back-propagation algorithm. The performance capability of the network is strongly dependent on the number of hidden layers, as these are responsible for the network's representation capabilities. In this application a 3-layer network has been used. It should be pointed out that the NN required a training process that has to be performed as first step at the starting of the production. Usually it is requested to train a network for each type of refrigerator that has very different behavior and the training consists in measuring good and faulty refrigerators and in saving the representative parameters. Once the NN has been trained the system is ready to analyze and classify the produced refrigerators.

RESULTS AND DISCUSSION

The study has been carried out on a certain number of different refrigerators, some with one compressor, others with two compressors. Some refrigerators do not work properly for different defects, such as: over charging or under charging of the refrigerant liquid, collapsed tubes, not correct flow in the evaporator.

First of all it has been verified that the temperature values measured after 10 minutes (depends on the models) from the lightning of the refrigerator are significant and consistent for the purpose of defect classification. In figure 3 the trend of the T_{IN} over a period of 17 minutes is reported. As it is possible to see, the start-up of a refrigerator is characterized by a sharp increase in temperature, but after this there is a period in which, even if the refrigerator has not yet reached the steady state, the temperature time derivative decreases. Based on this evidence, taking the temperature values after eleven minutes, it has been possible to qualify the refrigerators.

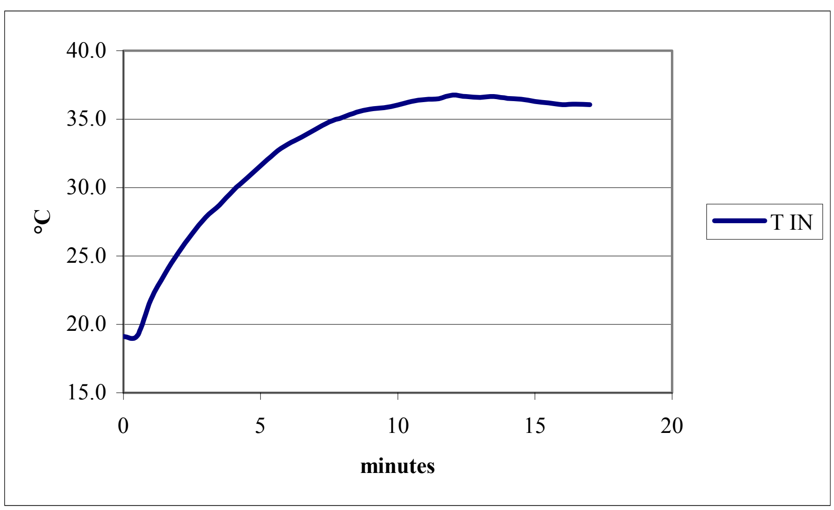
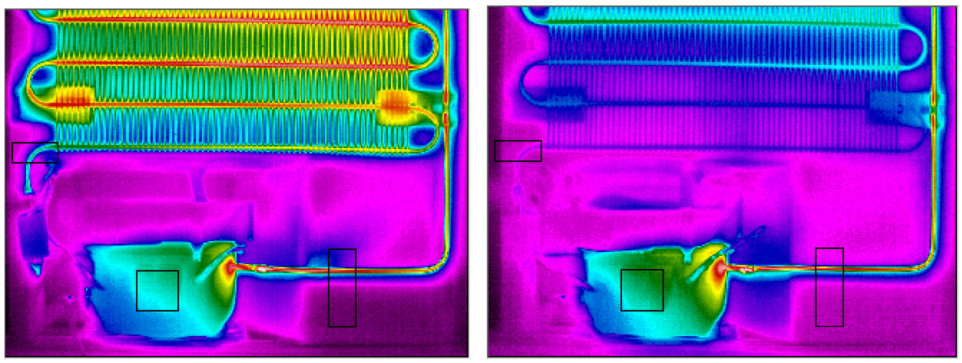


Fig. 3 Trend of the T_{IN} measured from the starting of the refrigerator, up to 17 minutes.

In figure 4 an example of infrared thermal images taken from a good refrigerator and a faulty one is reported. The faulty refrigerator illustrated is a refrigerator with a refrigerant liquid charge 20% under the nominal value. In terms of temperatures, this refrigerator shows a lower value of the outlet temperature in respect to the value of good refrigerator. In the graph reported in figure 5 the difference between the measured T_{IN} and Delta T of good and faulty refrigerators is illustrated. It is noticeable that between the two classes there is a good separation.



(a) (b)

Fig. 4 Examples of good (a) and faulty (b)refrigerators (under charged)

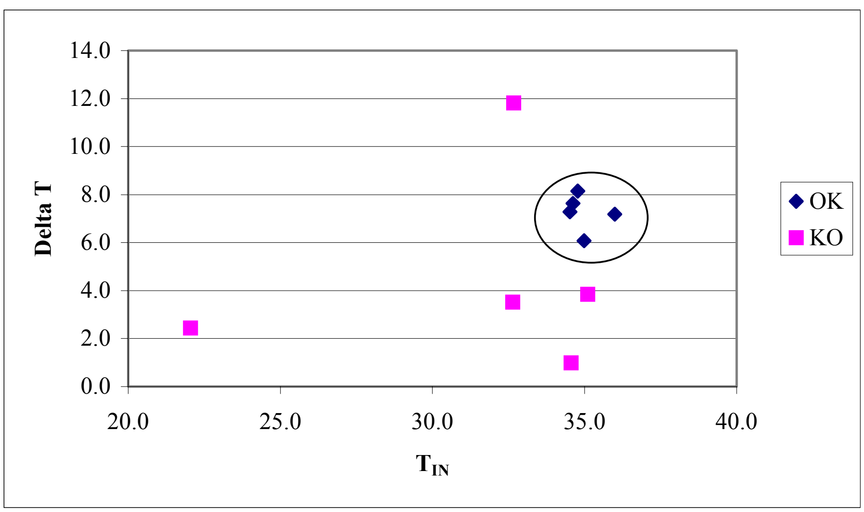


Fig. 5 The two classes of refrigerators: Good (OK) and Faulty (KO) illustrated in the 2D feature space T_{IN} and Delta T.

Before the use of the computed temperatures T_{IN}, T_{OUT}, T_C and Delta T as input of the NN that will classify the refrigerators, these temperatures have been compensated with respect to the ambient temperature. In this way the obtained values are always homogeneous and the NN is independent from T_A. As further information to classify the refrigerator, the power consumption has been used because the data are well correlated to a variety of defects and enforce classification success rate.

The chosen NN has an input layer with 5 neurons, a hidden layer and an output layer with 2 neurons. For the training phase of the network a set of good and faulty refrigerators have been used. The results of the training phase demonstrate that the selected temperatures and the power consumption are well representative of the behaviour of the refrigerators and allow a good classification of them. These results have been confirmed when the trained NN has been used in the production line. In fact the network has been tested with a high number of refrigerators and the results show that the classification has a percentage of success close to 99%.

CONCLUSIONS

The described system provides a complete test station based on Infrared Imaging for the on line quality control of refrigerators, capable to give an evaluation of the quality of the machine under test without any operator supervision. The final classification is made using a Neural Network that classifies the refrigerators into two classes, product complying or not the specifications, according to a pass or fail quality control strategy.

The drastic reduction in total testing time (10-12 minutes depending on the model of refrigerator) allows to save a large amount of energy and permits to avoid all the problems related to the long functioning, such us defrosting or drying the internal of the refrigerator.

The described system has been already used to classify different models of refrigerators and the obtained results are very encouraging. The selected temperatures and the power consumption seem to be able to discriminate the behavior of the refrigerators in a reliable way.

Therefore, the thermal image detection and Neural Network classification have been proven to be a powerful and suitable system for an innovative automatic on-line quality control of refrigerators.

REFERENCES

Cammarata S., "*Reti neuronali*", ETASLIBRI, 1997