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Production line quality control using infrared imaging

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HIGHLIGHTS

- Thermovision approach enables automatic production line quality control.
- The device classification based on PCA allows to shorten testing times.
- The classification can be based on the entire infrared image.
- There is no need to find regions of interests.
- The change of the ambient temperature could be easily taken into account.

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ABSTRACT

This paper addresses the problem how to bring advanced data analysis techniques to the reality of a production line in order to increase the productivity and cost-effectiveness while reducing failure rates and increasing reliability of the final product. The main goal was to develop techniques of fast thermal inspection for production line quality control using a knowledge-based machine vision system. The paper contains a description of the system as well as a proposition of the algorithm for automatic classification of devices on the base of information included in their infrared images. Data-driven pattern recognition, infrared imaging, and principal component analysis (PCA) were put together and resulted in a very effective production line quality control system. The algorithm has been validated using real production line data. Experiments revealed some interesting features of the proposed method, e.g. resistance to changes of the ambient temperature and early classification during the thermal transient state.

1. Introduction

Technological development and need for advanced tools make vision inspection systems more and more popular in production line quality control [1,2]. The new quality control software systems based on digital images captured in the industrial production line environment have been presented among others in [2–4]. The authors of these papers have emphasized the importance of flexible and self-adaptive behaviors in automated quality control systems. This paper follows such philosophy – as it has been shown in the following sections it is relatively easy to extend the proposed quality control algorithm in order to cover new product models.

In addition to flexibility, the other problem specific for industrial production line classification systems consists in feature set selection that enables not only reliable but also very fast product inspection [1,5,6]. It is more and more important as in the last years the concept of 100% quality control has become the aim of many manufacturers in order to cut down failure rates of their products. Complex quality flow models have been introduced to analyze quality propagations along production lines and enable inspection of each item leaving the production line [7,8].

Electrical and electronic devices, when operate, exhibit increase in temperature and so their quality control can be based on a feature set extracted from thermal measurements. The thermal image of a device under test can be compared with a thermal model [9–11] or a reference image [12], obtained from thermal images of good devices tested in the same conditions, providing information about the real condition of the device. It seems to be quite easy to perform. However, the number of references about applications of thermal imaging in production line quality control is relatively small comparing to the overall number of references in the field of civil and industrial applications. The reason for this could be relatively high cost of infrared equipment in the past and high computational power required to process thermal images

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in automatic way. These reasons are not longer valid because of reductions of thermal camera prices and increased performance of personal computers. In fact, the introduction of more affordable uncooled infrared cameras has broadened the range of applications from the commonly acceptable predictive and preventive maintenance [13,14]. Moreover, increasing interest in applications of infrared technology will certainly bring further improvements in IR camera sensitivity, array size, and variable optics, as well as further price reductions [15,16]. As with any technology cost as well as return on investment are driving factors.

Among the first applications of infrared imaging in the field of quality control there is non-destructive testing (NDT). It usually consists in single sample analysis to discover possible subsurface defects [17–20]. However, it could also be applied for quality control of components that are produced in a big number [21–23].

Automated infrared imaging has been used in many industrial production applications, including process monitoring and control, quality assurance, and machine-condition monitoring [11,24–28]. Production line quality control of home appliances as relatively less explored application of infrared imaging requires its own studies of the best pattern recognition techniques that enable automatic classification of products in accordance with production line requirements including reliability, calculation times, simplicity of operation, etc. This was the primary aim of the research that has been performed. The next step could consist in finding causes of the faults recorded with the help of infrared imaging [29].

The remainder of the paper is organized as follows. In Section 2, we introduced the background of the techniques used to solve the problem under consideration. Section 3 describes the algorithm proposed for infrared image classification. Experimental results and their analysis have been presented in Section 4. Finally, Section 5 concludes the paper.

2. Building blocks used to develop the problem solution

Traditional tests of home appliances comprise of visual inspections and electric tests including power consumption and temperature measurements. The aim of these tests is to improve the quality of the final product by detection and elimination of defects. The main drawback of this approach is very often a long testing time (about 1 h in the case of refrigerators), which starts to be a bottleneck of high volume production lines – the global annual production of household refrigerators and freezers is more than 80 million units [30]. The alternative approach consists in application of thermal analysis [1,2] and especially infrared imaging to perform device testing in production line test stations [3–5].

2.1. Thermal imaging

Infrared radiation is the invisible part of the electromagnetic spectrum, extending from 0.75 to 1000 μm, i.e. between visible light and radio waves. The infrared band could be arbitrarily divided into some sub-bands: near-infrared, middle-infrared, and far-infrared. In infrared temperature measurements only the range between 0.9 and 14 μm is normally used. It is important that infrared radiation is emitted and absorbed by all objects at a rate that depends on the absolute temperature and physical properties of the object. Generally, radiation striking the surface of an object is in some part absorbed, the other part is reflected or transmitted. These portions are expressed by the absorptivity, reflectivity, and transmissivity, respectively.

According to the well-known Stefan–Boltzman law, the radiation emitted from the surface of an object is proportional to the fourth power of its absolute temperature [31]:

$$P_{obj} = \varepsilon\beta\sigma(T_{obj}^4 - T_{amb}^4), \quad (1)$$

where ε is the emissivity of an object, β is a configuration factor depending on relative position and geometry of the object-detector system, σ is the Stefan–Boltzmann constant ($5.67 \cdot 10^{-8}$ W/m^2 K^4), T_{obj} is the object absolute temperature and T_{amb} is surroundings absolute temperature. In accordance with (1) in order to calculate the temperature of an object we need to know its spectral emissivity, which expresses the ratio of the spectral radiant power from it to that from a perfect radiator (blackbody) at the same temperature. In general, the value of this coefficient can vary with the wavelength. The emissivity as well as the distance to the object, surroundings temperature, atmospheric transmittance (τ) and temperature (T_{atm}) are important input parameters of the software developed within this research work to classify thermal images. Their importance comes out from the fact that thermal camera receives radiation not only emitted by the object (P_{obj}) but also reflected by its surface (P_{amb}). Besides, atmosphere attenuates these two components and adds its own radiation (P_{atm}), which is the third component of radiation received by the camera, Fig. 1. As a result above parameters are

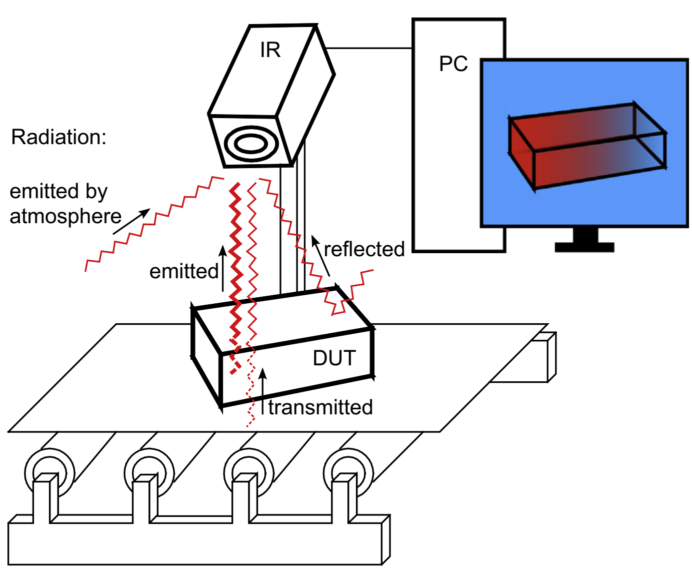

Fig. 1. Typical on-line quality control system based on infrared imaging with sources of radiation received by infrared camera pointed out (DUT – device under test, IR – infrared camera, PC – personal computer).