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USE OF HYBRID VISION METHODS FOR THE DIAGNOSTICS OF TECHNICAL PROCESSES

Key words

Hybrid vision system, passive thermography, image fusion, diagnostics of technical processes.

Abstract

The paper presents a hybrid method for simultaneous inspection of objects in the visible spectrum and infrared vision. In order to adapt the system to the industrial machines, both tracks of vision cameras were placed in a hybrid video head. Using the developed system, diagnostic tests of selected processes were performed. Measurements were made on the industrial line for washing bottles and at a glassworks. In the first case, the aim of the research was the diagnostics of process for automated cleaning of bottles. At the glassworks, the diagnostic measurements were performed for the bottom of the furnace. The benefits of using a hybrid method of vision are presented, including primarily the increase of research efficiency, the facilitation of the interpretation of the results, and the acceleration of sequence measurements for large areas.

Introduction

Technical diagnostics of equipment and machinery plays an increasingly important role in production. Failures as unforeseen events cause downtime on the production line and require emergency action for quick repair. This results in increased financial outlay. The need to achieve a competitive advantage is forcing factories to find ways to achieve the highest operating efficiency of equipment. One of the methods is the implementation of a predictive maintenance system. The main feature of the system is the preventive inspection and condition monitoring in the regime of the periodic analysis. In [1], vision inspection is listed as one of the most widely used technologies in this method. Among the existing solutions, visible band cameras and, increasingly, thermovision cameras are used. Wherever there is any cause or source of heat generation, thermal imaging measurements are becoming an indispensable tool for diagnostics [2]. Hybrid methods combining the advantages of both types of sensors find their applications in an increasing number of cases.

1. Hybrid vision system

The concept of a hybrid vision method consists in the use of two cameras allowing simultaneous inspection of the object in the visible band (VIS) and the infrared band (IR) (Fig. 1). In order to minimize errors of perspective, the cameras should be placed in close proximity to each other and angularly positioned so that the optical axes of the two video tracts intersect on the surface of the test object. Camera lenses should be chosen in such a way that the areas of observation in both spectral ranges were similar. The observation in the visible band allows the detection and identification of defects of surface structures, monitoring the presence and orientation of the elements, etc. Thermal vision is an imaging in the infrared band consisting in measuring the thermal radiation emitted by the object and determining the distribution of temperature on its surface. This allows the monitoring the temperature of objects and the detection of areas of local differences in temperature, such as heat accumulation zones. For diagnostics of technical processes, passive thermography is used, where the thermal energy is derived solely from the test object, which remains under the influence of the environment or is in normal operating conditions, without additional thermal stimulation [3].

In order to adapt to industrial conditions, the cameras were placed in a hybrid video head (Fig. 2). The housing protects the camera module from the adverse effects of external factors, particularly including the increased temperature of the controlled process, and possible pollution, dust, moisture, or mechanical shocks. The head is equipped with a thermal camera with an uncooled microbolometer sensor with a resolution of 640x480 pixels from InfraTec. For the registration of images in the visible band, a monochrome camera with a CCD sensor with a resolution of 1600x1200 pixels from Basler [4] was used.

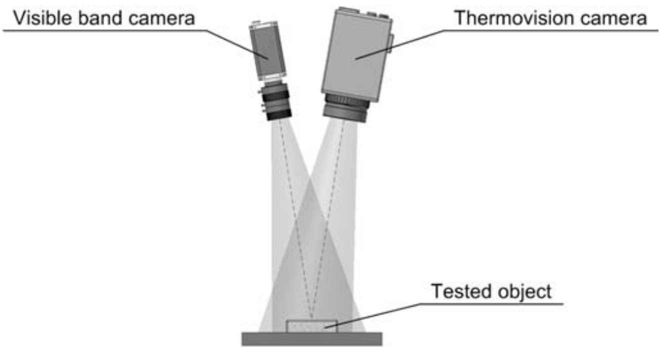
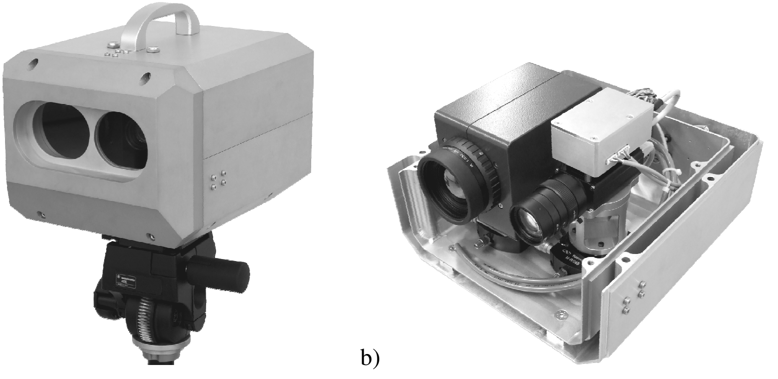


Fig. 1. The concept of hybrid vision method



a) b)

Fig. 2. Video head containing visible band camera and infrared camera: a) general view, b) view of the internal components after removing the front cover and the upper chassis

Cameras are fixed to the rotary tables that allow the manual change of the angular position depending on the distance of observation. The visible spectrum camera, due to the smaller dimensions, is placed on the adapter providing uniform height of the optical axes of both video tracts. The basic parameters of the cameras are presented in Table 1.

Table 1. Basic parameters of both vision tracts

	Infrared camera	Visible band camera
Basic parameters	resolution: 640x480 pixels, sensitivity: 40mK @ 30°C, spectral range: 7.5−14 μm, measurement range: -40–1200°C	resolution: 1600x1200 pixels, monochromatic CCD sensor, C-mount objective

For positioning the video head in three axes, a Manfrotto photographic head attached to a tripod was used. In order to facilitate the movement of the tripod with mounted vision head and positioning head, a base on wheels (trolley tripod) was applied. To illuminate the area of observation in the visible light, due to the considerable distance from the investigated objects of approximately 3 meters, a system of two halogen lights from Dedocool was used.

2. An example of application of the hybrid system in the food industry

The aim of the study was to diagnose the process of cleaning bottles in an industrial washer. Because of the significant total length of the line of about 4.85 meters (62 bottles), fragments of lines were studied to keep the required resolution of the recorded images (Fig. 3).

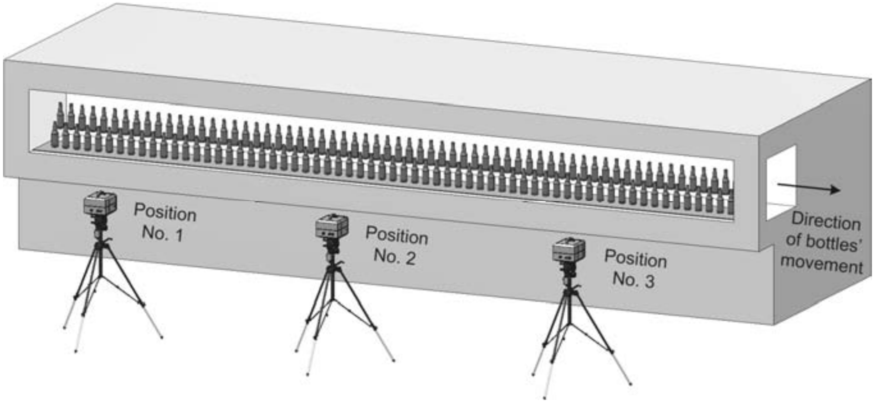


Fig. 3. Stand for vision diagnostics of the washing process of bottles in an industrial washer [4]

The hybrid vision head was placed consecutively in three positions on the line for washing the bottles. For each position of the vision head, recordings were made of images in two spectral bands over a period of about 45 minutes at a frequency of 15 Hz. The temperature of the glass with a thickness greater than 0.6 mm can be measured with a long-wave or short-wave IR camera. The latter must, however, be fitted with a narrowband filter with a passband of 5.0 ± 0.1 microns [2]. Measurements of the temperature of bottles were made with a long-wave IR camera. For thermal imaging, the value of the emissivity of glass surfaces equal to 0.93 was set based on the tables. Examples of obtained images of the two spectral ranges are shown in Figure 4.

Images from a thermal imaging camera allow the evaluation of the effectiveness of the cooling of the bottles after washing them by analysing the temperature distribution on the surface. The design of the washer provides the observation of two rows of bottles. The main infrared analysis is for the top row when the bottles come out of the socket immediately after the cleaning process. Rinsed bottles then fall onto the conveyor (bottom row) and are shifted to the right. Temperature monitoring is important because of the risk of the growth of microorganisms. The local temperature rise of bottles leaving the appropriate slot washer may be either systematic or short-term. The sustained higher temperature on the bottles coming out of the same slot, relative to the remaining bottles, allows the detection of a potential local obstruction of the cooling system of the cleaner (Fig. 5) [4].

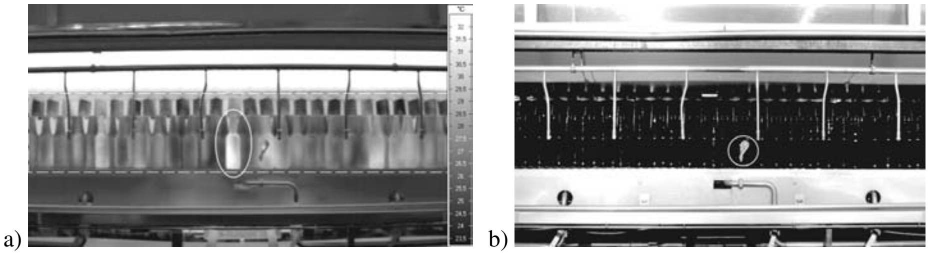


Fig. 4. A pair of sample images recorded by a hybrid vision system during the diagnostic process of washing the bottles (head position No. 2): a) increased temperature of one of the bottles (IR image), b) partially removed label on the bottle (VIS image)

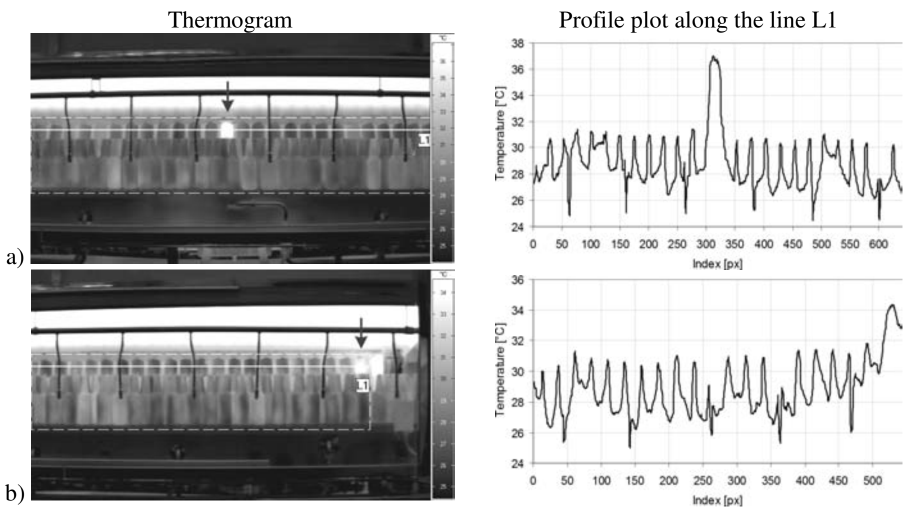


Fig. 5. Thermograms showing local temperature increase on the surface of bottles: a) the position of the head No. 2 (a disturbance of the central cooling slots), b) the position of the head No. 3 (a disturbance of the last slot)

An impaired cooling process could also show as a short-term increase in temperature on the surface of single bottles. During the study, individual cases of high temperature increases were found, and the probable reason is hot water left inside bottles after the process of washing (Fig. 6).

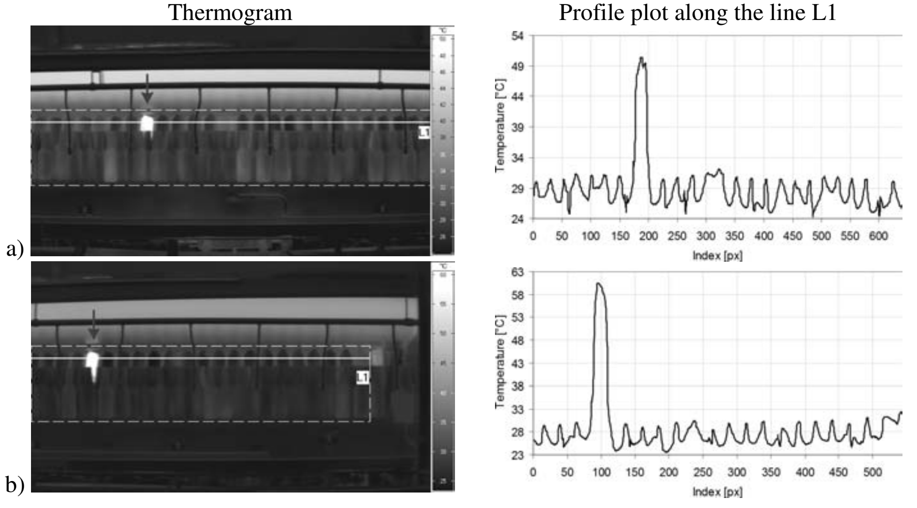


Fig. 6. Thermograms showing a local temperature increase on the surface of single bottles: a) the head position No. 2, b) the head position No. 3

Images from the visible band camera can be used for the detection partually removed labels on the bottles. The area of the wrapper is characterized by a much greater brightness on the recorded images relative to the surface of the bottles made of a dark brown glass. In this case, both rows of bottles in the camera field of view are analysed (Fig. 7).

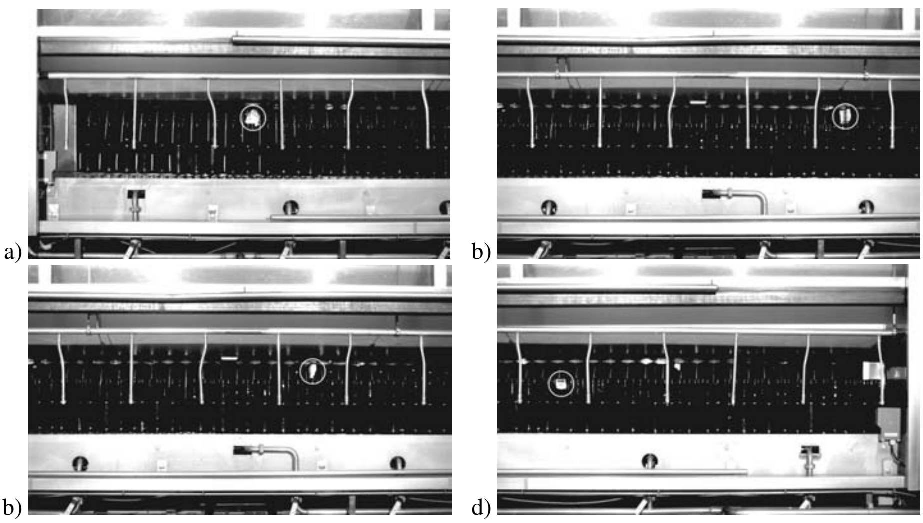


Fig. 7. Sample images from the visible band camera of the marked regions containing fragments of partially removed labels on the surface of the bottles: a) the location of the video head No. 1 (the beginning of the line), b, c) head position No. 2 (middle line), c) position No. 3 (end of line)

3. Example of application of the hybrid system in the glass industry

The hybrid vision method can also be applied in the diagnostics of glass furnaces. Thermal tests of the furnaces consist in the measurement of temperature distribution on their outer surfaces. On this basis, one can locate areas of heat accumulation where there is the greatest probability of failure. The resulting temperature distribution allows the evaluation of the condition of fireproof lining. The actions can be divided into two groups [5]:

- The determination and location of the area subjected to damage threat for emergency repair (e.g. local cooling with air or water); and,
- The quantitative assessment of the wear degree of the fireproof lining in order to extend the operation of the furnace.

Diagnostics of glass furnaces using thermography often regards the melting reservoir, which is the area of the furnace, which is covered with a glass substance. The destruction of the refractory lining appears on the internal invisible side of the furnace. Thermal measurements are performed both on the outer surface of the melting reservoir and on the bottom surface. Figure 8 summarizes the sample cross-section of a glass furnace with the selected direction of the vision inspection of the outer surface of the bottom of the furnace.

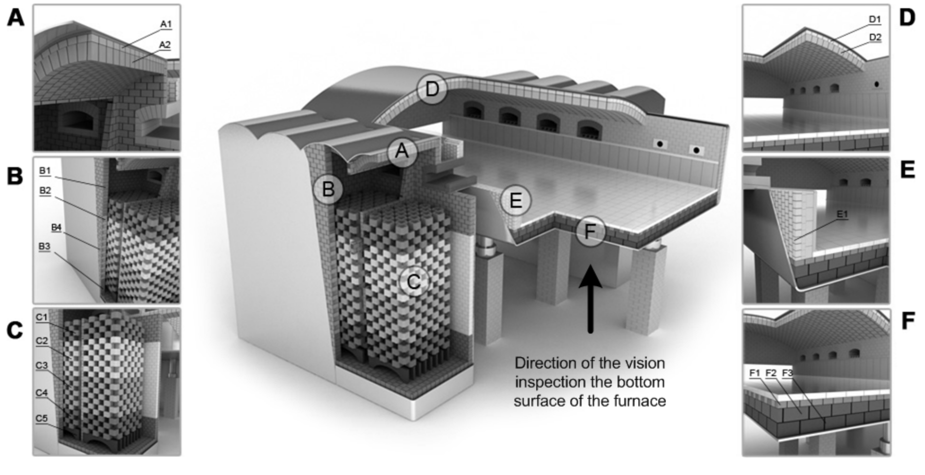


Fig. 8. Cross-section of the glass furnace [6]: A – regenerator ceiling, B – regenerator wall, C – regenerator, D – melting reservoir ceiling, E – outer layer of melting reservoir, F – bottom of melting reservoir

The occurrence of local temperature increases in this area may indicate a threat in the form of pits in the surface of the tank and the risk of leakage of hot molten glass. Sample pictures showing the damage of the bottom of the furnace are shown in Figure 9.

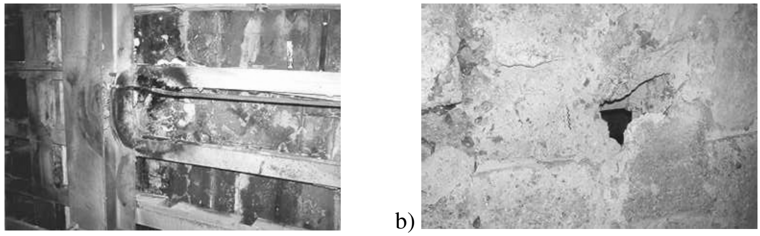


Fig. 9. Damage of the bottom of the tank: a) photo taken from below, b) photo taken from above [7]

In order to perform research, a hybrid vision head is set under the furnace and vertically upwards, perpendicular to the bottom surface of the furnace. The required spatial resolution is imposed by the need to perform a sequence of measurements. After registering a pair of images IR-VIS, the head was moved, in order to analyse the entire bottom surface of the furnace. Image analysis can be performed separately for each fragment of the surface or after combining individual pieces into a coherent whole in the form of a mosaic. The value of the emissivity coefficient of surface of ceramic blocks was set equal to 0.95. Figure 10 presents sample images recorded using a hybrid vision system.

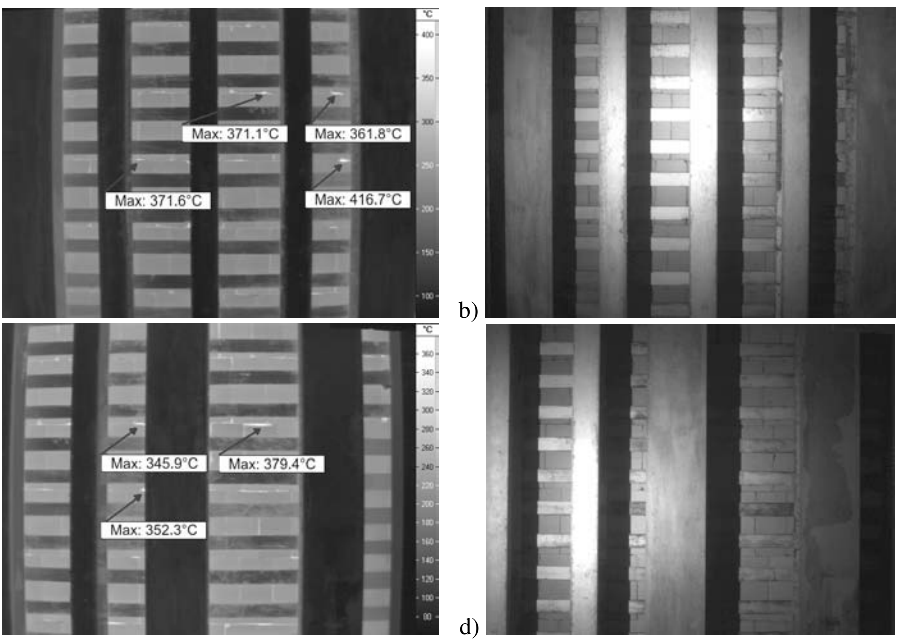


Fig. 10. Sample images recorded by a hybrid vision system during the diagnostics of the bottom surface of the glass furnace: a, c) thermal images with detected overheated areas, b, d) images in the visible spectrum allow identification of endangered areas

The use of suitable cooling times for the areas that are most at risk allows effective deceleration of the process of material destruction. Therefore, thermal imaging studies can be used to determine the start of cooling and optimize the cooling system during the operation time, and it can be used to practically locate the areas of increased corrosion and erosion of molten glass on materials [5, 8].

4. The advantages of using the hybrid vision method

The use of a hybrid vision method for the diagnostics of technical processes has many advantages. Images of the visible band are usually sharper, clearer, and have better spatial resolution than images taken in infrared. Reflected visible radiation can cause clear contrasts with sharp edges and intensity differences. Images of the visible band can be displayed in the same colours, shapes, and intensities, as they are seen by the human eye. For this reason, the variations in the structure and nature of the surface are more easily interpreted in the visible range. Changes in the intensity of infrared images are displayed using false colours [9], which sometimes causes the incorrect interpretation of the results. The solution is to present the infrared region of interest in a visible light image using an image fusion [10]. The degree of diffusion of the images may be freely changed from a complete picture of the infrared to the visible (Fig. 11).

Fig. 11. Example of location of missing filling in a wall of bricks: a) the image captured with IR camera, b) image captured with VIS camera c) fusion of images with the set value of diffusion of 50% (identification of defects) [9]

In the case of known temperature levels that indicate the occurrence of significant hazards it is possible to use the mode in which the image of the visible band will be presented only for the selected areas of the infrared camera (e.g. with exceeded allowable temperature).

Another advantage of the hybrid vision method that can be used in the diagnostics of the bottom surface of the glass furnace. It is possible to make a precise connection of individual images into a mosaic and create a full map of the surface of the analysed area. In [9], a method is presented for the identification of the location of objects in the absence of specific characteristic elements or in the presence of confusion elements on images in the visible band. In this case, the location of the position utilizes a laser pointer. The spot of light emitted by the laser is visible in the image in the visible band, but it is not visible in the infrared image. Using the method of image fusion, a laser dot can be seen in the combined IR-VIS pictures. By matching the position of the laser marker with disturbance region on infrared image, it is possible to precisely determine point of interest (Fig. 12).

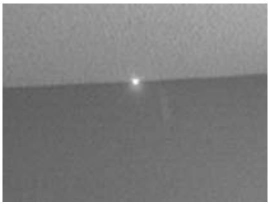
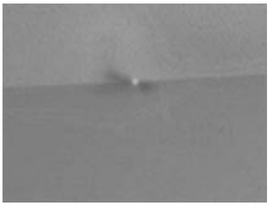
a)  b)  c) 

Fig. 12. Example of matching the laser pointer spot to the point of interest in the infrared image using the combined IR-VIS images: a) the found disturbance region on IR image, b) indicating the VIS image region of interest using the laser point, c) fusing the images with the set value of 50% transparency (laser spot coincident with infrared problem area) [9]

Application of the above solutions can be very helpful during the diagnostics of the bottom of the furnace. The bottom surface is characterized by a repeating texture, which makes it difficult or completely prevents the automatic creation of a mosaic of thermal images. It is also important that, during the measurements, only with the use of a thermal imaging camera is there a high risk of omitting certain areas because of the erroneous determination of the location on the thermogram. The application of hybrid method and active laser marker system allows thorough inspection of the bottom surface of the glass furnace. Figure 13 presents the concept of the system supporting the measurements.

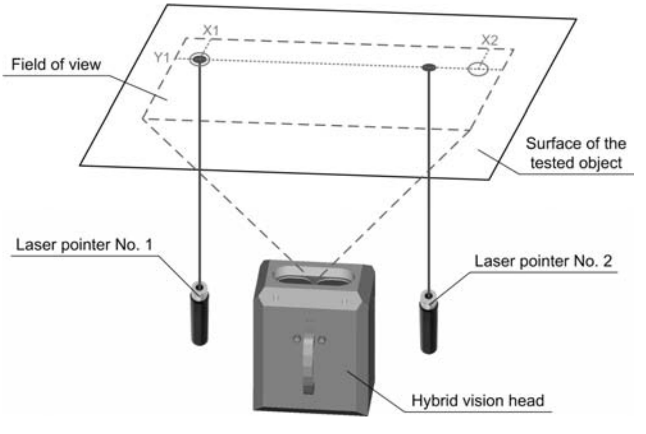


Fig. 13. The concept of a hybrid vision system IR-VIS with an active system using laser markers to support the infrared imaging

The vision head is directed vertically upwards, perpendicular to the bottom surface of the furnace. On the area observed by the visible light camera, point markers are emitted using two laser diodes. The software system using the implemented algorithms marks points at which tags should be located. The operator of the system, using the on-line preview, moves the laser modules so that tags were exactly in the place indicated by the software. X, Y coordinates of the indicators are chosen in such a way as to ensure the appropriate size for the common areas of successive images. After determining the position of the laser modules, a registration of a pair of IR-VIS images is performed. After shooting, without changing the lasers positions, the vision module is moved relative to the axis OY until tags will be symmetrically on the other side of the picture. Then, using the tips of the software, the indicators are moved by the operator for the new positions. This procedure is repeated until reaching the boundary of the area to be tested. Conducting measurements using the active support significantly accelerates recording of the full thermogram of the analysed surface.

Summary

The advantages of using machine vision methods for the diagnostics of technological processes include the following: non-contact measurements, the non-destructive nature of the research, and a wide range of possible applications. Additional advantages are obtained by the combination of an image recording of two or more spectral bands. Based on the survey, it was found that the hybrid method of inspection in the visible and infrared increases the efficiency of vision inspection. By combining the analysis of correlated images of the two spectral bands, one can obtain additional information about the test object. For example, the vision diagnostics of a bottle washing process using a hybrid system allows both the evaluation of the efficiency of the cooling process of the bottles, by analysis of the temperature distribution on the surface of the bottles (IR channel), as well as the detection of partially removed label fragments (VIS channel). In the case of glass furnace diagnostics, the primary source of information is the thermal imaging camera that allows the detection of heat accumulation, which causes the greatest risk of failure. The image in the visible band can be applied in this case to facilitate and speed up the location and identification of the controlled objects or to facilitate the interpretation of results. A very interesting solution also seems to be the concept of a hybrid vision IR -VIS system with an active support system for infrared measurements using laser markers working in the visible band. The advantage of the presented method is the ability to obtain the full mosaic of thermograms of the analysed surface without the risk of the omission of relevant areas and to facilitate and accelerate the measurement of large surfaces.

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Wykorzystanie hybrydowych metod wizyjnych do diagnostyki procesów technologicznych

Słowa kluczowe

Hybrydowy system wizyjny, termografia pasywna, fuzja obrazów, diagnostyka procesów technologicznych.

Streszczenie

W artykule przedstawiono hybrydową metodę wizyjną umożliwiającą jednoczesną inspekcję badanych obiektów w paśmie widzialnym i podczerwieni. W celu przystosowania systemu do warunków przemysłowych kamery obu torów wizyjnych zostały umieszczone w hybrydowej głowicy wizyjnej. Za pomocą opracowanego systemu wykonano badania diagnostyczne wybranych procesów technologicznych. Pomiary wykonano na linii do przemysłowego mycia butelek oraz w hucie szkła. W pierwszym przypadku celem badań była diagnostyka procesu automatycznego czyszczenia butelek. W hucie wykonano natomiast pomiary diagnostyczne dna pieca szklarskiego. Zaprezentowano korzyści wynikające z zastosowania hybrydowej metody wizyjnej, w tym przede wszystkim zwiększenie efektywności badań, ułatwienie interpretacji wyników oraz przyspieszenie sekwencji pomiarów dla dużych powierzchni.