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A QMS-COMPLIANT MULTIPARAMETER SYSTEM FOR OPTICAL INSPECTION OF MANUFACTURED PRODUCTS

Keywords

Machine vision systems, image processing and analysis, automated optical inspection, free-fall, acquisition of moving objects, databases, quality management systems.

Abstract

The system described in this paper provides automated optical inspection of free-falling products. It was designed to inspect plastic nose pads for eyeglasses. The solutions relating to the integrated image acquisition and the processing and analysis techniques allow achieving high inspection efficiency. The system also assures the possibility of full archiving of the inspection results for further reference, processing or statistical analysis.

Introduction

This paper outlines a multiparameter system for the inspection of manufactured products, developed jointly by Institute for Sustainable Technologies - National Research Institute (ITeE-PIB) and Industrial Institute of Electronics (PIE) within the scope of the research work on Automated Optical Inspection systems. The research work related to the development of the system has been done within the framework of the project: "Methods and Equipment to

Enhance Quality Systems in Manufacturing and Operation Processes" included in the Multi-Year Programme "Development of innovativeness system of manufacturing and maintenance 2004–2008". The mechatronic part of the system's station, the software for controlling the operation of the drive systems and the concept of the optical quality selection of free-falling eyeglass nose pads have been developed by the Institute for Sustainable Technologies in Radom, whilst the work related to the development of the vision system and all relating hardware and software for image acquisition, processing and analysis has been accomplished by the Industrial Institute of Electronics in Warsaw.

This paper outlines the characteristics of a machine vision system being part of the multiparameter system for the inspection of manufactured products.

Due to technological progress accelerated in recent years, the machine vision systems offer a number of possibilities, thus continuously minimising the distance to their biological counterparts, particularly in terms of their resolution, processing speed, interpretation of 3D images, learning and adaptation techniques. It can be ascertained that for many narrowly defined tasks such as colour discrimination, 2D and 3D measurements, or measurement velocity, the machine vision is often faster, cheaper and more accurate than human eyes, and it can be presumed that these systems would progressively eliminate human vision in the quality control inspection of manufactured objects and in process control applications.

Currently, there is available a variety of solutions in the area of machine vision systems - from PC-based Machine Vision to integrated vision systems termed as Smart Cameras, Vision Sensors or Intelligent Vision Sensors. Industrial products are required to have high and repeatable quality. Precise inspection of various parameters and their high reliability is crucial to achieving and maintaining the high quality of products. The problems with the assurance of quality production were, in past, an object of many research works conducted by manufacturing plants and numerous normalisation organisations. Most of modern quality control methods are automated, particularly those used in mass-scale production. Automation allows obtaining high inspection rates, accuracy and repeatability and avoiding the effect of subjective human judgement.

1. Automated Optical Inspection (AOI) systems

An automated optical inspection system consists of three main subsystems:

- a machine vision subsystem that performs automated optical inspection,
- a mechatronic subsystem to feed and sort manufactured pieces to be inspected,
- a subsystem for monitoring and archiving of the inspection results.

Once the AOI system's configuration and inspection optimum algorithms of image processing and analysis have been defined along with the quality control and classification criteria, the AOI system allows automated controlling of the objects and assigning them to individual quality classes. This technique offers a reliable, contactless and integrated quality control of large lots of products in terms of their various features. AOI systems are attracting growing interest in the area of industrial inspection, since they offer a complete inspection process automation and better process accuracy and efficiency. It is particularly important because of current tendencies toward attaining the goal of 100-percent quality control of products.

Some examples of the application of AOI systems include the following: verification of the assembly process, detection of defects, precise geometry measurements, object identification and positioning, sorting/sizing, optical character recognition (OCR) and optical character verification (OCV) systems. Below there are presented some examples of the inspection techniques related to the two main application areas of AOI systems: the inspection of the geometric parameters of products and the inspection of the surface quality of materials.

2. A system for automated optical inspection of free-falling products

2.1. System characteristics

ITeE and PIE developed a system that provides automated optical inspection of free-falling products. It was designed to inspect eyeglass plastic nose pads. In order to enhance the characteristics of the objects under inspection, the system is equipped with two vision channels, perpendicular to each other and equipped with backlight illumination for optimum visibility at very short exposition times, easy readability by highlighting edges and good exposition of various surfaces and material defects. The system is designed to select products into 3 quality groups.

2.2. The image acquisition process of falling products

The picture below is a view of the product under inspection (Fig. 1). The acquisition of free-falling products was done at backlight illumination. The velocity of the object during image acquisition was estimated to be approx. 2 m/s. It is worth commenting on several aspects of the image acquisition process in this case:

- the need to set very short exposition times approx. 40 μs because of the high velocity of the object and possible edge blurring,
- the need for good illumination of the product during several tens of microseconds,

– the need for an exact synchronisation of the acquisition camera with the signal from the optical window to assure repeatable product image location (the asynchronous mode of operation),
– the need to physically split the video channels in order to avoid cross-illumination within the channels.

PIE has developed an optoelectronic system that was found to meet the above mentioned requirements (Fig. 2).

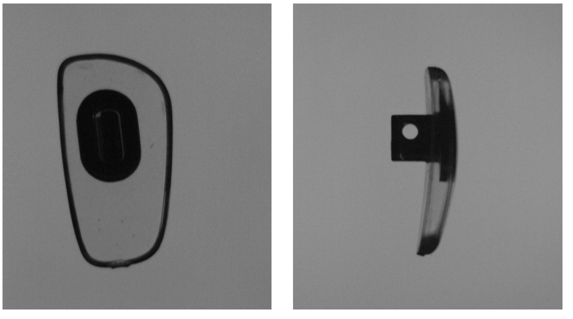


Fig. 1. The object under inspection (front view and end view respectively)

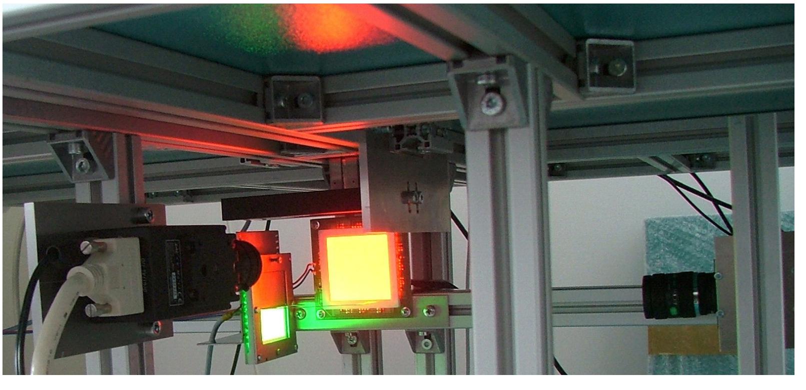


Fig. 2. View of the optoelectronic module

The optoelectronic system is based on JAI CV-A10CL cameras, backlight LED illuminators and the Euresys Grablink Expert 2-frame grabber.

The CV-A10CL uses the latest generation of monochrome progressive scan 1/2" CCD sensors with 782 x 582 pixel resolution [1]. The 1/2" format has the advantage of a large pixel size (8.3 x 8.3 μm), which results in higher sensitivity.

The CV-A10CL utilises Camera Link as an interface. The frame rate is 60 frames/second for the full resolution. One of the most important features of the CV-A10CL is the high speed shutter from 1/60 to 1/300000 second and the mode of operation, such as, edge pre-select, pulse width, sensor gate trigger modes, and Reset Continuous Trigger RTC mode. It makes it possible to set very short exposition times because of the high velocity of the object.

The Grablink Expert 2 is a Camera Link frame grabber for demanding industrial applications [2, 3]. It is connected to two CV-A10CL cameras. The Grablink Expert 2 is a 64-bit, 66 MHz PCI bus frame grabber. Each camera delivers images at a maximum speed of 60 MHz over the data paths towards the on-board memory. In a dual base configuration, it acquires images simultaneously and independently from two area-scan digital cameras. The Grablink Expert 2 incorporates a 16-Mbyte on-board memory. Clocked at 100 MHz, it provides a throughput of 800 Mbytes/s, implementing a huge FIFO for each camera.

The schematic diagram of the system as well as the data flow and time relations are shown below (Fig. 3). The inspection process starts when the optical sensor detects the free-falling product. The active signal of the optical window starts the acquisition process of two cameras with two different

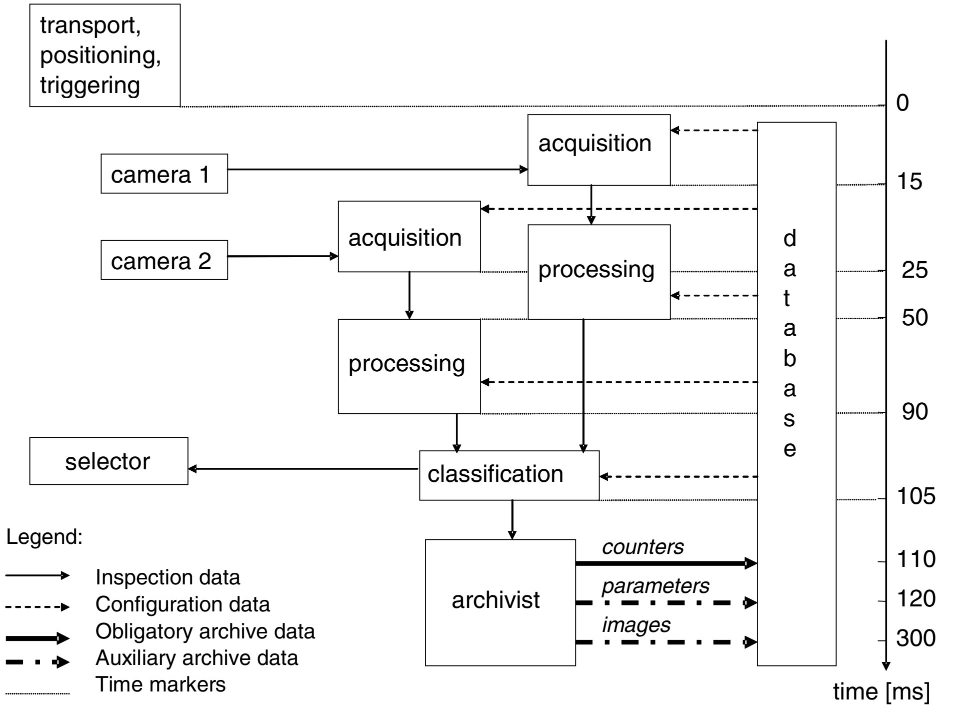


Fig. 3. Schematic diagram of the system, data flow and time relations

programmed delay trigger times for each channel, which correspond to the position of cameras in relation to the optical window. Finally, the image acquisition and processing of each channel is independent and organised in such a way as to maximise the inspection efficiency. As soon as the processing results from each channel are obtained, the classification of the complex result of inspection is performed. This result of classification is transferred to the mechatronic control system to activate the selector driver. The average time of the acquisition, processing and classification process for two channels is about 105 ms. The last phase of inspection process is archiving depends of the amount of data saved in database and can take from 50 to 230 ms.

2.3. The optical inspection system's capabilities

The falling product's image acquisition system and the integrated techniques of the image processing and analysis allow the detection of the following defects of nose pads: foreign inclusions in the plastic material, air bubbles in the plastic material, cracks, an irregular shape of the nose pad holder, plastic burrs at the nose pad holder (including the obstruction of the hole with plastic material), scratches on the plastic material, improper orientation of the holder in relation to the plastic portion, dirt contamination, opaqueness and inhomogeneities of the plastic material, large irregularities of the shape of the plastic portion of the nose pad, small cavities and burrs of the plastic material.

3. Identification of defects in materials

The picture below is an exemplary application of the blob analysis technique for the detection of the selected features of materials and product surface [4, 5]. Fig. 4 is the view of defects in the form of scratches and scores on the surface of a plastic nose pad photographed at the Diffuse Backlight Illumination. Here, the system has discriminated the objects based on the intensity level of the image of defects and has calculated the area of all defects and the position of their gravity centres. During the next stage, the system has sorted the objects according to the decreasing order of the area. The defect occurrence rate (the ratio between the surface defects and the entire surface), the

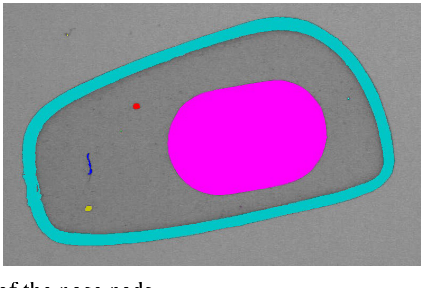


Fig. 4. Defects on the surface of the nose pads

regions of defect occurrence and the type of defects (e.g. distribution of the number of defects in the function of their size) can be obtained from the analysis of the structure of the feature vectors.

It is worth noticing that this technique of blob analysis is a very good measuring tool, allowing machine vision-based calculation or the estimation of several essential parameters of surface defects specified in the Polish Standard PN-EN ISO 8785:1999 [6].

4. Characteristic inspection parameters

Table 1 provides the characteristics of the main objects characterising the nose pads viewed frontally and laterally.

Table 1. Characteristics of the main objects that characterise the nose pad

Object No.	Object identification	Camera No.	View	Object Class	Specification
1	C1.B1	1	Front	Black	Nose pad– outer portion
2	C1.B2	1	Front	White	Nose pad– inner portion
3	C1.B3	1	Front	Black	Nose pad holder
4	C2.B1	2	Side	Black	Nose pad holder
5	C2.B2	2	Side	White	Hole in the nose pad holder

Each object has its basic geometrical parameters that, during the inspection of products, should be ensured within the established tolerance. The detection of additional objects in the area around the nose pad is an evidence of the presence of defects such as scratches, cracks, air bubbles, etc.

Fig. 5 illustrates the rule of estimation of the selected parameters resulting from the inspection based on the established partial parameters.

For example, in case of the front view of the nose pad, Feret boxes (Feret centers, widths, heights and angles) are determined. The Feret box for the main

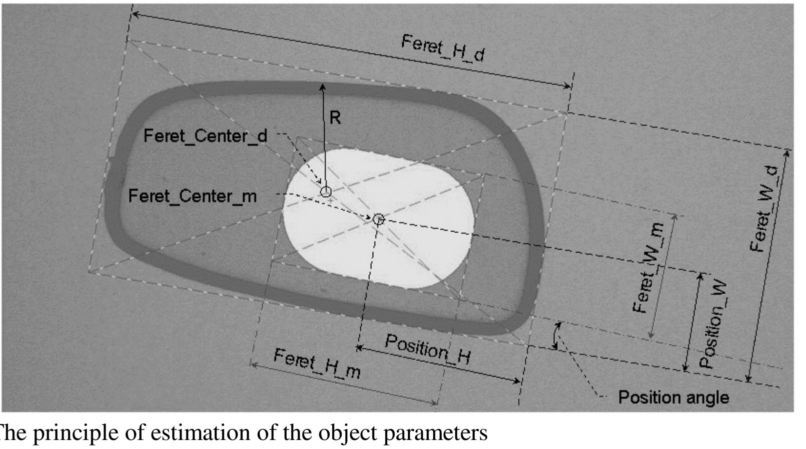


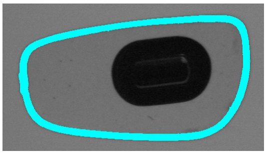
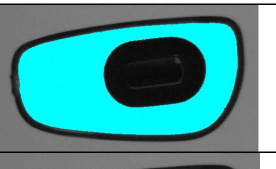
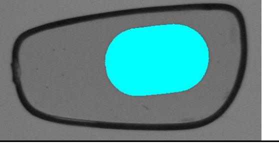
Fig. 5. The principle of estimation of the object parameters

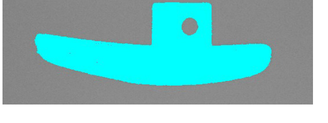
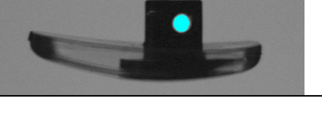
object, i.e. the plastic part of the nose pad (C1.B1), determines the reference system for the linear position of the Feret centre and the twist angle of the nose pad holder (the object C1.B3). Then, the object contour is developed around the given object Feret centre in order to determine the coefficient of wrinkles of individual objects. The measure of inhomogeneity of the edge of the object is the deviation of the value of the radius vector from this mean value.

In case of the front view, there are established 25 characteristic parameters and in case of the side view, there are established 15 characteristic parameters.

The list below is the specification of the characteristic parameters for each object under inspection (Table 2).

Table 2. Specification of the characteristic parameters for each object

Front view	
Object C1.B1 – Outer portion of the nose pad: *C1.B1.Area* *C1.B1.FeretCenterX* *C1.B1.FeretCenterY* *C1.B1.FeretWidth* *C1.B1.FeretHeight* *C1.B1.FeretAngle* *C1.B1.Elongation* *C1.B1.Ripples*	
Object C1.B2 – Inner portion of the nose pad: *C1.B2.Area* *C1.B2.FeretWidth* *C1.B2.FeretHeight* *C1.B2.Elongation* *C1.B2.Ripples*	
Object C1.B3 – Nose pad holder: *C1.B3.Area* *C1.B3.FeretWidth* *C1.B3.FeretHeight* *C1.B3.Elongation* *C1.B3.Ripples*	
C1.BlackBlobs *C1.WhiteBlobs* *C1.TotalArea* *C1.DefectsArea* *C1.AngleNoseHandle* *C1.HandleDistantX C1.HandleDistantY*	

Side view	
Object C2.B1 – Inner portion of the nose pad: *C2.B1.Area* *C2.B1.FeretCenterX* *C2.B1.FeretCenterY* *C2.B1.FeretWidth* *C2.B1.FeretHeight* *C2.B1.FeretAngle* *C2.B1.Elongation*	
Object C2.B2 – Hole in the nose pad holder: *C2.B2.Area* *C2.B2.FeretWidth* *C2.B2.FeretHeight* *C2.B2.Elongation*	
C2.BlackBlobs *C2.WhiteBlobs* *C2.TotalArea* *C2.DefectsArea*	

5. Selected operation modes of the inspection system

Below there are described two representative modes of the operation of the vision system: the preparation and setup mode and the automated inspection mode.

5.1. Interactive setup and maintenance modes

Setup and maintenance modes are designed in order to setup the system for operation and also for maintenance purposes. The system software allows making an interactive selection of the following basic operation parameters: exposition times for the two cameras at the simultaneous observation of both the images from the cameras and the image histograms, times of delayed triggering of the image acquisition process when triggered by an external signal, modes of operation of the cameras. In the extended setup and maintenance mode, there are set up additional operation parameters of the vision system. This operation mode is designed for each vision channel. In addition to the interactive selection of basic operation parameters there are also defined: the binarization level, the minimum and maximum values of the area of objects for so called the blob filtering, and the ROI (Region of Interest) image location and size are also determined. Both of the system's operational parameters interactively set up for the purpose of the above described modes and the system's configuration parameters determine the proper working conditions of the system [7].

5.2. The mode of automated inspection

This mode serves to perform automated inspection of the products conveyed by the feeding subsystem of the system's mechatronic module. The inspection results are then forwarded to the product selection subsystem where the products are sorted into individual selection groups. Fig. 6 is the view of the displayed screen in the automated operation mode.

The activation of the measuring cycle in this case is possible in two situations:

- the online measurement - single cycle and continuous operation. The inspection deals with the images of products obtained during the current (online) measuring cycle,
- the simulation of the measurement – using a browser. The inspection deals with the images of products previously stored in the database (off line).

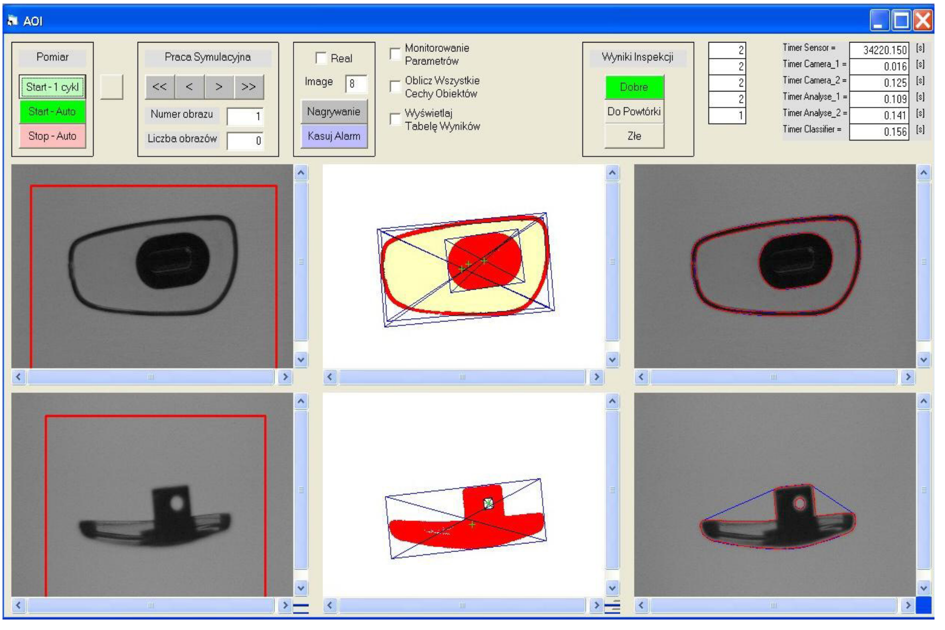


Fig. 6. The view of the displayed screen in the automated operation mode (the automated measuring cycle)

For each vision channel there are displayed the following inspection phases:

– the view of the product after image acquisition, with the indicated ROI
– the view of the product after object binarization and discrimination, with the indicated positions of the gravity centres of the objects, and Feret boxes,

the view of the product after defining the contours of the objects, with the indicated internal and external contours.

The inspection results are shown in a window and then saved in the database structure.

All characteristic parameters for each product under inspection are shown in the window of results and saved in the database structure.

In addition to the setup of the inspection parameters, it is possible to perform a detailed monitoring of the series of measurements with the visualisation of the relevant statistical parameters: the mean value of the parameter, the maximum and minimum values, the standard deviation, etc. Each inspection parameter can be accompanied by the histograms derived from the series of measurements displayed in the graphic mode. Fig. 7 illustrates the distribution of the values of a single feature of the product under inspection: C1.B1.FeretCenterX and statistical parameters of this feature (lower limit, upper limit, lot size, mean value, median).

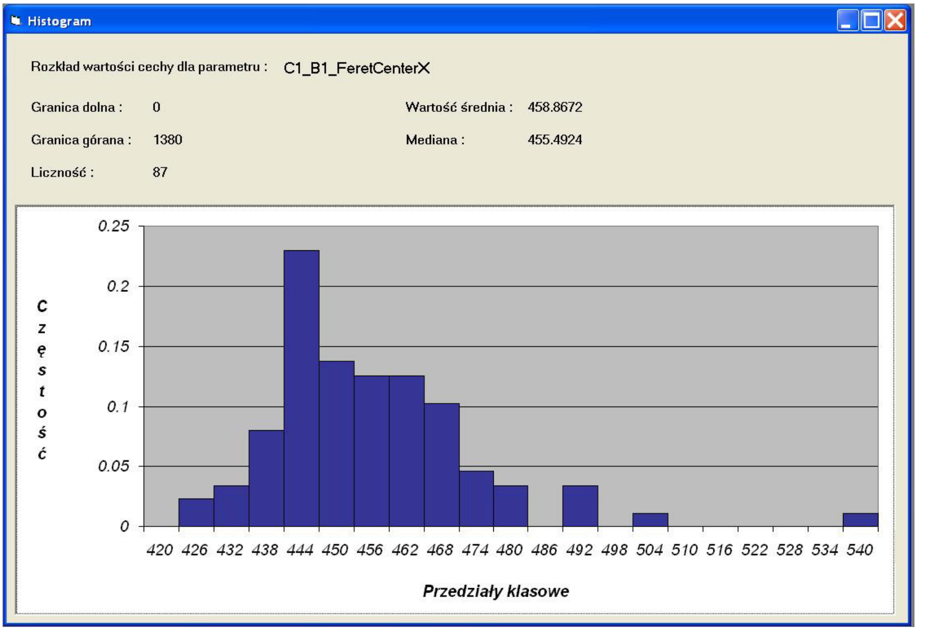


Fig. 7. Distribution of the values of a single feature of the product under inspection. The view of the displayed screen. (*Legend: Rozkład cech wartości dla parametru = Distribution of the values for the parameter, Częstość – relative frequency, Przedziały klasowe = Class Ganges)*

6. Monitoring of the inspection process. A archiving of results

6.1. Quality management systems

Quality management systems provide a frame function for aligning the whole organisation and achieving consistency across operations. In the operation of industrial plants, focus rests on the measurement results of the physical and technical parameters of the manufactured products since they determine the quality of plant's operations. General principles that govern the measurement procedures are compliant with the quality management rules and have been many times described in the available literature. It is worth recalling, in this regard,that they can be characterised as follows:

- measurements shall be defined and documented,
- personnel carrying out the measurements shall be certified,
- measurement results shall be archived for reference, authorised and validated,
- all factors potentially affecting the measurement results shall be archived for reference,
- tahe measuring hardware shall be validated.

In this context, the AOI systems can be considered as specific measuring systems. Their automation (computer control) helps in obtaining a high level of inspection repeatability. The AOI systems control software performs measuring procedures that can be defined within the quality management systems. A given AOI system can employ different procedures or their versions. Here, databases are a very comfortable and efficient tool to archive both the inspection procedures and results. The system's databases allow achieving all QMS requirements.

6.2. Place and role of databases in automated AOI systems

The AOI system's software developed by PIE is a database-integrated and meets the requirements of quality management systems and consists of three functional parts:

1. Framework modules – functioning as a general-purpose enclosure of the inspection process,
2. Inspection modules - being a dedicated part of the application dependent on specified tasks of the inspection, and
3. Inspection databases.

Two first parts are physically separated on the level of the application's source files only. Framework modules provide a homogeneous user interface for all applications, a common database structure and common data processing procedures, and also similar procedures of system initialisation and adjustment. They are the most versatile parts of the system that can easily function in different systems to integrate databases with the AOI system.

The inspection modules depend strongly upon the inspection type. While the hardware of the sub-inspection system includes certain general purpose features (cameras and illuminators are a must), the software can be modified depending upon the type of the products under inspection. The basic feature of the system described here is its large flexibility. It can employ different optical inspection module types that can be matched to operate in conjunction with a common information technology environment, thus allowing to comply with the requirements of quality management systems and to use similar operation procedures and almost the same user interface.

The inspection database allows storing the information about the AOI system (system configurations) and archiving the inspection results. The database management procedures are included in the framework modules' task. The structure of the database is flexible enough and permits operation in conjunction with many different AOI applications. The AOI application has its preset processing algorithm, a list of parameters under estimation and a fixed hardware configuration. Application setup is designed for many different similar products (including the setup of the comparison criteria for the parameters under estimation).

6.3. Product setup

The term "Product setup" refers to these AOI system software setup procedures that are defined for AOI modules and for framework modules and create definitions for the given product. The users have different authorisation levels within the application setup. The setup procedures include Rigid Configurations (concerning the AOI modules and connected strongly with these modules) and Flexible Configurations (concerning the framework modules).

6.4. Archiving of the inspection results

In a mass-scale, well-established production it is sufficient to archive the state of counters that assign the products into conforming and non-conforming groups for each manufactured lot. This could be, however, insufficient in the case of the occurrence of technological problems. Depending upon the importance of these problems, it could be necessary to enlarge the range of the archived data by adding technological categories' counters, estimated product parameters and even the images of the analysed products. The archiving range should be easily adapted to current needs. A range too wide could quickly overload the database with useless data.

The archiving mode defines the range of the information during the inspection session. In case of an AOI process, there always are archived the values of the counters of the selected groups (quality classes). Archiving can also include the following:

– The states of the category, counters (to allow, for example, performing technological analyses at low amount of processor time and disk space utilised during the inspection process).
– The values of the inspection parameters (to allow performing the analysis of the configuration correctness and adjusting the software after reconfiguration of the system). There are archived only these parameters that have been flagged as requiring the archiving in their definitions.
– The inspection images (to allow performing a detail analysis of the AOI process). The user can record either all images, or only these considered non-compliant to the criteria archived in the image definitions.

In order to ensure a high performance of the system, there is required a special, quick mode of archiving of the inspection results. This can be attained by ensuring the exclusive preference for the AOI process in accessing the database during the inspection.

7. Parameters of the inspection system

Table 3 provides the characteristics of the main parameters of the implemented inspection system.

Table 3. Parameters of the inspection system

Number of estimated parameters	34
Number of technological categories	"any"
Number of selection groups (quality classes)	3 (pass, fail, uncertain)
Classification (categories and groups)	Programmable
Number of stored products	"any"
Visualization of inspection parameters	parameter values, groups counters, categories counters, images
Archive of system settings	products, parameter limits, configuration of groups and categories, vision parameters
Archive of inspection results	group counters, categories counters, parameter values, images
Organization of inspection results archive	grouping by sessions and products
Statistical analysis of inspection results	groups and categories counters, parameter values statistics, parameter histograms
Inspection duration	~ 150 ms
Maximal throughput of complete system (including mechatronics)	~ 10 000 objects/h

Conclusions

Automated Optical Inspection (AOI) systems are attracting growing interest in the area of industrial inspection, since they offer a complete inspection process automation and better process accuracy and efficiency. It is particularly important because of current tendencies toward attaining the goal of 100-percent quality control of products. It is a challenge to manufacturers to seek solutions that can assure full and effective products' quality control and selection.

This paper describes a PIE and ITeE-developed system that provides automated optical inspection of free-falling products. It was designed to inspect plastic nose pads for eyeglasses. In order to ensure a high quality of the inspection process, it was necessary to consider certain conditions related to the moving objects' image acquisition and analysis: setting up very short exposition times of approx. 40 μs, suitable illumination of objects during these several dozen microseconds, precise synchronisation of the camera acquisition with the signal from the optical window, physical separation of video channels to avoid false illumination within individual channels; using techniques of quick image processing and analysis. These solutions relating to the integrated image acquisition and the processing and analysis techniques allow achieving high inspection efficiency (the image acquisition and analysis times for two channels less than 200 ms). The system also assures the possibility of full archiving of the inspection results for further reference, processing or statistical analysis.

Acknowledgements

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System wieloparametrycznej kontroli wyrobów w procesie produkcji z wykorzystaniem metod optycznej inspekcji przystosowanej do wymagań systemów zarządzania jakością

Słowa kluczowe

Systemy wizji maszynowej, przetwarzanie i analiza obrazów, automatyczna inspekcja optyczna, swobodny spadek, akwizycja poruszających się obiektów, bazy danych, systemy zarządzania jakością.

Streszczenie

Opisany w artykule system automatycznej inspekcji optycznej przeznaczony jest do inspekcji jakości swobodnie spadających detali. Zrealizowano aplikację, w której inspekcji podlegają plastikowe noski do okularów. Zastosowane rozwiązania w zakresie akwizycji obrazów oraz technik przetwarzania i analizy umożliwiły uzyskanie dużej wydajności inspekcji. Opracowany system zapewnia również możliwość pełnego archiwizowania wyników inspekcji w celu późniejszego porównywania, przetwarzania czy analizy statystycznej.