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Machine Vision and Metrology Systems: An Overview

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ABSTRACT

Metrology and machine vision are two fields that have been considered together frequently due to the versatility of artificial vision to solve industrial inspection problems. Metrology is one of the many applications of machine vision, which has the advantage that allows for the inspection of a total production batch that leaves an assembly line without creating a bottleneck in production. The aim of this paper is to present an overview of the current advancement in machine vision and metrology systems. The paper exposes a wide range of machine vision software aimed at the inspection of application processes, systematically highlighting the relationship between machine vision and metrology systems. Some applications of machine vision and metrology for quality control inspections are also highlighted.

1. Introduction

One of the most common applications of machine vision is the inspection of products, such as integrated circuits, vehicle parts and components, food and pharmaceuticals [1]. The purpose of visual inspection is to identify whether a particular attribute is present or properly located in a predetermined area [2]. As described in [3], inspection also helps to determine whether an object deviates from a given set of specifications. Machine vision systems are designed to support human operators in industrial inspection process and achieve a more robust and high quality of performance of manufacturing process and quality control. Different from computer vision, which refers to a broad term for the capture and automation of image analysis, machine vision needs an engineering system design with additional hardware I/O and computer networks to transmit information [4]. A modern machine vision system consists of digital input/output devices and computer networks for automatic operation of equipment or quality control systems [5]. There are basically three categories: PC-based vision system, embedded vision system, and smart cameras. Figure 1 shows the three types of machine vision systems. The smart camera-based systems cover a wider range of applications, while embedded vision and PC-based systems offer less flexibility and higher performance due to the increased complexity of the overall system.

A typical PC-based machine vision system consists of the following components: cameras and optics, lighting, frame grabber, PC platform, inspection software, digital I/O and network connection.

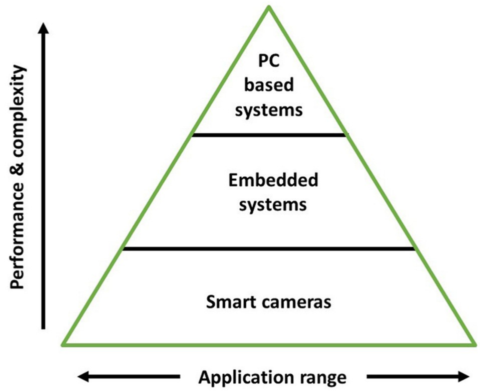

Fig. 1 Overview of typical machine vision systems [11]

The PC-based machine vision system employs one or more cameras and lenses to capture a picture of the object under inspection [6]. Different types of cameras can be used, such as monochrome camera, RGB color camera, and progressive-scan or line-scan camera. To assure a better quality of the image, the object is illuminated with the lighting device. The lighting of high-frequency fluorescent, light-emitting diode (LED) incandescent, and quart-halogen fiber optic can be configured in various shapes, colors and sizes with a variety of intensities. Frame grabbers or video capture cards provide low-level interface capabilities with other system components and host computer [7]. It can also control the camera by setting the triggering, exposure/integration time, shutter speed, etc. The PC platform runs the inspection software to process acquired image data and even make a binary decision, e.g., accept/reject. For varied inspection tasks, algorithms need to be tailored with proper software tools. The data exchange and communication with outside systems and databases are done through the digital I/O interface and/or network connection. The PC-based machine vision system is configured based on the specific requirements and goal of the inspection task. The contributions of the paper are summarized thus:

- To study the architecture of a machine vision system.
- To study machine vision and metrology system, highlighting the two basic kind of dimensional metrology techniques: post-process and on- process dimensional measurement.
- To highlight the quality control process in machine vision and metrology systems.

The paper is arranged as follows. Section 2 studies the state of the art in machine vision. In Section 3, we describe the architecture of machine vision systems. Section 4 describes the relationship between machine vision and metrology. Some applications of machine vision for metrology are explained in Section 5. Section 6 describes the conclusions from the study.

2. State of the Art

The process of identification of problems which can prevent errors and al- low manufacturers to take corrective action is one of the key advantages of integration machine vision systems into industrial processes. This helps identify trends and random occurrences which could enhance quality control processes. The flexibility and complexity of modern manufacturing process brings challenges for the assurance of speed of production and quality of product [8]. The increasing demands on constant precision and reliability need sophisticated machine vision systems to carry out significantly varied inspection tasks. An early survey reported automated visual inspection systems and techniques [3], in which both the benefits and challenges of using CAD data or models, which contain exact specifications of an object in inspection, are highlighted and discussed. Based on the inspected features, the inspection tasks are categorized into four basic groups: dimensional characteristics, surface characteristics, structural quality, and operational quality [3]. Furthermore, a variety of software and hardware solutions for the ma- chine vision system development are reviewed [7]. In the review, real-time performance and verification of industrial machine vision systems as well as the temporal reliability were discussed and described. Machine vision systems are evolving with the technology advances, such as imaging sensors, digital interfaces, illumination, computational capability, artificial intelligence, communication, and network [9]. The emergence of low-cost and high-efficient embedded vision systems and smart cameras make it possible to build a scalable machine vision system for varied industrial applications. The integration of multiple cameras and multi-modal imaging systems offer a more robust solution for the difficulties in industrial inspection [10]. Fusing the visual information and those beyond visual spectrum can achieve a comprehensive inspection with less uncertainty. Industrial inspection is benefiting from such advances for improved accuracy and performance [11]. Mennel et al. [12] demonstrated that an image sensor can itself constitute an artificial neural network that can simultaneously sense and process optical images without latency. They developed a machine vision system based on a reconfigurable two-dimensional (2D) semiconductor photodiode array [13] [14], and the synaptic weights of the network are stored in a continuously tunable photoresponsivity matrix through supervised and unsupervised learning. Chai [15] developed an image-sensor array that acts as its own artificial neural network to capture and identify optical images simultaneously, processing the information rapidly without needing to convert it to a digital format. According to the study, development of such intelligent systems, together with the arrival of the 5G fast wireless network, should allow real-time edge (low-latency) computing in the future. Wu et al. [16] developed a human-computer interaction system based on machine vision of a smart assembly workbench. The purpose of this study was to achieve multi-variety and small-batch assembly through direct cooperation between equipment and people and to improve assembly efficiency as well as flexibility. The result showed that multi-variety and small-batch considerable increases assembly time and the developed human-computer interaction features, including prompting and introduction, effectively decrease assembly time.

Metrology is the science of measurement. And with that in mind, most machine vision systems perform some metrology task when determining if an object or feature is manufactured to within specified tolerances. Leite et al. [17] developed an optical metrology system for the measurement of the refractive index of glass. The study aimed to optimize a known technique to a simple, cost-effective and reliable system to be implemented in a lab environment, with an accuracy in the results better than 10−2. Choi et al. [18] proposed an in-process metrology technique that mitigates post-assembly process complications. This system monitors the co-phase character of the segmented optics during UV cured assembly, guiding the overall process. Zhang et al. [19] set up a correlation approach for quality assurance of additive manufactured parts based on optical metrology. The study provides standard validation approach to evaluate the plausibility of metrology data from in-situ real-time surface analysis for process planning of additive manufacturing [20] [21] [22].

3. Machine Vision Systems

Machine vision is the technology and method used to provide imaging-based automatic inspection and analysis for applications such as automatic inspection, process control, and robot guidance, usually in the industry [1]. It integrates image capture systems with digital input/output devices and computer networks to provide real time quality control and for general control of manufacturing equipment such as robots. Manufacturing industries favor machine vision for visual inspections that require high-speed, high- magnification, 24-hour operation, and repeatability of measurements. A machine vision system can work tirelessly performing 100% inspection, resulting in improved product quality, higher yields and lower production costs [23]. It consists of several critical components, from the sensor camera that captures a picture for inspection, to the processing engine itself (vision application) that renders and communicates the result [24]. It is an excellent tool for inspecting a variety of items such as industrial components, and machine tools. Figure 2 shows an outline of a machine vision system [25].

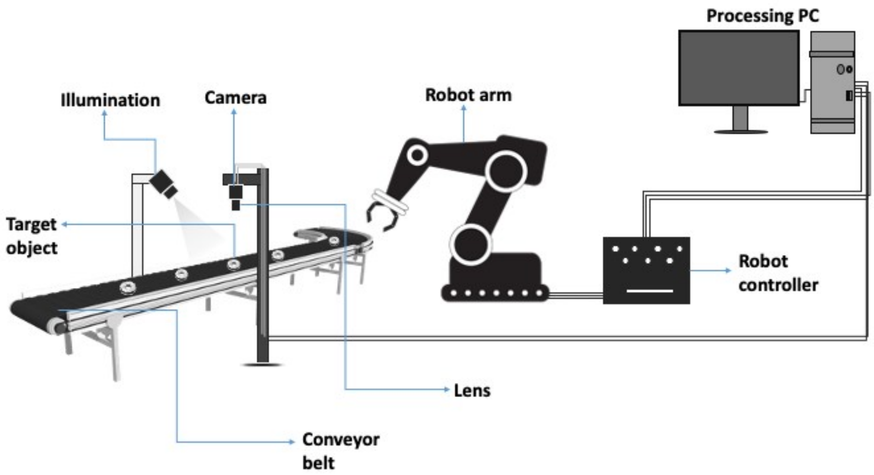

Fig. 2 An outline of a machine vision system [11]

4. Machine Vision and Metrology

Metrology is one of the many applications of machine vision. It involves an advanced analysis of a production line without becoming a bottleneck in the process [26]. Metrology is the science of calibrating and using physical measurement equipment to quantify the physical size or distance of any given object [27] [28]. It requires the use of a variety of physical scales to determine dimension and distance based on a combination of touch and/or optics. Traditionally, there are two kinds of dimensional metrology techniques: post- process and on-process dimensional measurement.

In the post-process, the measurements are made after the part has been produced. The inspection can be made over a percentage of the production or over the 100% of the parts. In the first case, if the dimensions are not within the given tolerance zone, corrective actions (modifications or even rejections) have to be made over the whole batch. On the other hand, 100% inspection ensures zero defects production, modifying or rejecting the defective parts. The inconvenience of the 100% inspection is that the inspection has to ensure the production cycle time as well as the required accuracy.

When the manufactured parts are big, with higher material cost and longer cycle times, on-process measurement is required to monitor the process, improve the productivity and reduce the cost. In the on-process measurement, parts are measured while they still are on the manufacturing process [29].

5. Application of Machine Vision

There is a wide range of Machine Vision software aimed at inspection applications. Machine Vision necessarily involves the harmonious integration of mechanical handling, lighting, optics, video cameras and image sensors. Depending on the user requirements, the software can be simpler, with a straightforward user interface, or software designed for more advanced users.

5.1 Quality Control Inspection Process

Moru & Borro [11] accomplished the desired quality inspection process measurement of gears acquired from a developed application when comparing the gears with the measurement of the nominal derived from a Coordinate Measuring Machine (CMM) analysis, within a specified tolerance. The standard gear parameters were set into the application for automatic reference. The parameters to be inspected were verified and their allowable tolerances assigned. The application interface performs the measurement of all gear parameter by calculating three parameters: the outer diameter, the inner diameter (also called root diameter) and the number of tooth. These three parameters were the most necessary values needed to calculate the rest of the gear parameters. The gear to be inspected was acquired and measured by the application, then the calculated parameters are compared with the nominal parameters according to the tolerances given.

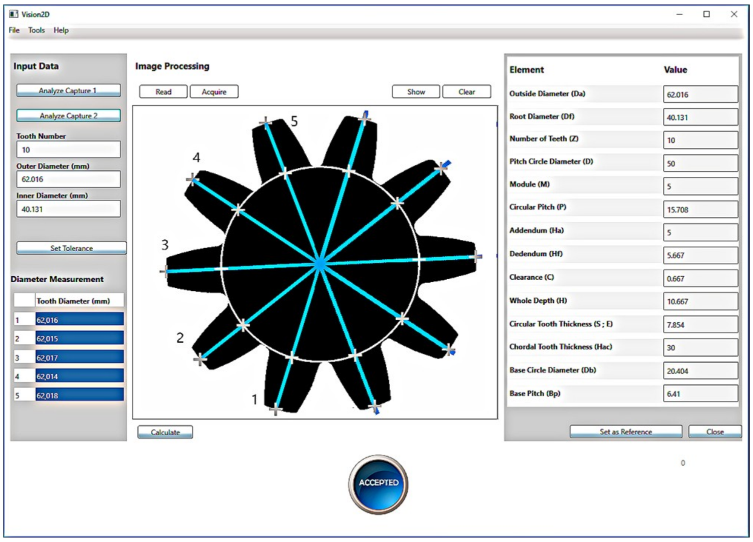

Fig. 3 Application interface [11]

5.2 A novel algorithm for tool wear online inspection based on machine vision

In order to inspect the tool wear condition in the process of numerical control (NC) machining for difficult-to-cut material, Hui et al [30] developed an online inspection system for tool wear based on machine vision. A self- matching algorithm was proposed according to the characteristics of tool wear images with the aid of MATLAB. The result showed that the absolute values of errors on the maximum wear width are less than 0.007 mm by using the self-matching algorithm. The system features high response speed, high inspecting accuracy, and anti-noise performance.

5.3 Inspection to verify adhesive beads

The inspection to verify adhesive beads shows how to use inspection to verify adhesive beads. Bead inspection can be used to detect the following errors: segments where adhesive is missing, segments with too much or too little adhesive, segments where adhesive is too far from its destined and position of beads. This application ensures that adhesives are placed on a part's surface in the precise location, without missing sections, and that each bead is the appropriate width and height [31].

5.4 Machine vision based papaya disease recognition

Habib et al. [32] proposed a set of features from the view point of distinguishing attributes to recognize papaya diseases through detection and classification. The online machine vision-based agro-medical expert system processes an image captured through mobile or handheld device and deter- mines the diseases in order to help distant farmers to address the problem. More than 90% classification accuracy was achieved, which appeared to be good as well as promising by comparing performances obtained with reported relevant works.

5.5 Improving optical pipeline through better alignment and calibration process

In this study, Moru & Borro [33] used a machine vision algorithm in the study of light and object alignments to monitor and achieve an optimal alignment system, in order to eliminate the effects of misalignment. The algorithm was tested with a not-optimal system to ascertain its efficiency. The study result showed that the effects of lens misalignment can be highly pronounced. If the lens is not mounted correctly, then the result will be an image that is not perfectly focused. Also, as a result of adjustments and motions during a measuring process, it becomes important to have an alignment system to avoid any possible errors that may result from a lack of alignment.

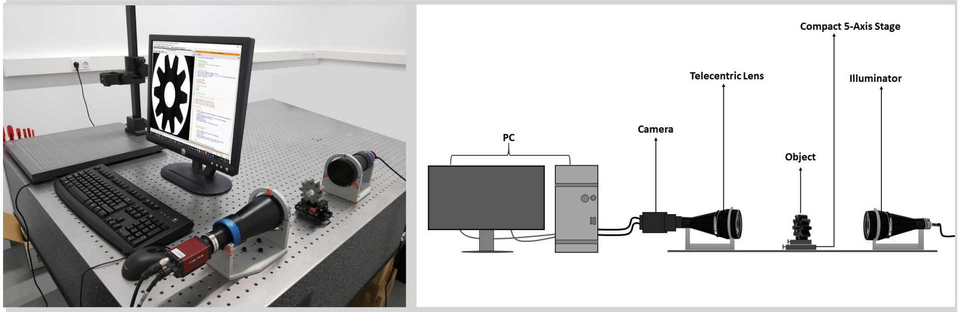

Fig. 4 Object alignment setup configuration [33]

5.6 Machine vision methods for analyzing social interactions

Quantitative analysis of social behavior has immensely improved both the scale and level of resolution with which we can dissect interactions between members of the same species using automatic machine vision methods. In this study, Robie et al. [34] reviewed these methods, with a particular focus on how biologists can apply them to their own work. They discussed several components of machine vision-based analyses: methods to record high-quality video for automated analyses, video-based tracking algorithms for estimating the positions of interacting animals, and machine learning methods for recognizing patterns of interactions.

As there is a wide range of software, it is important to analyze each software, focusing on those features that are useful for a given project [35]. Some example of different softwares from MVTec company are: iNspect, Sherlock, Merlic and Halcon. iNspect and Sherlock come as embedded software with the Teledyne DALSA BOA cameras, while Merlic and Halcon are external softwares for which a license is required for use.

6. Conclusion

This paper presents an overview study of machine vision and metrology systems. It studies machine vision and metrology systems, highlighting the two basic kind of dimensional metrology techniques. The paper studies some applications of machine vision systems and also highlights the range of machine vision applications for industrial inspection processes, stressing the importance of analyzing each application and focusing on the features that are useful for the particular experiment or project.

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