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Automated visual inspection in the semiconductor industry: A survey

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ABSTRACT

Automated visual inspection is an image-processing technique for quality control and production line automation. This paper reviews various optical inspection approaches in the semiconductor industry and categorize the previous literatures by the inspection algorithm and inspected products. The vision-based algorithms that had been adopted in the visual inspection systems include projection methods, filtering-based approaches, learning-based approaches, and hybrid methods. To discuss about the practical applications, the semiconductor industry covers the manufacturing and production of wafer, thin-film transistor liquid crystal displays, and light-emitting diodes. To improve the yield rate and reduce manufacturing costs, the inspection devices are widely installed in the design, layout, fabrication, assembly, and testing processes of production lines. To achieve a high robustness and computational efficiency of automated visual inspection, interdisciplinary knowledge between precision manufacturing and advanced image-processing techniques is required in the novel system design. This paper reviews multiple defect types of various inspected products which can be referenced for further implementations and improvements.

Contents

1. Introduction

Automated visual inspection (AVI) is image-processing method for quality control that has been widely applied in the production line of traditional manufacturing industries, such as for mechanical parts, vehicles, and the garment industry. The survey papers have reviewed several early inspection applications and related computer vision techniques, which consist of image representation, template matching, and pattern classification algorithms [1,2]. With the rapid development of computers and digital image-capturing devices in recent years, real-time optical inspection systems have also been realized in current precision production

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and assembly lines. This paper reviews various automated visual inspection approaches and related techniques in the semiconductor industry.

In most manufacturing industries, one goal is to achieve 100% quality assurance of the parts, subassemblies, and finished products, especially in mass-production industries. Product inspection is an important step in the manufacture process, and how to ensure that the quality of each product meets the standard is a challenging task. However, inspection tasks are time consuming, and mostly performed by human inspectors. The performance of the inspectors is inadequate, and the accuracy is often affected because of the fatigue of perfunctory task; moreover, human inspectors require training, and skills require time to develop. Compared to machines, the working hours of human inspectors are relatively short, and the cost of labor is a main consideration factor for manufacturers as well.

The electronics industry plays a vital role in modern precision engineering and manufacturing, which includes the design, layout, fabrication, assembly, and testing of various semiconductor components and products. The major products manufactured by the semiconductor industry include wafers, thin-film transistor liquid crystal displays (TFT-LCDs), and light-emitting diodes (LED). Because of growing competition and a decreasing gross profit margin, manufacturing process automation is critical for reducing production costs and improving efficiency. Over the past 15 years, the fabrication technology node used by the semiconductor industry has improved from 130 nm to 14 nm. Quality control and automated visual inspection systems employed in precision manufacturing have also been discussed widely to facilitate developing novel manufacturing techniques. The automatic visual inspection system is among the most critical automation tools used to reduce the labor force and increase yield rates. The goal of this survey was to study state-of-the-art AVI techniques and review several previous effective systems used by the semiconductor industry. In addition, this paper assesses various inspection products and related applications, and can be a reference for implementing and improving future manufacturing processes.

AVI has been developed for decades; the system can detect the same type of surface-related defect. The object or the product would be inspected by sensors, and visual data would be collected and returned to the system for analysis. The inspection process often involves a measurement of assembly integrity, surface finish, and geometric dimensions. Compared to the effectiveness of manual inspection, AVI is a desirable choice. Advances in technology and manufacturing devices have resulted in cheaper industrial visual inspection equipment. With better sensing devices and automatic equipment and a combination of computer technology, including pattern recognition, image processing, and artificial intelligence, an automatic inspection system can run in real time and be consistent, robust, and reliable. The use of an AVI increases productivity and improves product quality as well. In addition to ensuring product quality control, an automated inspection system can also gather statistical information to provide feedback to the manufacturing process.

As computer vision-based inspection has become one of the most important application areas, numerous related studies and works have been conducted, including on the conditions of hardware, the development of software, and related applications. Chin and Harlow surveyed AVIs from 1972 to 1980, including the application on Printed circuit boards (PCBs), photomasks, and integrated circuits [1]. They also discussed the system and the non-electrical industry. Chin conducted a survey following related development in the 1980s [2]. Thomas et al. provided a review of related works from 1973 to 1994 [56]. They focused on the machine vision algorithm, illumination, schemes, and real-time performance and verification. Newman and Jain also reviewed relevant works from 1988 to 1993 [57]. They especially focused on the CAD applied in AVI and the system. Malamas et al. classified applications into two parts: inspected features of the industrial product or process and the inspection independent characteristics of the inspected product or process [25]. They also reviewed the software and hardware tools of industrial vision systems.

Some of the studies focused mainly on specific products or techniques applied in automated inspection. Moganti et al. reviewed the algorithms and techniques applied in PCB AVIs [11]. Markou and Singh provided an overview of approaches of novelty detection, including the statistical approach and neural network (NN)-based approaches [23,24]. Kumar focused on the application on fabric defect detection, and presented a survey on the available techniques for the inspection of fabric defects [44]. Xie reviewed texture analysis techniques used in surface detection, and also discussed color texture analysis [45].

These studies presented an overview of automated inspection development in the past few decades. Advances in equipment, technology, and the methods applied in AVI have been significant. Moreover, manufacturing technology has improved; precision manufacturing has been gradually developed, such as micro-precision manufacturing and nano-manufacturing. Semiconductor fabrication technology advanced from micrometers to nanometers in a few years, and currently, the 14 nm manufacturing technology has been achieved. Product inspection requirements have become stricter and more challenging as products become smaller, and the assembly process is increasingly precise. However, studies investigating the application of AVI in the semiconductor industry are few, and a comprehensive survey has yet to be conducted. Therefore, this paper reviews the applications and related analysis algorithms of semiconductor product inspection developed between 2000 and 2013. AVI systems feature several specific elements designed to suit the unique characteristics of semiconductor products. Because the inspected electronic components may be composed of compound materials, such as silicon, germanium, and gallium, the complex image texture [8,16,50] contains abundant information that must be analyzed and understood. Moreover, precise inspection of nanometer-scale objects may require a high-quality imaging system. For high-resolution images, multiscale and super-resolution techniques [55] have been proposed to reduce time consumption. Various researchers have focused on the path planning in AVI systems [48] or on parallel computation [8,31,39] applied to increase system efficiency. In addition, designing special-purpose light sources or changing the image acquisition equipment may simplify the image analysis problems. For example, laser beams [3] and magneto-optic images [62] have been used to inspect semiconductor surfaces featuring special materials, such as translucent wafer.

In addition to the survey papers [1,2,11,23–25,44,45,56,57], previous literature was reviewed using two parallel methodologies. First, inspection algorithms were classified into four major categories: projection methods, filter-based approaches, learning-based approaches, and hybrid methods. Section 2 introduces these algorithms and reviews related previous studies, which are summarized in each subsection. Second, inspected products and applications used in the semiconductor industry were investigated. Semiconductor products discussed in previous studies can be classified into three categories: wafers, TFT-LCDs, and LEDs. Section 3 discusses the related studies and product defects. The current paper presents a profile of AVI systems used in semiconductor industry. Reviewing relevant literature using the two classifications of algorithms and products can clearly determine the algorithm characteristics, and also enable companies to select proper algorithms for developing their own inspection systems for manufacturing. Fig. 1 displays a review methodology tree showing the paper organization and related studies in each leaf node.