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Research Article

Optical System for Thin Transparent Surface Inspection

Dau Sy Hieu[1,*], Ta Chiu Hy[1], Le Nguyen An Khang[1], Thi Phuc Dang[2]

ABSTRACT

Automated inspection system now a day is a must in mass production lines. To optimize the abilities of the inspection system using computer vision (CV) technology in terms of accuracy and speed the input data should be as good as possible. The quality of input data for a computer vision system plays a very important role in this story. We can define a high-quality image as one that is characterized by clarity, sharp contrast, exceptional resolution, and a high system resolution (um/pixel). The ability to highlight defects in contrast to non-defective areas within a sample is a critical aspect of good input data, as it facilitates precise defect detection. When input data meets these criteria, computer vision systems can operate with enhanced accuracy and speed, ultimately improving the overall efficiency of quality control processes.

All above requirements can be archived just in case considering to the optical system (OPS) of CS system. The design of an optical system will be based on samples as per material, dimension, defect descriptions and requested system speed. There's many types of inspected samples and defects that will lead to the OPS's design being impossible or cannot be optimized to fit with requested requirement. One of them is the thin and transparent surface with tiny defects as: crack, dent, chip off... with the size of couple of 100 μm.

This paper introduces an OPS specifically tailored for inspecting storage disk surfaces before the coating stage in production lines, addressing these challenges. The goal is to enhance precision and efficiency in defect detection, contributing to advancements in automated inspection systems for specialized industrial applications.

Key words: Automatic Optical Inspection, Computer Vision, Illumination, LED lamp, Optics

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INTRODUCTION

In a factory, one of the most important requirements is inspection product quality with as high as possible accuracy. Manual inspection on random products is limited by human abilities, speed and experience which may lead to mistakes at any time. In last few decades, automatic inspection systems were widely applied to mass production line using many different techniques as per sensor, camera, laser scan…

In many sides of production factories, machine vision using digital camera now is applied and has brough new abilities, better accuracy, and longtime stability to inspection technics[1]. To achieve consistently accurate results, quality of input images must be considered in highest priority[2].

Quality of input image strongly depends on the lighting conditions and then, the result of algorithms depends on the quality of input images. In many cases, reflection from ambient light, uneven lighting intensity in series input images, the similarity of defects and normal areas are main reasons for missing detection. There are two missing detection types: underkill or overkill. Underkill is the case when the true defects cannot be detected and products can be sent out to market, Overkill is the case when wrong defect is recognized as true one so the good product will be rejected. Mostly, factory will put requirements on zero underkill even if the ratio of overkill is higher, it means the vision system must be designed with highest ability in highlighting object's abnormal area.

To have optimized design for vision system, engineers must understand that there's no general design for all objects. Size, outer and inner sharp, material, color of object or inspected area on object must be considered and put on calculation.

Numerous studies have been conducted over the past few decades to explore inspection methods for objects fabricated from transparent materials. Various techniques have been employed, including digital holography, parallel spectral domain optical coherence tomography, and adaptive energy analysis[3–6] or inspection and thickness measurement of thin films, glass wafers, and the detection of bubbles within transparent objects have been subjects of extensive research[7–10]. These proposed methods exhibit high efficiency in terms of accuracy, achieving detection rates exceeding 90% for detection purposes, with measurement errors ranging from 3% to 5%. However, a notable drawback of these methods lies in their

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optics systems, particularly the complexity associated with holography, tomography, and similar techniques when applied to on-the-fly systems. Additionally, the optical system's performance can be significantly affected by the working environment, further complicating the implementation of these methods.

In this research article, we have selected transparent plastic bases of hard disks as the object of study, providing a detailed description as follows. By utilizing this specific object, we propose an improved lighting design for an inspection system. This optical system allows highlight defects on inner, outer, and surface of transparent plastic bases of hard disks just in one image using a customized light head designed based on object parameters. The system provides ability of highlighting defects of the size 25x25μm. The test speed of each defect detection using Halcon library is less than 20ms, which is quite fast for real system deployments.

However, it should be noted that this illumination system is tailored to suit the experimental simulation of an inspection station within a controlled production line setting. In a real-world production line scenario, modifications will be made to the system to adapt and function optimally within the actual working environments.

OBJECTS, SYSTEM AND METHODOLOGY

Objects

To prove the ability of optical systems designed for thin transparent objects can bring better accuracy, high speed, we choose plastic bases of hard disk, which is made of plat, thin, transparent plastic material like hard disk as shown in Figure 1.

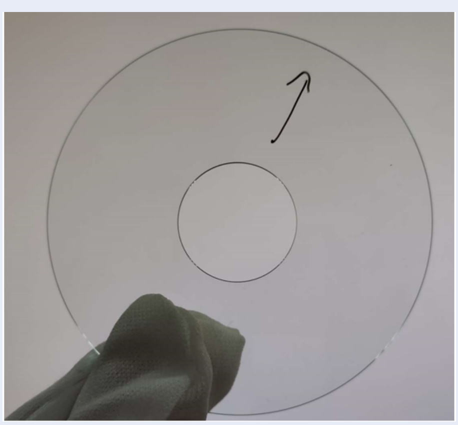

Figure 1: Plastic base of hard disk.

Inspection is usually carried out by operators or automated computer vision systems. It is easy to recognize the image in the worker's eyes when performing the inspection as shown in Figure 1. With this image, the inspection process will have to be performed with many influences of the worker's experience and take longer as the worker needs to rotate the sample in many different positions to be able to observe the entire top, bottom surfaces, or inner, and outer edges of the sample (hard disk surface). Easily to realize that in real samples, with human eyes (Figure 1), it's so hard to find the tinny edge defect which was shown by ink arrow on disk's surface.

The use of automated inspection systems always begins with the design of the optical system for image acquisition. The image requirements for inspection always include important points such as clear, good highlighting the objects to be inspected (in this case, defects on the hard disk surface), covering all the entire area requiring inspection, and other specific requirements for each particular object, such as color (if detailed color calibration is required), and the ability to see deeper under the surface [11–13].

Our inspection checklist includes cosmetic defects such as outer, inner sharps, surface cracks, surface scratches, surface dirty, edge tear, edge uniform, foreign materials.

System

Camera and lens. The image acquisition system in this article is taken using 12M resolution digital mono camera (4024 x 3036 pixels) with Rolling Shutter mode and a C-Mount 25mm lens to capitalize the high resolution of the camera. Rolling shutter mode was chosen because we decided to take pictures when the objects are stopped at inspection position. The physical size of each pixel in digital camera using is 1.85 x 1.85 μm, the field of view-FOV of this system is 95 x 72 mm that can cover all each object. Mono image is used because of higher contrast, lower optical aberration due to optical lens and lower images size in comparison with color images [14,15]. Schematic diagram and real images of the system are shown in Figure 2.

LED and LED Controller. We use blue high-power LED 1W (wavelength is 450-480 nm) for our lighting system. LED is used instead of halogen, or any other light source comes from two points that can affect on decision whether apply this design to real production line.

First: LED lighting system can work in pulse mode with very low duty cycle (less than 10%) instead of

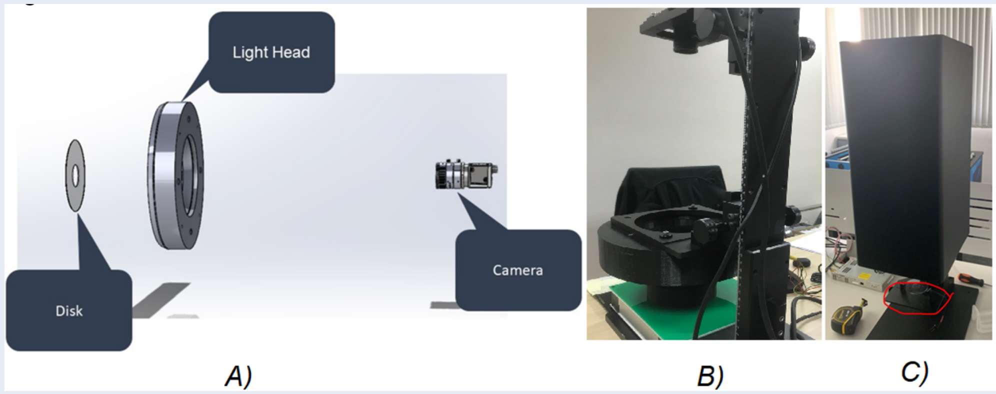

Figure 2: Schematic diagram of system (A), test system (B), and final system (C).

continuous mode, which leads to high power consumption.

Second: LED with pulse mode working in low duty cycle won't produce much heat even that's high-power LED. Sometime, the second reason get very high advantage point in decision from customer's point of view since it related to safety requirement in industrial environment[16–19]. Blue color LED was chosen due to the lighting technique we are going to use in this article is scattering Dark Field as described below. Average scattering ratio depend on λ^{-4} where λ is wavelength of incident light[20]. It means shorter wavelength better scattering.

To control the lighting system, we use a 48V PWM LED controller which manages stable output current instead of voltage to LED. This controller with current stable control will make sure that the intensity of lighting system can be maintained during longtime working. The LED controller can be set up with output current, pulse width and delay time of trigger in a flexible manner. The pulse width of output current can range from a few dozens to a few hundred microseconds. The pulses width is synchronized with the camera shutter speed, therefore, reduce LED active time, heat generation is also minimized and increase the lifetime of LED[21,22].

Illumination Lighting Method

Based on checklist of defects with cosmetic types as outer, inner sharps, surface cracks, surface scratches, surface dirty, edge tear, edge uniform, foreign materials…happen in a flat transparent surface, the illumination lighting method we consider using is scattering Dark Field (DF) with a designed light head which is suitable for individual above object. The principle of DF technique is shown in Figure 3A.

The reason is that the whole object is transparent material which allows light rays go through without deflection. At the position of defects, properties of surface will be abnormal, it scatters light rays in other directions. A part of the ray scattering comes to optical lens and in the image that certain area will be totally different with other position, as we call, it will be highlighted[23,24].

To get better highlighting of defects, angle between the main light ray area and the object's dimension need to be carefully consider. The main point of design is not any reflection of light can go directly to optical lens.

Based on the above notice, the real system was designed with the parameter as Figure 3B.

Pulse width we set in range of 0.1-1.0ms, with this speed, results can be considered to applied to real system in factory.

The background of the system should be black, to achieve this requirement we can design the system in two ways: put a non-reflection surface behind the objects or make sure that behind the object is an empty space without any ambient lighting source. In this article, we go with the first option: We put a black matter surface paper behind the inspected hard disk.

RESULTS AND DISCUSSION

DF illumination with a small ray angle related to disk's surface refracts on the edge which can be considered as an abnormal area with other area, goes to optical lens creating an enhanced effect. The edge can be highlighted very well as shown in FigFigure 4. With a non-defect disk, the inner and outer edge of the disk in image is very rough with even intensity as show in Figure 4A in other edge area except top position. At the position of edge defect (on the top area of Figure 4A),

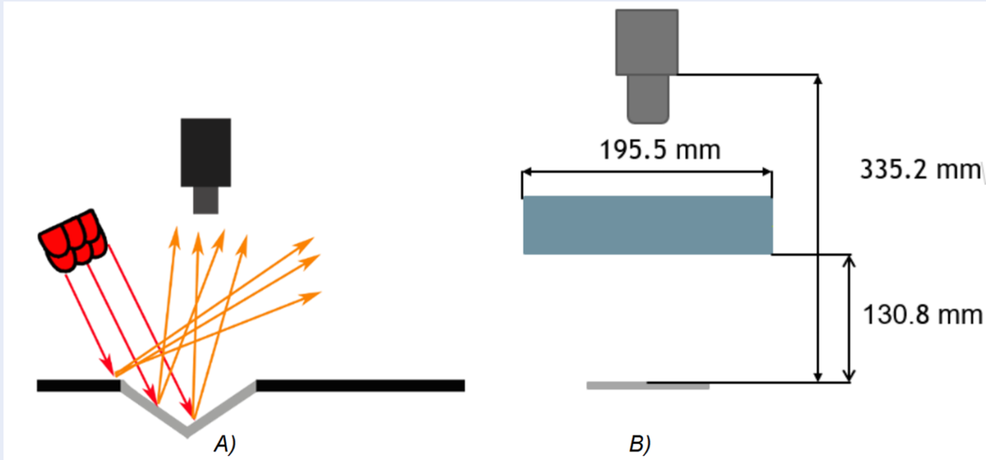

Figure 3: Scattering Dark Field principle.

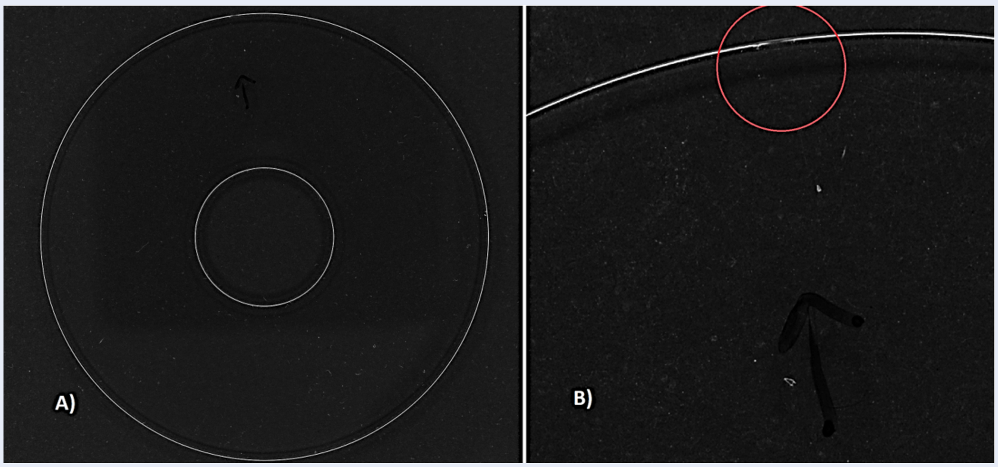

Figure 4: Image of object with outer edge defect (A) and zoom-in defect area (B).

those properties will be ruined in many ways that algorithms can easily detect as show in Figure 4B.

With defect at inner edge (Figure 5A at 6 o'clock position, in case of defect caused by a chip off, it will appear in image as a discontinuous area as shown in Figure 5B.

To make sure that this system can be applied to the real system, we put the disk on a 3-points holder that is used for fixing disk in production line at inspection station. The appearance of the holder can lead to unexpected light reflection, so we suggest making the holder form black plastic or covering it with matter black surface.

Scratches happen on disk's surface can be a deep or shallow peeled line due to friction between disks and convention line or is a result of a bad molding, cutting, or polishing during manufacturing. In principle with low angle lighting rays, reflection from those areas will create a brighter image on dark background as shown in Figure 6. In Figure 6B the scratch is shallow so can see that the different of gray values between defect and background a low and in general that value cannot be maintained the same in different cases but in design we should set LED brightness how to maintain background gray value less than 20. In this case, image processing algorithms can use a threshold with low value to eliminate background and detect scratches.

With a clear room environment, dust or fiber is an unacceptable type of defect. In the case of fiber, foreign materials or dust appearing on surface of disk, the coating process after this inspection station will be ruined. With this lighting technique and system reso-

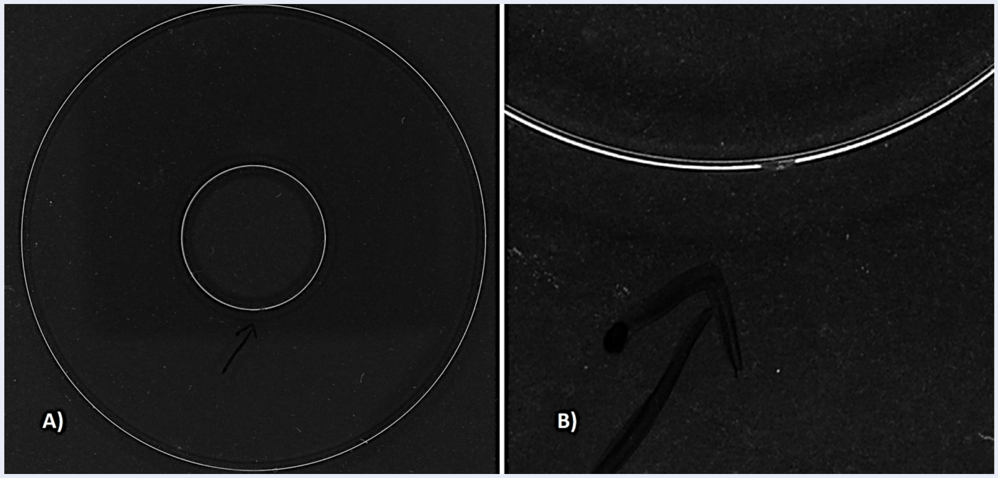

Figure 5: Image of object with inner edge defect (A) and zoom-in defect area (B).

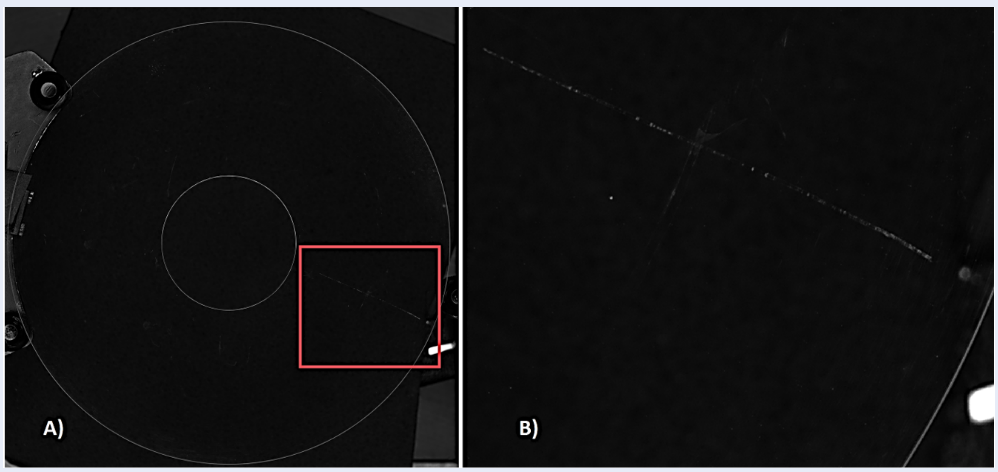

Figure 6: Image of object with surface defect (scratch) (A) and zoom-in defect area (B).

lution, fiber or dust with size more than 25μm should be detected as shown in Figure 7. The value 25 μm come from a basic calculation of system resolution as below:

$$SR = \frac{FOVw}{SSw} \quad (1)$$

Where SR is system resolution, FOVw is width of Field of View, SSw is Sensor Size width.

With more accuracy requirement, designer needs to consider not only focal length of optical lens but also the minimum spot image that lens can provide. For example, with physical pixel size is 2x2 μm, that doesn't make sense if we choose an optical lens with smallest provided diameter spot image bigger than 2 μm and waiting for an ability of detection any defect bigger than 2 pixels in final images.

To evaluate the advantage of input images from the designed optical system, we use and image processing script using Halcon library to detect defects. As shown in Figure 8 with fastest and slowest inference time over detecting on 154 images taken by our system, we can see that the inference time for detecting small defects (their size is less than 0.3mm) on sample is 9.7-12.2ms. We can see that with this fast inference time, this optical system can be allied to a real factory system.

To have a comparison on power consumption between continuous mode and pulse mode in our designed system, we can use the following formula:

$$P = kUI \quad (2)$$

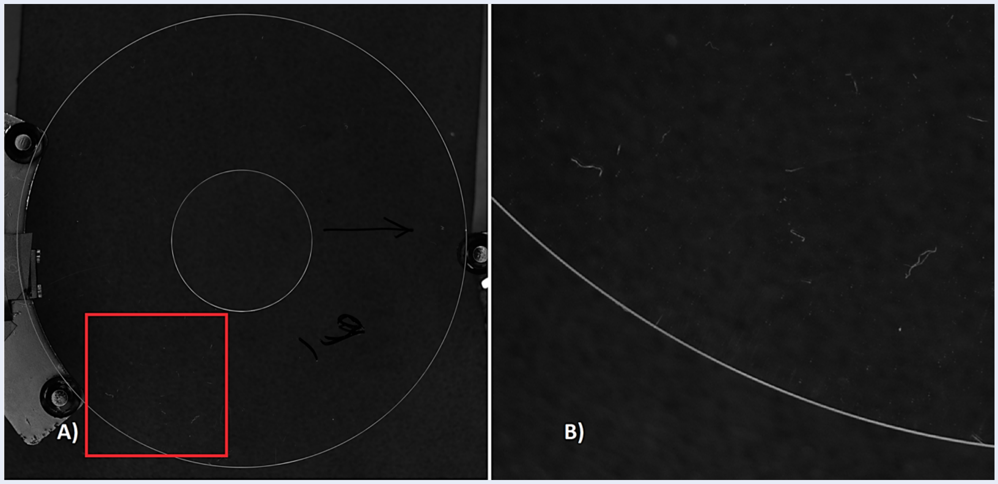

Figure 7: Image of object with dirty, fiber on surface defect (scratch) (A) and zoom-in defect area (B).

Where P is the power consumption, U is the input voltage of light head, in this case it is 48V, I is the input current to light head, in this research we set at 400 mA, k is the duty cycle, in case of continuous mode it is 1.0 and with our design, it can be calculated as:

$$k = \frac{t_{pul}}{\frac{1}{n}} \quad (3)$$

Where n is frame rate (fps) of camera, for this research we set at 10 fps, t_{pul} is the pulse width, in this case, the longest pulse width we set at 1ms.

Using (2) and (3) formulas, the power consumption of continuous mode should be 19.2W and for our pulse mode design with maximum pulse width is 0.192W. In terms of lighting system's power consumption, pulse mode can save about 99% in comparison to continuous mode. That is an important point that must be considered on vision system using for real factory line.

CONCLUSION

With a thin transparent object, scattering DF technique of lighting is a better choice for inspection purpose. In this article, we work on customized design of a vision system using for inspection edge and surface qualities of thin transparent base of hard disk before coating process.

With lighting technique, high resolution camera with suitable optical lens, defects clearly appear on image taken by vision system. With those images, image processing technique can be applied with not complicated algorithms to detect all indicated defects on edge or surface with minimum size of defect is 25μm. With defects such as surface scratches, cracks, and chip off on the edges of transparent thin objects, specifically in this study, the surface of a hard disk, the research results have demonstrated the feasibility of implementing an on-the-fly inspection system. Acquiring clear images with high contrast between the defective and non-defective areas on the surface of transparent thin objects helps optimize the input data, making the design of defect detection algorithms or models simpler and more efficient. Additionally, a dedicated lighting system designed for each product ensures consistent and stable lighting conditions to highlight defects, ensuring long-term accuracy and stability for the inspection system.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHORS' CONTRIBUTIONS

Dr. Sy Hieu Dau, Chiu Hy Ta, and Le Nguyen An Khang participated in the design of the optical system and the acquisition of image data from the specimens. Dr. Thi Phuc Dang contributed to the image processing and verification.

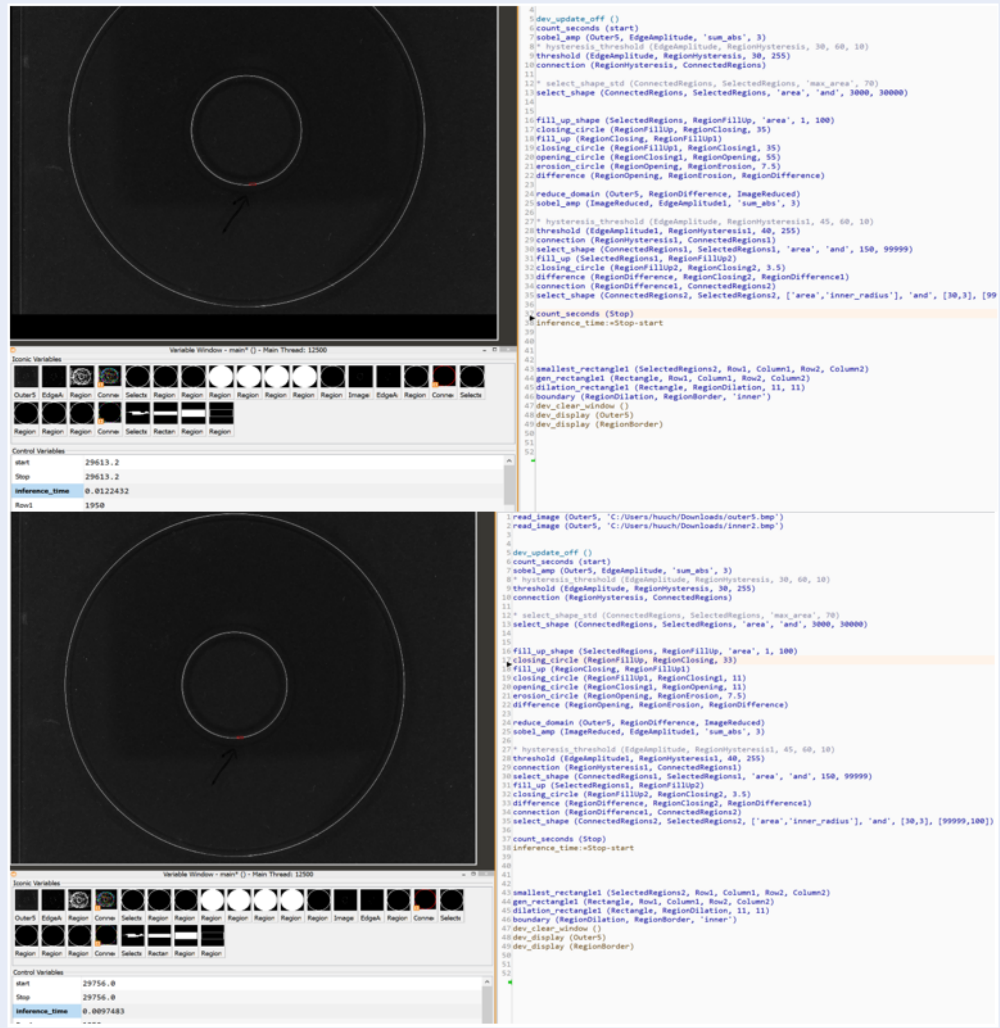

Figure 8: Image processing results.

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Tạp chí Phát triển Khoa học và Công nghệ – Engineering and Technology 2023, 5(SI2):1-9

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Bài nghiên cứu

Hệ thống quang học dành cho kiểm tra lỗi trên bề mặt mỏng, trong suốt

Đậu Sỹ Hiếu[1,*], Tạ Chiu Hỷ[1], Lê Nguyễn An Khang[1], Đặng Thị Phúc[2]

TÓM TẮT

Hệ thống kiểm tra tự động hiện nay đã trở thành một yếu tố không thể thiếu trong các dây chuyền sản xuất hàng loạt. Để tối ưu hóa khả năng của hệ thống kiểm tra bằng công nghệ thị giác máy tính (CV) về độ chính xác và tốc độ, dữ liệu đầu vào nên được cải thiện tối đa. Chất lượng của dữ liệu đầu vào cho hệ thống thị giác máy tính đóng một vai trò rất quan trọng trong câu chuyện này. Chúng ta có thể định nghĩa một hình ảnh chất lượng cao như một hình ảnh có độ rõ ràng, sự tương phản sắc nét, độ phân giải xuất sắc và độ phân giải hệ thống cao (micromet trên mỗi pixel). Khả năng làm nổi bật các khuyết điểm so với các khu vực không bị lỗi trong mẫu là một khía cạnh quan trọng của dữ liệu đầu vào tốt, giúp tạo điều kiện cho việc phát hiện khuyết điểm chính xác. Khi dữ liệu đầu vào đáp ứng những tiêu chí này, hệ thống thị giác máy tính có thể hoạt động với độ chính xác và tốc độ cao hơn, từ đó cải thiện hiệu suất tổng thể của quy trình kiểm tra chất lượng. Tất cả những yêu cầu trên có thể được đạt được chỉ khi xem xét đến hệ thống quang học (OPS) của hệ thống CV. Thiết kế của một hệ thống quang học sẽ dựa trên các mẫu vật về chất liệu, kích thước, mô tả khuyết điểm và tốc độ yêu cầu của hệ thống. Có nhiều loại mẫu vật và khuyết điểm được kiểm tra có thể dẫn đến việc thiết kế OPS trở nên không khả thi hoặc không thể tối ưu hóa để phù hợp với yêu cầu.

Một trong những trường hợp phức tạp đó là khi xử lý các bề mặt mỏng và trong suốt có khuyết điểm nhỏ như vết nứt, lõm hoặc bong ra... với kích thước chỉ vài trăm micromet. Trong bài báo này, chúng tôi giới thiệu một OPS được thiết kế đặc biệt để kiểm tra bề mặt đĩa lưu trữ trước giai đoạn phủ trong dây chuyền sản xuất, nhằm giải quyết những thách thức này. Mục tiêu là tăng cường độ chính xác và hiệu suất trong việc phát hiện khuyết điểm, đóng góp cho sự tiến bộ trong các hệ thống kiểm tra tự động dành cho các ứng dụng công nghiệp chuyên biệt.

Từ khoá: Kiểm tra quang học tự động, Thị giác máy tính, Hệ chiếu sáng, Hệ led, Quang học

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