Invited Paper

Microscopic Image Analysis of Defect Areas in Optical Disks

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ABSTRACT

This paper presents techniques developed at the Information Technology Laboratory of the US National Institute of Standards and Technology (NIST / ITL) for enabling microscopic image analysis of optical data storage media such as optical disks. These non-destructive techniques allow investigators to easily locate on the media a pre-existing series of media defects. These techniques can be applied to any type of optical disks including CDs and DVDs. The paper describes the experimental setup and the techniques utilized to achieve localization and registration of media defects. These techniques include data acquisition, computer control, auto focus, image processing, and remote control and observation. An extension of this setup utilizing available graphical programming environments can allow investigators at different locations to share and discuss the information on media defects by use of the Internet.

Keywords: CD, DVD, microscopic defect analysis; microscopic image processing; optical disks measurements, data storage, media defects analysis.

1. INTRODUCTION

The microscopic image analysis of media defects described in this paper is performed by means of experimental metrology developed at NIST. It is utilized as a measurement tool for optical disk media defect localization (e.g., relation to tracks). The measurement system has the capability of working in conjunction with commercially available testers for easy localization and statistical acquisition of a very large number of defects, and quantization of defect sizes. It is currently being used for the analysis of optical disc media acquiring media defect information (e.g., location, defect image, defect size). One of its purposes is analyzing detailed defect growth after the media is subjected to different environmental conditions. Testers previously developed at NIST [1] and commercial testers based on rotating optical disk media, provide comprehensive information about media characteristics including the location of defective sectors, bit error rates and burst error rate values.

The experimental setup for microscopic image analysis described below, in conjunction with these testers, allows for a nondestructive measurement approach to determine optical storage media reliability and their aging characteristics [2]. It is also being developed as a collaborative remote measurement tool for teams of investigators developing new types of optical data storage media. The procedure described below is not aimed at producing an exhaustive analysis of the entire disc surface but rather at obtaining in-depth inspection of interesting areas. Defect localization utilizes of the commercially available image processing software. An analysis of the evolution of defect areas is possible after specific environmental or other aging procedures are conducted on the media. The media analysis compares successive media defect images before and after environmental experiments are performed.

2. EXPERIMENTAL SETUP

The image analysis subsystem depicted in Figure 1 consists of a microscope that uses a mercury lamp as the light source. The setup includes an interference filter at 546 nm as well as an objective lens (x100, NA = 0.8) with an adjustable correction for the optical media substrate thickness.

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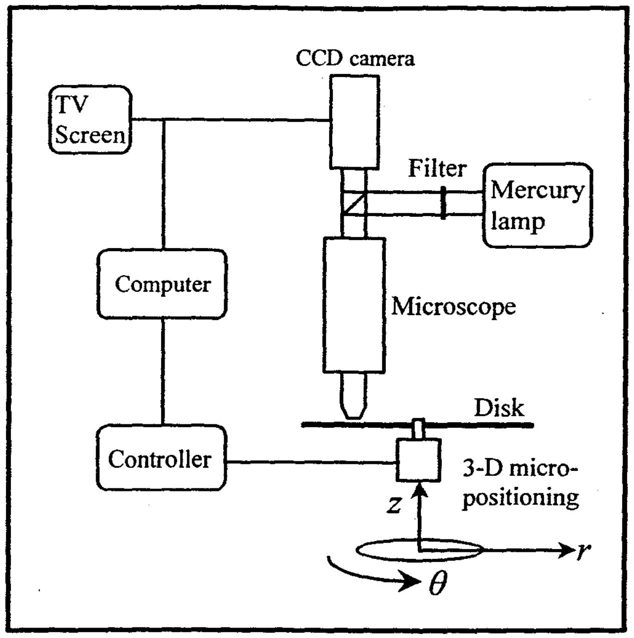

Figure I -Image analysis experimental setup

A CCD camera is used to acquire an image of the selected media surface. The subsystem includes image acquisition hardware and software developed in LabVIEW##, a graphical programming development environment [3]. LabVIEW includes features required for this application such as libraries of functions for data acquisition, GPIB and other interfaces for instrument control, data analysis, data presentation, storage and remote monitoring and control of experiments.

The configuration utilized in this experimental setup includes strong image analysis capabilities. The subsystem also includes a micro-positioning stage that allows for a 3-D displacement of the stage along r, e and z coordinates.

3. PRINCIPLES OF MEASUREMENTS

Reliability analysis of data storage media consists of subjecting these media to different tests, including extreme environmental conditions. Approaches to media analysis include monitoring defect manifestation and growth with time, or the localization of new defects, when the media is subjected to certain testing environments. When the media needs to be inspected with both image analysis systems as described above and also with commercial testers to obtain other indicators of media degradation (e.g., Bit Error Rate), non-destructive testing techniques are required. These tests allow for analysis of the correlation between defect growth and the behavior of the media under other testing systems that required utilizing whole media.

To utilize the experimental setup described in this paper for media reliability analysis, it is necessary for the computer-controlled micro-positioning system to be able to return to known positions on the medium or to localize defects previously found on the medium. To achieve the correct localization of media defects, the image analysis system must be able to achieve auto-focus (without normal media rotation) and correct re-positioning of the microscope over these media defects.

Certain commercial products may be identified in order to adequately specify or describe the subject matter of this work.

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The experimental setup utilizes the recurrent characteristics of the optical data storage to achieve, via image processing software, the micro-positioning of the medium under study. It utilizes these recurring optical disc characteristics for the automatic localization of defect areas. Typical image processing techniques such as filters and thresholds are used. The current setup allows analysis of the evolution of defects by comparing successive images of the same storage media areas.

3.1 Auto-focusing capabilities

Commercial optical disk drives require auto-focusing mechanisms for correct reading and writing of the disks [4], [5]. Although the measurement method described in this paper does not require rotating the media at normal operating speed as in a commercial drive, the testing setup includes auto-focusing capabilities required by the micro-positioning subsystem.

Different approaches for achieving the required auto-focus were examined including hardware-based solutions [6] but the decision was made to incorporate more flexible software-based solutions. In this case, a general-purpose microscope can be used without any modification. The current solution allows for simultaneous movement of the micro-positioning stage and auto-focus.

One of the initial approaches to achieving auto-focus was to develop a method based on Fourier Transform. This method is based on performing a comparison of image frequency spectrum when focus is achieved versus when the medium is out of focus. The method did not render satisfactory results when it was applied to written or unwritten optical disk media. Some of the disadvantages of this method include the limited maximum size (smaller than the original images that could be obtained directly from the microscope) and the limited overall speed that could be achieved.

For a subsystem that is nearly in focus, the algorithm that rendered highly satisfactory results was based on obtaining the mean and the standard deviation from the histogram of pixel gray values as explained below.

The classical definition of the standard deviation σ is:

$$\sigma = [(\Sigma (P_i - \mu)^2)/ n]^{1/2}$$

where:

"i" is the gray level of a pixel [0 to 255]
P_i. is the number of pixels with a gray level of i
"n" is the total number of pixels

In the experimental setup described in this paper n is 640 x 474 = 303,360.

The mean value μ is:

$$\mu = \Sigma P_i / n$$

Characteristics observed by utilizing σ and μ as the indicators include the following (see Figure 2):

- During movement of the micro-positioning system along the z direction, σ reaches a sharp peak at the best focus position with no presence of secondary peaks around it.
- When the image is out of focus, the σ values are smaller than the value in the focus position. In those instances, σ does not provide information about the required direction of movement along the Z axis (up or down) to achieve the focus position. Another indicator is required.
- The mean value μ shows a monotonic variation near the focus position. This indicator, as shown in Figure 2, provides feedback information on what direction the focusing system should move to achieve focus.

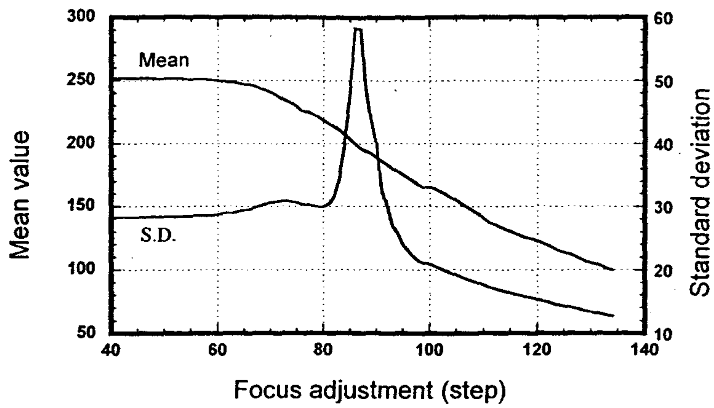

Figure 2 -Standard deviation and mean values along the Z axis

These two indicators (σ and μ) have rendered very satisfactory results for this application because the mean curve profile is monotonic. To obtain this profile, however, a good image acquisition system is required before any digital processing can be performed. The experimental setup produced the required image quality.

The best mean value on focus is around 150 -200. This is the case because this value allows for a wide monotonic profile on both sides of the focus point. This is met when the histogram has the profile shown in Figure 3. This profile depicts pass-band limiting total black and total white pixel values and the presence of two maxima in between.

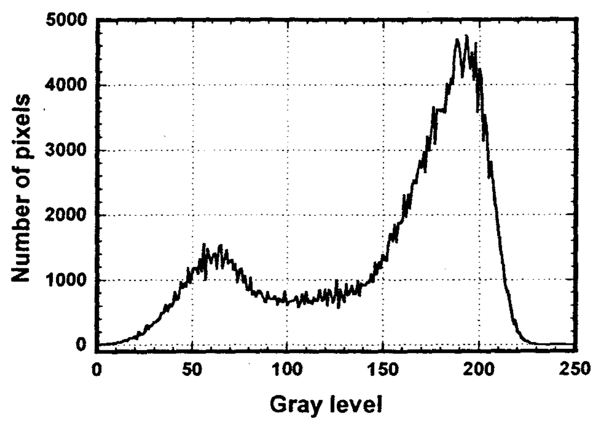

Figure 3 -Histogram profile

3.2 Displacement and Defect Localization

As stated above, one of the requirements of the experimental setup is to precisely return to previously identified areas of interest (e.g., media defects) after non-destructive experiments have been conducted on the medium. In order to do that, the location of any area of interest or defect is recorded in a virtual library (using its coordinates). The virtual library is used to ease the management of the areas of interest. A program that has been developed as part of this experimental setup allows for the movement of the microscope stage to new areas of the medium (by entering the parameters of a new area) or the localization of areas previously inspected. The image processing software uses the medium to enable micro-positioning and automatic localization of interesting or defective areas as discussed above.

The micro-positioning subsystem provides relative, instead of absolute, coordinate information. Therefore, to re-examine an area of interest the image processor routines require determination of a reference point in advance. The method used with the current setup is to start the analysis from a known region of the medium.

To do this, the localization program moves the microscope stage along the radial direction (r) until it reaches a reference point such as the blank outer area of the disk and then localizes (along the 9 direction) the beginning of the bit stream. This location (expressed as number of pulses counted by the micro-positioning subsystem along the r and 9-axis) is stored in the virtual library. Another reference point is the center of rotation of the micro-positioning stage.

When a certain area of the disk or defect recorded in the library needs to be found, the system positions the microscope stage above the reference point and the micro-positioner is moved to the location of interest using the coordinates previously obtained. Development of remote monitoring and controlling for defect localization is underway. The method consists in providing on-line communication over the Internet to enable remote tester operation and media analysis. More specifically, the on-line infrastructure is designed to achieve full remote controlling of instrumentation and acquisition of the testing results. This feature is useful when researchers or developers involved in the same project are geographically separated. The design goals include: (a) providing still images directly from the microscope; (b) remotely accessing the experimental results (including the display of charts and processed images); and (c) enabling remote scanning of the media surface.

4. FUTURE OPTIMIZATION OF THE EXPERIMENTAL SETUP

4.1 Required improvements

A few improvements, which could help the experimental setup to reach better quality in defect registration and localization, include better optics, more precise micro-positioning stages and improved searching algorithms. More details about these possible improvements are discussed below.

Improved optics in the experimental setup would enable a total characterization of developmental or commercially available optical disc media such as DVD-ROM and DVD-RAM discs. A new objective lens with a coversheet compensation collar, which fits the DVD's plastic substrate thickness (0.6 ~m), is needed to replace the current adjustable correction objective lens.

A more precise stage can avoid the large variations along the θ-axis that are encountered in the current setup.

An optimized automatic search algorithm for optical disks has been tested but it is not yet fully developed. This search algorithm is based on an analysis of the distance between the disk tracks as depicted in Figure 4.

The algorithm is designed so that the experimental setup can localize defects such as air bubbles, distortion, bumps, holes, and scratches. In order to achieve this goal, the design calls for applying a threshold to obtain a binary image of the separation between pits from lands and the determination of lines that depict each disk track. Vertical lines are then drawn to measure the distances between the horizontal lines.

The signal-to-noise ratio (S/N) that is achieved is good enough for the experimental system except for some very bright input. The good image quality assured previously limits this problem in the good area, that is, approximately at the middle of the pixel gray levels) with the exception of input light intensity variations which can exist when the lamp has aged or is
ON for a long time.

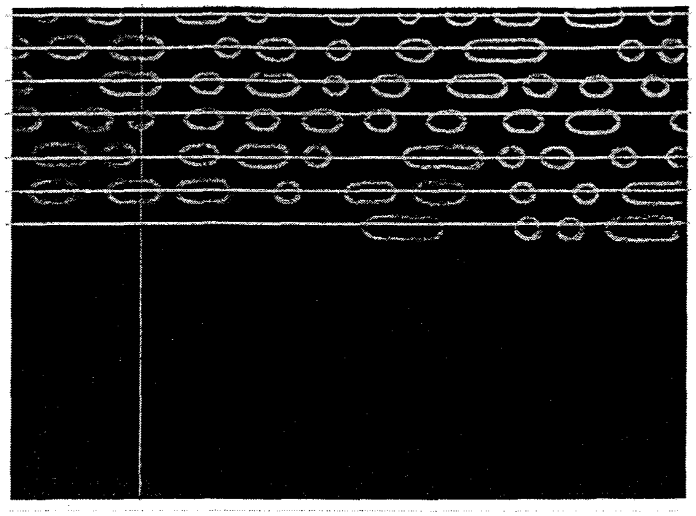

Figure 4 -Automatic defect search

4.2 Synchronization with commercially available testers

Another feature under development includes synchronizing the experimental setup with data provided by commercially available media testers. These testers provide global information about disk media characteristics (e.g., Byte or Burst Error Rate, and count and localization of defective sectors). Other available testers previously developed in-house also provide information on defective sectors and media error distributions. Figure 5 depicts a graphical representation of media error distribution on an optical disk, obtained from one of these testers [1]. The chart represents maximum number of errors measured on band of tracks (from the inner area to the outer area of the disk) for a particular sector number.

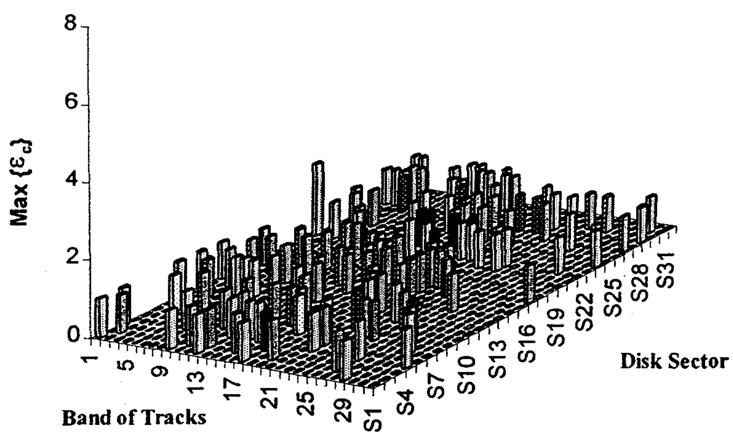

Figure 5 -Representation of data errors on optical disk storage media as maximum number of errors per band of tracks and disr::-sector

5. CONCLUSIONS

We have shown the development and implementation of a microscopic image analysis of optical disks. We have developed techniques to easily locate on the media a pre-existing series of media defects. The auto-focusing algorithm developed for the experimental setup has rendered highly satisfactory results. The method is based on obtaining the mean and standard deviation from the histogram of pixel gray levels. Although limited in precision, the cUITently available micro-positioning subsystem allows for the correct localization of media defects. The current setup allows for monitoring of defect growth or new defect localization when the media is subjected to environmental and other aging tests. Future optimization of the experimental setup includes improved optics (i.e., a new objective lens with a coversheet compensation collar for DVD measurements, and testing of the optimized search algorithm. Future work includes developing the techniques for remote monitoring and control of defect analysis systems that would allow a team of investigators to remotely examine developmental media.

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