Detection of Secondary Reflections Using Morphology

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ABSTRACT

This paper discusses very simple but effective one-dimensional morphological techniques for the identification of primary and secondary peak locations associated with reflected light patterns from glass surfaces. A common optical technique for measuring glass thickness and related properties is to observe light reflected from the glass surfaces. Two reflections can be observed when an appropriate structured light source is used to illuminate a glass surface. A very bright primary reflection associated with the reflection from the front surface will be observed along with a much fainter secondary reflection from the back surface. The secondary reflection is difficult to detect reliably given the large difference in magnitude between the two peaks, the presence of noise, and the varying amounts of overlap between the two peaks that can occur. The methods described in the paper have been implemented successfully for two vision applications using images acquired using standard matrix and linear cameras. The signal is pre-processed using one-dimensional morphological and linear methods to normalize the background and remove noise. Further morphological operations are performed to identify the peaks associated with primary and secondary reflections.

Keywords: signal processing, mathematical morphology, dielectric thickness measurements, light section microscope, structured light

1. INTRODUCTION

Morphology has been a significant and very useful technique for image analysis and processing. Initially developed for binary image processing, it has been developed further to process gray-scale images by treating gray-scale images as three-dimensional surfaces. In this paper, elementary gray-scale morphological concepts are applied to one-dimensional signals to find distances between primary and secondary peaks associated with light reflections. Light reflections associated with a change in the index of refraction commonly occur, and are useful for detecting boundaries between different materials.

The morphological techniques that are used here are based on the basic properties of erosion and dilation. Gray-scale erosion is given as

\[(X \ominus B)(x, y) = \min_{(j, y) \in B} \{X(y + j, x + j) - B(j, i)\}\]

in which \(X\) represents a gray-scale image and \(B\) is a structuring element. When the structuring element is placed over the pixel at \((x, y)\), the difference between the image pixels and corresponding structuring element values is calculated. The minimum value becomes the pixel value at \((x, y)\) in the eroded image. Similarly, the expression for dilation is

\[(X \oplus B)(x, y) = \max_{(j, y) \in B} \{X(y - j, x - i) + B(j, i)\}\]

which is similar to erosion except that the pixel and structuring element values are added and the maximum value is chosen. Note also that if the structuring element is not symmetrical, the reflection of the structuring element about its origin must be used for erosion.

Performing a gray-scale erosion on an image produces a new image that is generally darker than the original image, at least in certain regions. If there are small bright regions in an image that are spanned by the structuring element, they will be removed. The opposite effect is observed with gray-scale dilation. At least some portions of a dilated image will be brighter and dark regions smaller than the structuring element will disappear.

Morphological openings and closings are obtained by using both erosion and dilation. To perform an opening on an image, the image is eroded with a given structuring element and the resultant image is dilated using the same structuring
element. To close an image, the operators are used in the reverse order with a common structuring element. The advantage of openings and closings is that they have no effect on image areas that lack features smaller than the selected structuring element. Openings suppress small bright regions and closings suppress small dark regions. The shape and gray-scale values of the structuring element also determine the effect that a given operation will have on an image.

In this paper, two applications which use morphology to identify primary and secondary reflections are presented. The first application, the measurement of dielectric thickness in AC plasma display panels, employs a light section microscope (LSM). Figure 1 illustrates the basic construction of this type of display device in which dielectric material is applied over a glass substrate with thin-film metal electrodes. When the device is assembled, the substrates are oriented so that the electrode patterns are orthogonal to each other with spacers separating the two substrates. Prior to final assembly, dielectric thickness is measured using a video camera and frame grabber with the LSM. An image is captured in which the top surface of the dielectric appears as a very bright horizontal line. A secondary reflection, associated with the dielectric/glass interface causes a much dimmer reflection. A plot of the intensity profile given in Figure 2 illustrates the nature of the data. The distance between the two peaks is proportional to the dielectric thickness. It should be noted that the difference between the two peaks is actually much greater than the plot indicates since the data has been logarithmically transformed prior to plotting.

The other application is similar but the data are of poorer quality because of the manner in which acquisition was performed. A linear camera was used here. Due to confidentiality considerations, no further information about the application can be disclosed except for the basic approach used to preprocess the data and find the distance between the primary and secondary peaks.

In both applications, data analysis is performed to measure the distance between the two peaks but important differences exist. With the proprietary application, preprocessing reduced the effects of high noise levels. For dielectric thickness measurements, obtaining accurate measurements with limited spatial resolution was a prime objective. Averaging was used extensively so noise was less of a problem but the relatively coarse spatial quantization imposed special processing requirements.

A description of this hardware is given in the next section. In the following section, the basic algorithms used to find the distance between primary and secondary peaks are presented. A discussion of the processing unique to each application is also provided.

2. DATA ACQUISITION

In order to achieve accurate measurements, various components including the LSM, video camera, frame grabber, and motion control hardware had to be assembled into a suitable system. The LSM was the most important component since it provided images that could be analyzed to extract three-dimensional information including dielectric thickness. A general overview of the system is shown in figure 3, illustrating the various system components.
2.1 Surface Profile Measurements

The LSM is a surface testing instrument which produces a surface profile. With this method, an optical "cut" is made across the surface to be measured using structured light. An incandescent lamp is masked by a slit and the result is focused using an objective lens. This produces a narrow band of light at a 45 degree angle to the surface of the dielectric surface. The light band is reflected off of the surface and is imaged by the microscope at the 45 degree angle of reflection corresponding to the angle of incidence.

![Diagram of LSM setup](image)

Figure 3. Hardware used for dielectric thickness measurements. The box in the lower left corner provides additional information about the optical head.

A cross-line reticule is provided in the eyepiece for manual measurements but is not used in this application. A camera port is provided on the microscope suitable for use with a video camera. A moveable mirror is provided to select the camera port or eyepiece but for this application, the camera port is normally used.

2.2 Motion Control Hardware

In order to measure dielectric thickness at various locations on a glass substrate, either the substrate or microscope must be moved. Moving the substrate was more practical since it weighs less than the microscope and video camera assembly and has no cables attached. An X-Y table with stepper motors is used to position the substrate. With this
the substrate is mounted on the table with a fixture to secure and position the substrate in a consistent manner relative to the table. Given that there is some variation in the electrode pattern relative to the substrate, X and Y offset adjustments can be made using a fiducial reference point in the electrode pattern.

The stepper motors are driven by a pair of controllers that accept ASCII commands from the host computer via a serial cable. The controllers provide the necessary velocity profile by controlling acceleration and deceleration to minimize the time required for movement. A variety of commands may be presented to the controllers such as relative and absolute moves, setting various motion parameters, enabling either the X or Y controller, etc. Status information is obtained by reading characters from the controller after the appropriate command has been issued to it.

Since panel substrates will not be perfectly flat, it is also necessary to control the distance between the microscope and the surface in a given region of the substrate. In this case, the microscope is moved since the distance is quite small. As the X-Y stage moves to a given location, the microscope height is adjusted so that the dielectric surface remains in the same relative position in the field of view of the LSM.

After each image acquisition, the dielectric surface is identified and a corrective movement is made if the position of the surface was above or below the target location. If the discrepancy is large, a new image is acquired after correction. Generally, a second image is only required when moving to a new spacer location.

2.3 Image Acquisition Hardware

For image acquisition, a standard RS-170 camera is attached to the camera port of the LSM using a custom C-mount adapter. A combination VGA and frame grabber card digitizes and stores the camera signal. A live video image can be shown on the VGA monitor with this board so that an additional monitor is not required for setup. The VGA memory is also used for image capture so that text or graphics may be combined with a recently captured image.

3. GENERAL APPROACH FOR IDENTIFYING PRIMARY AND SECONDARY PEAKS

As stated in the introduction, both applications provided measurements based on the distance between the primary and secondary peaks. The same basic technique for identifying peak values was employed in both applications although preprocessing differed considerably.

3.1 One-Dimensional Gray-Scale Morphology

In these applications, data can be analyzed using one-dimensional (signal) analysis techniques. This simplifies the processing since the one-dimensional dilation and erosion operations are expressed as

\[(X \oplus B)(x) = \max_{(i) \in B} \{X(x - i) + B(i)\}\]

\[(X \ominus B)(x) = \min_{(i) \in B} \{X(x + i) - B(i)\}\]

respectively. A further reduction in processing complexity was achieved by using a zero-thickness structuring element consisting of a set of adjacent points of variable length. Dilation and erosion could now be expressed as

\[(X \oplus B)(x) = \max_{(i) \in B} \{X(x - i)\}\]

\[(X \ominus B)(x) = \min_{(i) \in B} \{X(x + i)\}\]

in which the spatial extent of the structuring element is the only adjustable parameter.

As noted previously, these operations were combined to perform opening and closing operations. Using an opening operation with a structuring element wider than the base of the peaks provides an estimate of the sensor shading or DC offset. Subtracting this from the original data generates a signal consisting only of the peak data. The results from each step in this procedure are illustrated in Figure 4. The top curve is the original data with the primary and secondary peaks. The dashed horizontal line segments below the peaks represent the processed data after an opening operation. In many locations the original data covers the opened data so it is not seen. Subtracting the opened data from the original data provides the third plot in which all points are zero or nearly so except for peak locations.

The next step is to find the location of the valley between the two peaks. The valley region is detected using a closing operation on the original data which fills in the valley as illustrated in Figure 5. The horizontal dashed lines in this figure correspond to the data from the closing. As with the opening, many of the closed data points are obscured by the original.
data. Subtracting the original data from the closed data produces the peak corresponding to the location of the valley. This is indicated by the longer dashed lines at the bottom along with some much smaller peaks which are basically noise.

The maximum value from the bottom plot is used as the starting point of the search to locate the two peaks. Finding the maximum values to the left and right of the starting point provides the locations of the two peaks. This approach has proven to be very robust and will identify peaks correctly under a variety of conditions. The presence of noise can affect the results so some preprocessing for noise suppression is very desirable. The next two sections describe the special processing unique to each application.

### 3.2 Dielectric Thickness Measurements

In order to measure the dielectric thickness of AC plasma panels with a light-section microscope, locations of reflections from both the dielectric surface and the dielectric/substrate interface need to be detected accurately and unambiguously. By finding the difference between the two reflections, the dielectric thickness can be estimated. Detection of the reflection from the dielectric surface is quite easy because the dielectric surface is highly reflective. This reflection results in a bright horizontal line in a LSM. However, the reflection from the dielectric/substrate interface is much fainter which requires processing to locate it accurately.

#### 3.2.1 Noise Reduction Considerations

Video camera noise causes significant problems at low light levels so techniques must be used which minimizes it. Frame integration is one effective technique for reducing video noise since doubling the number of frames in a given integration sequence approximately doubles the SNR of the resulting image. The main drawback with this approach is the time penalty imposed when performing the frame integration.

A similar approach takes advantage of the nature of the image. Each column of pixels contains information degraded by noise about the two reflections. In principle, all of the columns of pixels could be summed together to provide a low-noise estimate of the light profile through the two reflections.

However, unless the camera is very carefully aligned with the horizontal reflections, the resulting estimate will be degraded and the peaks of the two reflections will be distorted. This problem can be alleviated by summing over smaller vertical regions and obtaining a number of low-noise estimates of the light profile across the image.

#### 3.2.2 Calculating Dielectric Thickness

Although an estimate of dielectric thickness can be obtained by finding the distance between the two peaks, the results are not very accurate. Errors caused by quantization effects are large because the separation between peaks is only about 20
pixels which corresponds to a dielectric thickness of 1.5 mils. The desired accuracy of the thickness measurement was on the order of .01 mils which was achieved by calculating the first order moment about each peak.

In order to estimate dielectric thickness, the procedures described previously are used in sequence. Frame integration reduces the effects of camera noise. To reduce noise further, the image is divided into a number of vertical strips and all columns of pixels in a given strip are added together. Morphological processing is then used to find the primary and secondary peaks for a given image strip and the first order moment is calculated about each peak to reduce quantization errors. As the last step, the dielectric thickness estimates for each image strip are averaged to obtain a better estimate.

3.3. Proprietary Application

Unlike the dielectric thickness measurements, it was not feasible to average a number of scan lines together to suppress noise for the proprietary application for the proprietary application. In addition, the linear camera exhibited a significant amount of nonuniformity between odd and even pixels which acted like a synchronous noise source. The top trace in Figure 6 represents typical data with the odd/even pixel nonuniformity very evident in low-gradient regions.

Opening and closing operations with five-element structuring elements were used to remove these degradations followed the previously described procedure to find the peaks. The lower trace in Figure 6 illustrates this result. Once the valley between the two peaks was identified, the primary and secondary peaks could be found. As was the case for the general approach with the previous application, the use of one-dimensional morphology provided a very reliable and robust means for primary and secondary peak detection.

4. CONCLUSIONS

The application of very simple morphological processing techniques to signals resulting from light reflections can provide a very effective means for extracting important information. This type of signal processing provides very effective and robust techniques and is easy to implement in software.

5. ACKNOWLEDGMENTS

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6. REFERENCES
