공학석사학위논문

흑백카메라 백색광 간섭계에서 컬러 이미지 획득에 관한 연구

Acquisition of Color Image Using a Monochrome Camera in White-Light Interferometer

2018년 2월

서울대학교 대학원

기계항공공학부

김 승 재

흑백카메라 백색광 간섭계에서 컬러 이미지 획득에 관한 연구

Acquisition of Color Image Using a Monochrome Camera in White-Light Interferometer

지도교수 박 희 재

이 논문을 공학석사 학위논문으로 제출함

2017년 10월

서울대학교 대학원
기계항공공학부
김 승 재

김승재의 공학석사 학위논문을 인준함

2017년 12월

위 원 장 ______________________

부위원장 ______________________

위 원 ______________________

Abstract

Acquisition of Color Image Using a Monochrome Camera in White-Light Interferometer

In this research, it is suggested to acquire a color image using a monochrome camera from white-light scanning interferometer without any hardware modification and addition. Previous research is necessarily required to install a color camera and other optical system change. Therefore, this research aims to obtain the spectral intensity of interferogram by Fourier transform from existing monochrome camera. Since the intensity also includes reference mirror component, it is removed by measuring silicon sample which is known its reflection coefficient. After RGB filtering of acquired sample intensity, it is converted to 8-bit digital value and the whole surface is expressed as color image by applying the above process to each pixel. Lastly, 3 sample's color images are obtained and they are evaluated by PSNR. It is verified that the color can be recognized by color acquisition method meeting up at least 24dB. This research is expected to reduce hardware cost and obtain color image by the software process. The acquired color image helps understanding of sample intuitively and can be utilized for sample review, target positioning and pattern matching.

Keywords: White-light interferometry, frequency domain analysis, FFT, color image

Student Number: 2016-20677

Table of Contents

List of Figures

List of Tables

List of Symbols

λ	Wavelength of light
k	Wave number of light
E_i	Electric wave of light source
E_{obj}	Electric wave reflected from sample
E_{ref}	Electric wave reflected from reference mirror
ρ	Penetration ratio of beam splitter
l	Common path of light
h	Surface profile of sample
z	Position of scanner
φ	Phase change in reflection
I	Intensity of interferogram
A	Average intensity of monochromatic interferogram
B	Visibility magnitude of monochromatic interferogram
I_{DC}	Background intensity of white-light interferogram
γ	Visibility function of white light interferogram
λ_c	Central wavelength of white light source
r	Reflection coefficient
c	Ratio of two white-light spectrum
C_{ref}	Reference mirror component
F	Filtering function
S	Intensity to Digital value conversion scale

List of Abbreviations

CCD	Charge-Coupled Device
FT	Fourier Transform
LCD	Liquid Crystal Display
MSE	Mean Squared Error
OLED	Organic Light Emitting Diodes
OPD	Optical Path Difference
PSI	Phase-Shifting Interferometry
PSNR	Peak Signal-to-Noise Ratio
RGB	Red, Green, Blue
WLPSI	White-Light Phase Shifting Interferometry
WSI	White-light Scanning Interferometry

Chapter 1. Introduction

1.1 Background

In recent years, semiconductor and display manufacturing industries are showing a rapid growth. As manufacturing technology develops in high precision field, improvement of measurement performance is also demanded for process management.

Interferometry is widely used to measure micro or nano unit elements' height, width and thickness. Since interferometry measures target's topography by analyzing reflected light, it doesn't sustain damage to sample's surface. Furthermore, by obtaining interferogram signal through CCD camera, it can measure whole surface shape at once within seconds. With those advantages, White-Light Phase Shifting Interferometry (WLPSI) is considered appropriate measurement instrument as an in-situ monitoring system.

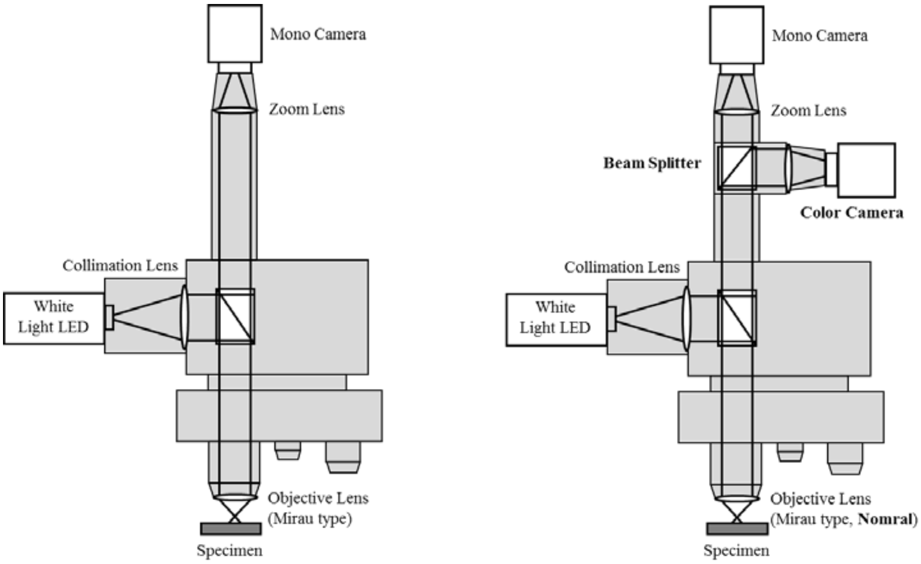
In LCD/OLED industries, manufacturing technologies are developing and a variety of applications have to be measured in constraint conditions which specific color sample should be traced or RGB pixels should be classified in color image. Since existing interferometry uses monochrome camera, it is required installing additional hardware configuration and changing software to cope with such issues.

1.2 Previous Research

To acquire a color image, additional color camera is necessarily installed through hardware configuration change. The example is shown in Fig. 1. It is required beam splitter (BS), color camera and system structure change.

For interferometry measurement, Mirau type lens is used as shown in Fig. 2. Since the reference and object beam cause white light interference, the result color image also shows interfered image (Fig. 3). To solve this problem, additional normal lens is used for color camera. However, the color image has rotation, scale, shift offset and different focus position with measured height image because the both of cameras are installed in different position and use different lens. Therefore, it is required to adjust position and focus to capture same spot.

To overcome offset limitation and normal lens use, Peter de Groot [1] introduced sampling window method to get fringe-free image from the interfered image and Kim [2] introduced improved sampling window and Lavenberg-Marquardt fitting algorithm for color image. However, it still requires hardware configuration changes.



(a) Interferometry **(b) Interferometry with color hardware**

Fig. 1 Hardware configuration change

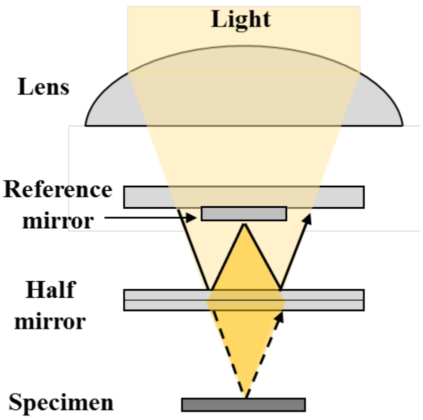


Fig. 2 Optical path in a Mirau lens

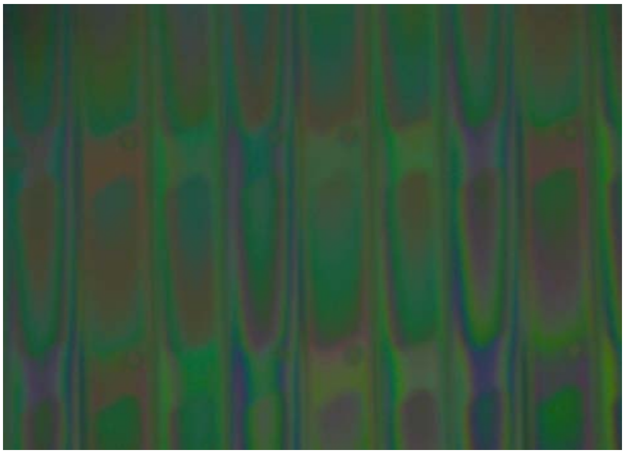


Fig. 3 Example of interfered color image

1.3 Purpose of Research

All previous research necessarily require hardware change and addition. Namely, beam splitter, color camera, system alteration and software modification add extra costs. In addition, it should solve offset problems and remove interference fringes with Mirau type lens.

This research focuses on obtaining a color image from a monochrome camera and Mirau type lens without any hardware installation by analyzing interference signal. Interference signal is sum of spectral light intensity in white-light range. Through Fourier Transform (FT), it is possible to get light intensity of specific wavelength. However, the intensity includes not only light reflected from target but also light reflected reference mirror. Therefore, new method will be suggested for acquiring RGB intensity by removing reference mirror component.

At the last, the acquired color image is evaluated with an image taken from color camera by Peak Signal-to-Noise Ratio (PSNR) method. Evaluated quality of image will be discussed at the chapter 4.

Chapter 2. Theoretical Background

2.1 Principles of Interferometer

2.1.1. Equation for a Coherence Signal

Interferometry is a surface topography measurement instrument which applies interference of light came from one light source. The light splits into 2 paths. One is reflected from a sample and the other is reflected from reference mirror. As shown in Fig. 4, electric wave from a light source is E_i, the electric wave reflected from a sample is E_{obj}, the electric wave reflected from reference mirror is E_{ref} and they can be expressed as follows.

$$E_{ref} = E_i\rho(1-\rho)\left|r_{ref}\right|\exp[j(2kl+\varphi_{ref})] \quad (2.1)$$

$$E_{obj} = E_i\rho(1-\rho)\left|r_{obj}\right|\exp[j(2k(l+h-z)+\varphi_{obj})] \quad (2.2)$$

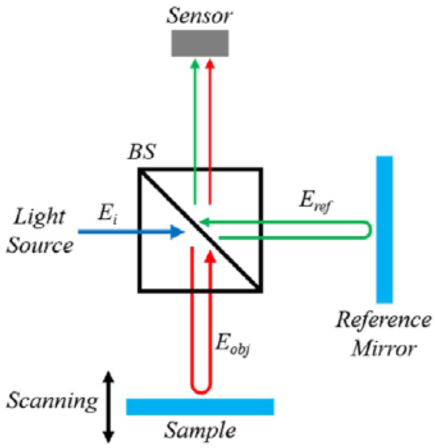


Fig. 4 Schematic diagram of Interferometry

ρ is transmissivity of BS, $|r|$ is Fresnel reflection coefficient of reference mirror and sample, l is common path which the two light pass, h is sample's height, z is position of scanner, $k(=\frac{2\pi}{\lambda})$ is wave number and φ means phase change of reference mirror and sample.

The light intensity which is captured by sensor is electric wave squared and expressed as follows.

$$\begin{aligned} I(\mathrm{z},\mathrm{k}) &= \left(E_{\mathrm{ref}} + E_{obj}\right)\left(\bar{E}_{ref} + \bar{E}_{obj}\right) \\ &= \left(E_{\mathrm{i}}\rho(1-\rho)\right)^2\left[\left|r_{ref}\right|^2 + \left|r_{obj}\right|^2\right] \\ &\quad + \left(E_{\mathrm{i}}\rho(1-\rho)\right)^2\left[2\mathrm{r}_{\mathrm{ref}}\mathrm{r}_{\mathrm{obj}}\right]\cos[2\mathrm{k}(\mathrm{h}-\mathrm{z}) + \Delta\varphi] \\ &= \mathrm{A}(\mathrm{k}) + \mathrm{B}(\mathrm{k})\cos\phi(k) \end{aligned} \tag{2.3}$$

Depending on the optical path difference (OPD) that is difference of each light's moving distance, constructive and destructive interferences occur and they make interference signal. By moving PZT scanner, sample's height can be measured. Average intensity, A, visibility magnitude, B and phase, ϕ are function of wave number, k. A and B are expressed as follows. I is light intensity reflected from reference mirror and sample.

$$\mathrm{A}(\mathrm{k}) = I_{ref}(k) + I_{obj}(k) \tag{2.4}$$

$$\mathrm{B}(\mathrm{k}) = 2\sqrt{I_{ref}(k)I_{obj}(k)} \tag{2.5}$$

2.1.2. White-light Scanning Interferometry (WSI)

In white-light scanning interferometry, halogen or white-light LED ramp is used as a light source which includes wide wavelength range. The wavelength range used in this research is shown in Fig. 5.

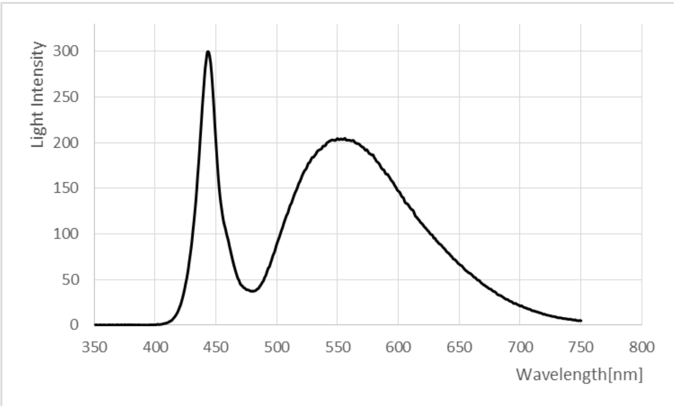


Fig.5 Wavelength range of white-light LED

The wavelength of the white-light LED ranges from 400 nm to 750 nm. Therefore, its coherence signal can be expressed as sum of each wavelength's signal. As shown in Fig. 6, the signal has short coherence length and one peak. It is because every wavelength's signal interferes constructively at the position where the OPD is 0 which means the position can be a specific height of sample. Away from the peak, destructive interference occurs and the signal shows a constant value. WSI use this coherence signal to detect peak and sample's topography is found out by comparing the relative peak positions.

White-light coherence signal can be expressed as sum of each wavelength's coherence signal as follows.

$$
\begin{aligned}
I(\mathrm{z}) &= \int_{\lambda} A(\lambda) + B(\lambda)\cos\left[\frac{4\pi}{\lambda}(h-z)\right] d\lambda \\
&= I_{\mathrm{DC}}(z) + \gamma(z)\cos\left[\frac{4\pi}{\lambda_c}(h-z)\right]
\end{aligned}
\tag{2.6}
$$

I_{DC} is background intensity, γ is visibility function and λ_c is a central wavelength of light. To measure height, visibility function is calculated from coherence signal and Larkin modulus method [3] is commonly used to detect the position of the peak. Since this method doesn't have phase ambiguity, high step height measurement is possible. However, measurement resolution is lower than Phase-Shifting Interferometry (PSI). To get high resolution, WLPSI algorithm [4] was developed. It corrects the position of the modulus peak to actual compensated position by phase calculation. The WLPSI process is shown in Fig. 7.

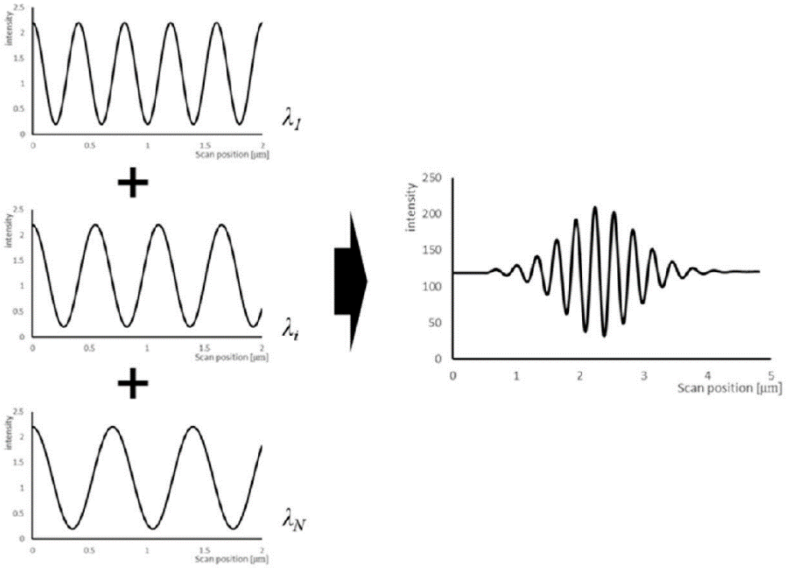


Fig.6 Composition of coherence signals

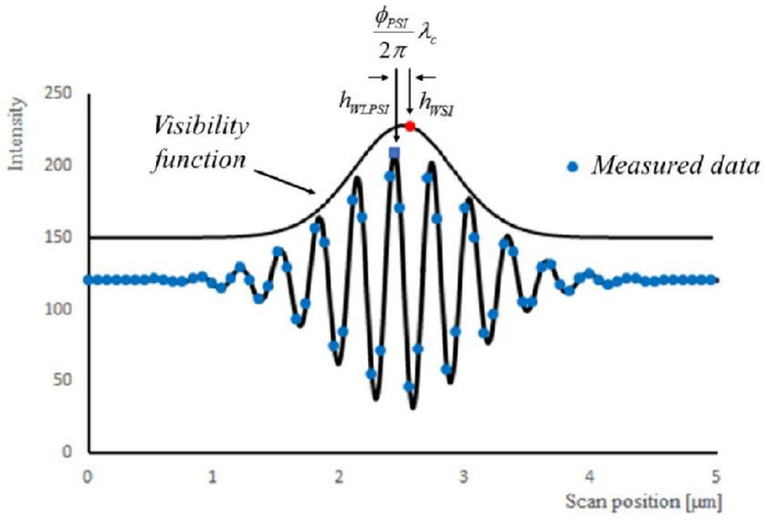


Fig. 7 Calculation of actual height in WLPSI

2.2 Spectral Resolved Method − Fourier Transform

Fourier transform is a method to express an input signal as periodic functions which have various frequencies. In this method, the periodic functions are sinusoidal and the input signal is decomposed into the sum of the functions. Each periodic functions' component has its own frequency, amplitude and phase.

In white-light interferometry, coherence signal is obtained by PZT scanning and the interferogram has constant interval along the z-axis. This data in spatial domain converts to spectral components in frequency domain by Fourier transform. Spectral magnitude is related to sample's thickness and spectral phase is related to height and thickness. Therefore, those components can be used to measure height [5], reflectance and thickness [6]. Fourier transform of the white-light interferogram is expressed as follows.

$$
\begin{aligned}
\tilde{I}(u) &= FT\big(I(z)\big) \\
&= \mathrm{FT}(\textstyle\int_k \ A(k) + B(k)\cos[k(h-z) + \Delta\varphi]dk) \\
&= \textstyle\int_k \ A(k)FT(1)dk + \frac{1}{2}\int_k \ B(k)FT\big(e^{i(kh-kz+\Delta\varphi)} + e^{-i(kh-kz+\Delta\varphi)}\big)dk \\
&= \textstyle\int_k \ A(k)dk \times \delta(u) \\
&\quad + \tfrac{1}{2}B(-u)e^{i(-uh+\Delta\varphi)} \times \delta(u+k) + \tfrac{1}{2}B(u)e^{-i(uh+\Delta\varphi)} \times \delta(u-k)
\end{aligned} \tag{2.7}
$$

The transformed signal is a function of frequency and it shows symmetrical graph respect to the y-axis as shown in Fig. 8. The phase of $\tilde{I}(0)$ is 0 and it only has amplitude which means sum of each spectrum's average intensity. In positive range, $|\tilde{I}(u)|$ is in proportion to the spectrum's visibility magnitude, $B(k)$. Since monochrome interferogram is a function of cosine, it is verified that the coefficient of cosine can be obtained. The phase, $\angle\tilde{I}(u)$ is each spectrum's phase, $uh + \Delta\varphi$. Using these restored magnitude and phase, thickness and height can be measured.

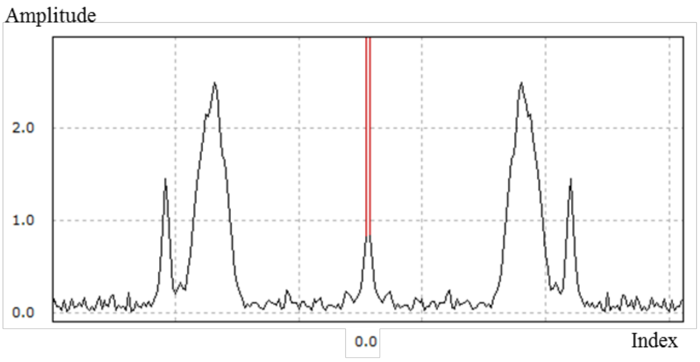


Fig. 8 Example of Fourier transformed signal

2.3 Color CCD Camera

To recover the color image from light intensity, a concept of color CCD camera is applied to color acquisition method. CCD camera is an instrument which converts the light energy into current. It has an array of millions of tiny light cavities called ‘photosites’ to record light intensity. When a shutter is open, photosites collect photons and store them as an electrical signal during exposure time. Depending on the strength of the electrical signal, image intensity is determined at each pixel. However, the photosites collect all photons regardless of their wavelength. To collect specific color’s photons, RGB filter should be placed over each cavity. In this section, the color filter and post-processing are examined.

2.3.1. Color Filter

Because the photosites cannot distinguish the color of photons, it needs color filter. The most common structure of color filter is ‘Bayer array’ as shown in Fig. 9. The array consists of alternating rows of blue-green and green-red filters. Since the human eye detects more green light than the others, bayer array also has twice as many green as red or blue filter. After getting this bayer color, it is translated to final image by processing demosaicing. Therefore, one pixel contains red, green and blue value.

Each camera has their own filters and their filtering range and level are different. In this research, the target color camera model is ‘acA1300-200uc’ developed by ‘Basler’ and its filtering range is shown in Fig. 10. After light passes those filters, the specific wavelength range is filtered.

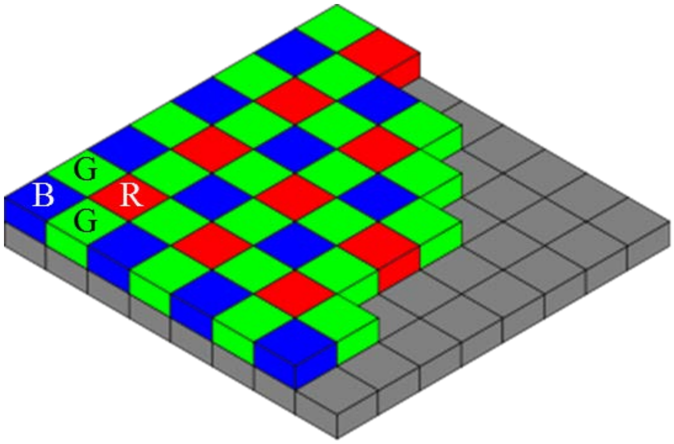


Fig.9 Example of Bayer Filter

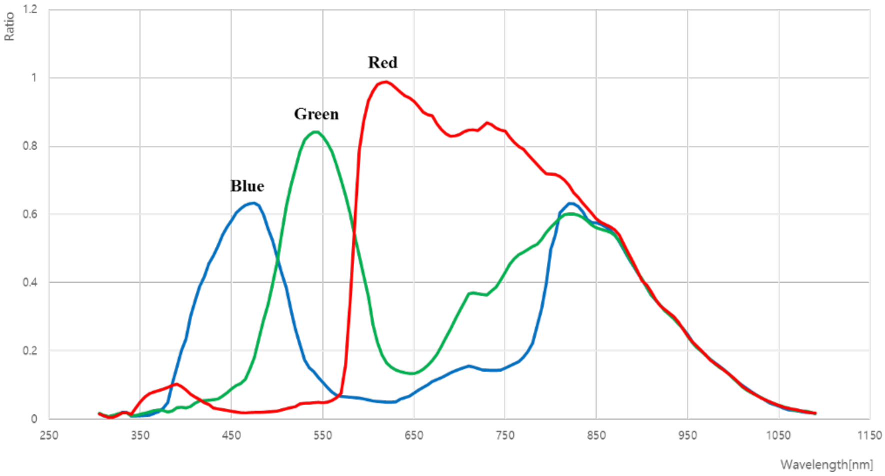


Fig. 10 Example of Filtering Range

2.3.2. Post-Processing

In this research, two post-processing is applied to the color image according to camera settings which are color transformation and white balance. The main objective of color transformation is to make corrections of each RGB value delivered by the camera's sensor. This processing compensates the imperfection of sensors. The color transformation uses a 3×3 matrix with RGB data. RGB to RGB color matrix is expressed as follows.

$$\begin{bmatrix} Gain00 & Gain01 & Gain02 \\ Gain10 & Gain11 & Gain12 \\ Gain20 & Gain21 & Gain22 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{2.8}$$

Depending on the light circumstance, color is expressed differently. For example, if color temperature is low, it shows more red light and in opposite case, the blue light becomes strong. Therefore, same objective has different color under sun light, incandescent lamp or fluorescent lamp. To compensate this phenomenon, white balance controls RGB color's gain using a white object to express it as white. For white balance, QP card, white balance filter and white spot card are used as tools. In most current cameras, manual gain setting is available and has auto white balance function as well.

Chapter 3. Color Acquisition Method

The desired objective is obtaining a spectrum of sample from interferogram excluding a spectrum of reference mirror. However, interferogram is a data expressed in spatial domain and the signal includes of light intensity reflected from both of sample and reference mirror. Fourier transform converts the signal into spectral intensity and then it is necessary to remove reference mirror components. Sample intensity at specific wave number is expressed as follows.

$$\mathrm{I_{obj}}(k) = I_i(k)\left|r_{obj}(k)\right|^2 \tag{3.1}$$

I_i is input intensity of light source and it is assumed in proportion to white-light LED intensity which is measurable by spectrometer.

3.1 Acquisition of Reference Mirror Component

As the equation (2.7), after Fourier transform of the white-light interferogram, average intensity and visibility magnitude can be calculated. Each wave number's magnitude of FT is expressed as follows by the equation (2.3). I_i and r are function of wave number, k.

$$\left|\tilde{I}_{obj}(k)\right| = \frac{1}{2}B(k) = I_i \left|\mathrm{r_{ref}}\right|\left|\mathrm{r_{obj}}\right| \tag{3.2}$$

For recovering color image, reflection coefficient of reference mirror is unnecessary. However, the mirror is located in mirau lens so it is impossible to measure its reflectance coefficient exactly by spectrometer. Instead of measuring objective sample, if the sample is replaced to another sample of which reflection coefficient is known in advance, reference mirror component can be calculated. Used sample is silicon wafer and its reflectance coefficient graph is shown in Fig. 11.

Therefore, reference mirror component, C_{ref} is expressed as follows. $I_i{}'$ is input intensity of light source when the silicon wafer is measured.

$$C_{ref}(k) = I_i{}' \, |\mathrm{r_{ref}}| = \frac{|\tilde{I}_{SI}(k)|}{|\mathrm{r_{SI}}|} \tag{3.3}$$

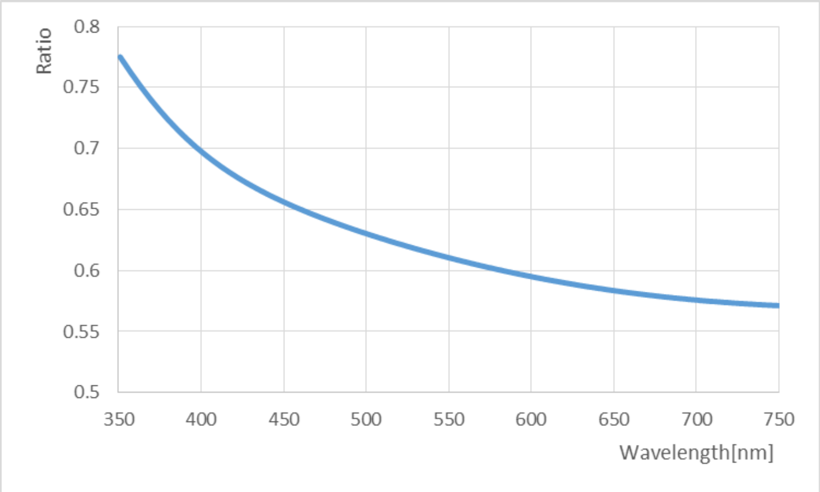


Fig. 11 Graph of silicon reflection coefficient

3.2 Calculation of Sample Component

Since reference mirror component was acquired, it is possible to calculate sample component by dividing equation (3.2) by equation (3.3). It is expressed as follows.

$$\frac{I_i|\mathrm{r_{ref}}||\mathrm{r_{obj}}|}{I_i^{'}|\mathrm{r_{ref}}|} = c|\mathrm{r_{obj}}| = \frac{|\tilde{I}_{obj}(k)|}{C_{ref}(k)} \tag{3.4}$$

Because the input intensities are different in case of that each silicon and sample are measured, the divided term of both intensities is expressed as c which is constant in assumption that white-light LED spectrum shows in proportion in terms of intensity. C_{ref} is already known value in previous section, therefore it is not necessary to measure it again from the next measurement. Whenever each sample is measured, sample component is acquired by dividing FT results, $|\tilde{I}_{obj}(k)|$ by C_{ref}.

Substituting equation (3.1) with (3.4), proportional value to sample intensity can be obtained as follows.

$$\mathrm{I_{obj}}'(k) = \mathrm{c}^2\,\mathrm{I_{obj}}(k) = I_i(k)\left(\frac{|\tilde{I}_{obj}(k)|}{C_{ref}(k)}\right)^2 \tag{3.5}$$

3.3 RGB Filtering

After separating proportional sample intensity from interferogram, it should be filtered by color filter to be expressed as RGB intensity value. By convolution RGB filter functions and intensity, each RGB value is obtained as follows.

$$\mathrm{I_R}' = \int_{\lambda_1}^{\lambda_2} I_{obj}'(\lambda)\, F_R(\lambda)\, d\lambda$$

$$\mathrm{I_G}' = \int_{\lambda_1}^{\lambda_2} I_{obj}'(\lambda)\, F_G(\lambda)\, d\lambda$$

$$\mathrm{I_B}' = \int_{\lambda_1}^{\lambda_2} I_{obj}'(\lambda)\, F_B(\lambda)\, d\lambda \qquad (3.6)$$

F is filtering function of each color as shown in Fig. 10. Convolution range is from 400nm to 700nm which is the visible light range.

3.4 Converting Intensity to Digital Value

Each obtained RGB value from the previous section is not real RGB value because the sample intensity is proportional to real intensity as equation (3.5). Furthermore, the RGB values have to be changed to digital values determined by the bit depth. In this research, the format is an 8-bit file and it has a value from 0 to 255. For converting intensity to the digital value, gray value comparison method is used.

From interferogram, the average value is expressed by equation (2.4) and (2.6) as follows. The value includes sample's gray value and reference mirror's gray value which are digital value.

$$I_{\mathrm{DC}} = I_{obj} + I_{ref} \tag{3.7}$$

Therefore, to get sample's gray value, it is necessary to subtract reference mirror's gray value. In identical intensity circumstance, one gray image of mirror can be obtained when the sample is defocused or put away. Namely, without sample, this image can be stored in library in terms of light source intensity. By then, only sample's intensity can be obtained as follows.

$$I_{\mathrm{obj}} = I_{DC} - I_{ref} \tag{3.8}$$

This sample's gray value should be identical with gray conversion form of RGB digital value. However, since scale offset exists in RGB intensity, it applies to them and changes to digital value. The equation is expressed as follows.

$$I_{\text{obj}} = S \times (0.299{I_R}' + 0.587{I_G}' + 0.114{I_B}') \tag{3.9}$$

$$I_R = S \times {I_R}'$$

$$I_G = S \times {I_G}'$$

$$I_B = S \times {I_B}' \tag{3.10}$$

$0.299{I_R}' + 0.587{I_G}' + 0.114{I_B}'$ is a general equation to change RGB color to gray color. *S* is intensity to digital value conversion scale. After obtaining scale value, it is applied to RGB intensity to change it into digital value. Those process work on every pixel and color image is acquired.

3.5 Flow Chart

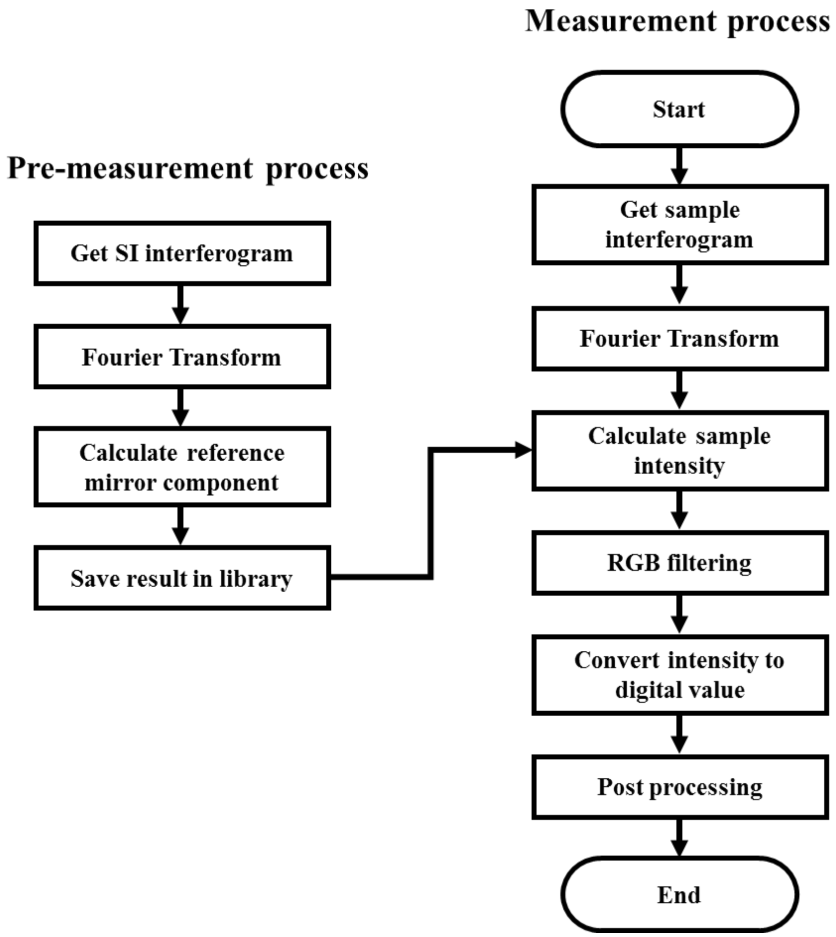


Fig. 12 Process of color image acquisition

The process of color image acquisition is shown in Fig. 12. In the pre-measurement process, by obtaining silicon's interferogram, it is possible to get reference mirror component because silicon's reflection coefficient is already known. The result is stored in a library and used in each measurement step.

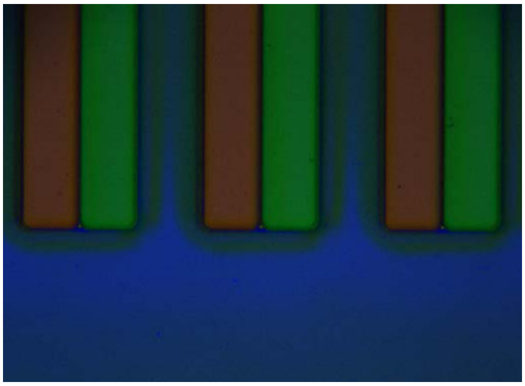
In measurement process, a sample is measured as interferometry usually does. The interferogram is processed by Fourier transform and the result means interfered sum of sample and reference mirror's intensity at each wavelength. The sample intensity can be calculated with reference mirror component. The one sample's intensity is filtered by RGB filter and each RGB intensity is converted to digital value. After post-processing, color image is acquired.

Chapter 4. Experiment Results

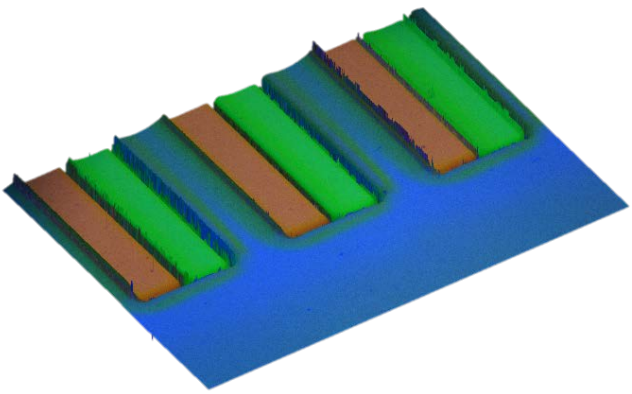
4.1 Acquired Color Images of Samples

3 samples are tested to obtain color image. One is color filter, another is quarterly segmented sample which has different 4 height and colors and the last one is 4 coloured sample. From each sample's interfered images, recovered color images can be gained by color acquisition method as shown in Fig. 13 (b), Fig. 14 (b) and Fig. 15 (b). These images are compared with original color image taken by color camera. The results show they have a tendency to correspond colors with original image as shown in Fig. 13 (a), Fig. 14 (a) and Fig. 15 (a). The numerical similarity is evaluated after this section. Post-processing parameters are adopted from the same setting of color camera. Overall light intensity is low because reference mirror light is subtracted from input light intensity. In the case of too much low light, color visibility can be improved by image processing which increases brightness. Lastly, after getting the color image, it is possible that 3D color image can be represented with height information from height measurement by interferometry as shown in Fig. 13 (c), Fig. 14 (c) and Fig. 15 (c). Their brightness is increased by 40% for better visibility.

(a) Color camera image

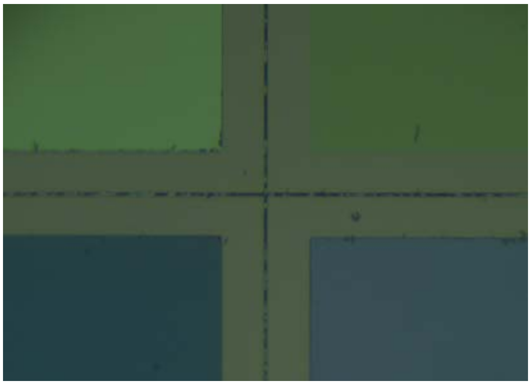


(b) Recovered color image

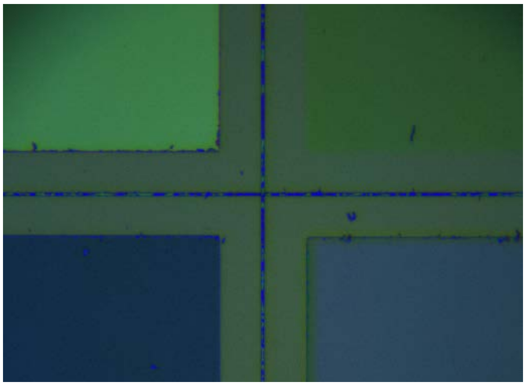


(c) 3D shape

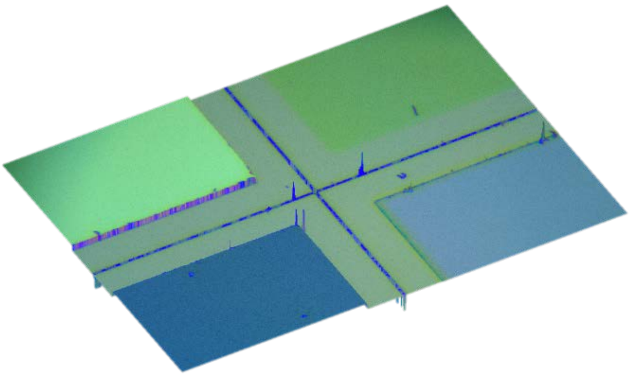
Fig. 13 Color images of color filter



(a) Color camera image

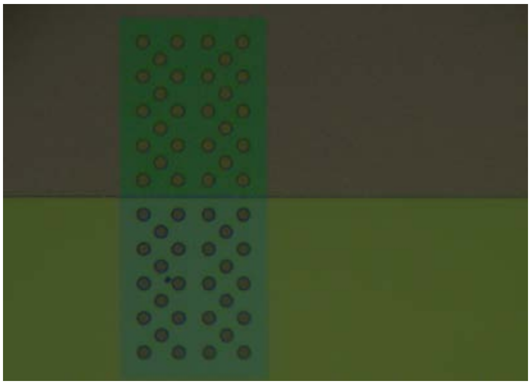


(b) Recovered color image

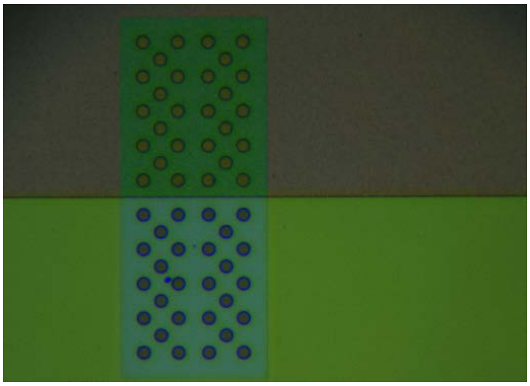


(c) 3D shape

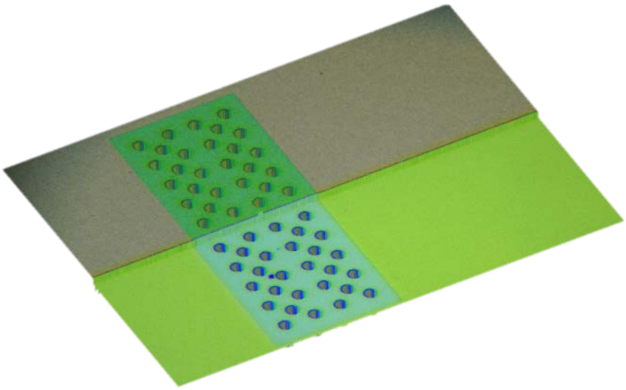
Fig. 14 Color images of quarterly segmented sample



(a) Color camera image



(b) Recovered color image



(d) 3D shape

Fig. 15 Color images of 4 coloured sample

4.2 Performance Evaluation

For evaluating how much the color image is different with original image taken by color camera, Peak Signal-to-Noise Ratio (PSNR) is used. PSNR is one of common method to measure the quality of reconstruction in image compression. Its meaning is the ratio between the maximum value of a signal and the possible value of noise. PSNR is based on the mean squared error (MSE). Given $m \times n$ original color image, X_{org} and restored image, X_{re}, the MSE and PSNR are defined as follows.

$$\mathrm{MSE} = \frac{1}{\mathrm{mn}} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left[X_{org}(i,j) - X_{re}(i,j)\right]^2 \tag{4.1}$$

$$\mathrm{PSNR} = 10 \log_{10}\left(\frac{MAX^2}{MSE}\right) \tag{4.2}$$

In this research, since the pixels are represented using 8 bits, the maximum, MAX becomes 255. The more the two images are same, PSNR is getting close to infinity. Typically lossy image and compressed video have value between 30 and 50 dB in 8 bits file. For wireless transmission, 20~25 dB PSNR is considered as acceptable values [9].

The recovered color images of each sample are compared with original image by PSNR. In terms of RGB data and the whole color data, PSNR results are indicated as shown in table 1. The results show at least 24dB and it is verified that the color image can be obtained by color acquisition method meeting certain quality. In the process of Fourier transform, low wavelength region cannot be restored because of noisy signal from thin film. Therefore, certain samples would show low PSNR value at the blue wavelength range.

	Color filter	4 segmented sample	4 coloured sample
PSNR R	30.749	23.608	31.377
PSNR G	31.145	26.515	24.220
PSNR B	20.426	24.830	26.221
PSNR(dB)	24.487	24.825	26.683

Table 1 PSNR results of each sample

Chapter 5. Conclusion

In this thesis, it is suggested to acquire color image using a monochrome camera from white-light scanning interferometry without any hardware modification and addition. Previous research is necessarily required to install a color camera. This research aims to reduce hardware cost and obtain color image by a software process.

Acquisition of color image proceeds in existing white-light interferometry. Therefore, it is not necessary to change system configuration and install beam splitter and color camera. After getting interferogram signal by PZT scanning, it is expressed as spectral intensity in frequency domain by Fourier transform. However, it includes reference mirror component so the component is removed by measuring silicon sample which is known its reflectance coefficient. The acquired sample intensity is filtered by RGB filter and each RGB intensity is converted to 8bits digital value. Lastly, the final color image is obtained after post-processing.

3 samples are evaluated by PSNR comparing with the original image and they meet at least 24dB. It is verified that the color can be recognized by color acquisition method. This suggested method helps understanding of sample intuitively and can also be utilized for sample review, target positioning and pattern matching.

Bibliography

[1] P. de Groot, "*Generating fringe-free images from phase-shifted interferometry data*", Applied Optics, 2005. 44(33): p. 7062-7069

[2] 김진용, "백색광 간섭계에서 칼라카메라를 이용하여 간섭상이 제거된 칼라영상 획득에 관한 연구", 서울대학교 석사학위논문, 2012

[3] Larkin, K.G., "*Efficient nonlinear algorithm for envelope detection in white light interferometry*", J. Opt. Soc. Am. A. 1996. 43(8): p. 1545-1554

[4] Sandoz, P., "*An algorithm for profilometry by white-light phase-shifting interferometry*", J.Mod. Optic. 1996. 43(8): p. 1545-1554

[5] P. de Groot, L. Deck, "*Three-dimensional imaging by sub-Nyquist sampling of white-light interferograms*", Opt. Lett. 1993. 18(17): p.1462-1464

[6] SW Kim, GH Kim, "*Thickness-profile measurement of transparent thin-film layers by white-light scanning interferometry*", Applied Optics, 1999. 38(28): p.5968-5973

[7] Paul E. D., Jitendra M., "*Recovering high dynamic range radiance maps from photographs*", ACM SIGGRAPH. 2008, Article No. 31

[8] Brian A. W., "*The synthesis and analysis of color images*", IEEE transactions on pattern analysis and machine intelligence, 1987, 9(1): p. 2-13

[9] Xiangjun, L., Jianfei, C., "*Robust transmission of JPEG2000 encoded images over packet loss channels*", ICME, 2007, p. 947-950

초 록

흑백카메라 백색광 간섭계에서 컬러 이미지 획득에 관한 연구

김승재
기계항공공학부
대학원
서울대학교

본 논문에서는 백색광 위상 천이 간섭계에서 흑백 카메라를 사용하여 기존 하드웨어 구성의 변경 없이 컬러 이미지를 획득하는 과정에 대해 연구하였다. 기존의 컬러 영상 획득 시, 필연적으로 컬러 카메라와 부수적인 하드웨어 변경이 요구된다. 그리하여, 기존 높이 측정과 마찬가지로 흑백카메라를 그대로 이용하여 간섭신호를 얻고 푸리에 변환을 통해 파장별 세기를 분석하는 방법을 제시하였다. 푸리에 변환된 신호에서 반사계수를 알고 있는 실리콘 샘플 측정을 통해 기준 거울에 의한 영향을 없애고 샘플에 반사된 신호만을 얻어낸다. 이후 RGB 필터링 하여 각각에 대한 세기를 얻어내고 빛의 세기를 8-bit digital value로 변경하여 컬러 이미지로 나타낼 수 있다. 최종적으로 3가지 샘플에 대해 컬러 이미지를 획득하였고 PSNR을 통한 원본 이미지와의 유사도를 평가하여 기존 컬러를 재현해낼 수 있음을 확인하였다. 본 연구를 통해 컬러 카메라 시스템 구축에 따른 비용과 추가적인 처리를 줄일 수 있으며 얻어낸 컬러 이미지를 통해 샘플에 대한 직관적인 이해를 돕고 샘플 리뷰, 대상 추적, 패턴 매칭 등에 사용될 것으로 기대된다.

주요어: 백색광 간섭계, 주파수 영역 분석, 푸리에 변환, 컬러 이미지

학 번: 2016-20677