Nontranslational three-dimensional profilometry by chromatic confocal microscopy with dynamically configurable micromirror scanning

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A confocal microscope profilometer, which incorporates chromatic depth scanning with a diffractive optical element and a digital micromirror device for configurable transverse scanning, provides three-dimensional (3D) quantitative measurements without mechanical translation of either the sample or the microscope. We used a microscope with various objective lenses (e.g., 40×, 60×, and 100×) to achieve different system characteristics. With a 100× objective, the microscope acquires stable measurements over a 320 μm × 240 μm surface area with a depth resolution of 0.39 μm at a 3-Hz scan rate. The total longitudinal field of view is 26.4 μm for a wavelength tuning range of 48.3 nm. The FWHM value of the longitudinal point-spread function is measured to be 0.99 μm. We present 3D measurements of a four-phase-level diffractive element and an integrated-circuit chip. The resolution and the accuracy are shown to be equivalent to those found with use of conventional mechanical scanning. © 2000 Optical Society of America

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1. Introduction

Confocal microscopy is an old invention, dating back to Minsky’s patent in the early 1960’s. However, it did not become popular as a standard tool until the 1980’s, and it is now widely used in the field of biology. Its advantages of depth-section imaging and superresolution make the confocal microscope well suited for the inspection of thick biological specimens stained with fluorescence labels. The confocal microscope also has other advantages that are applicable to surface profilometry, to measurements requiring a high longitudinal depth resolution, and to applications in which it will not scratch or damage the sample. Its effectiveness as a profilometry device has been limited by its rate of scanning and its suitability for materials of different scattering or reflectivity characteristics. This has greatly limited its application for commercial inspection.

A confocal microscope works by geometrically matching two conjugate focal points in image space. When the two points, a point source and a point detector, are well matched, satisfying the confocal condition, the point source will be imaged to the detector with maximal intensity. If the points are not well matched and are displaced from the focus locations, the point detector rejects the broadened scattered light and detects a lower intensity. In practice, for a reflection-mode confocal microscope, a point source is imaged onto the sample surface, which then reflects and is reimaged back to a point detector. As the sample is moved (scanned) through the focal point, then a peak intensity will be detected only when the focal point lies directly on the surface of the sample.

In this paper we introduce a totally nontranslational confocal microscope design that achieves three-dimensional (3D) quantitative imaging. The key elements of our design are a digital micromirror device (DMD), which can generate a configurable two-dimensional (2D) array of pinholes operating in parallel for parallel transverse scanning, and a diffractive lens with a tunable source for chromatic depth scanning. In Section 2 we briefly review various confocal scanning techniques to provide motivation for developing the profilometer. In Section 3 we...
describe the nontranslational confocal microscope system, including system design and experimental implementation. Sources of noise intrinsic to the DMD are introduced and discussed, and methods to overcome these issues are demonstrated. In Section 4 critical system characteristics such as the point-spread function (PSF), depth resolution, and field of view are experimentally evaluated. We demonstrate the 3D imaging capability of the DMD-based confocal microscope in Section 5 by measuring and creating 3D profiles of a diffractive element with known dimensions and of an integrated-circuit chip. In Section 6 we conclude this paper and discuss application of our scanning system to real-time 3D profilometry including some future research directions.

2. Review of Confocal Scanning

3D profilometry is typically performed by means of scanning a confocal microscope through the sample volume in \((x, y, z)\) space.\(^6\) We can divide this process into two distinct steps: translation in the longitudinal depth \((z)\) direction and planar scanning in the transverse \((x, y)\) directions. We can perform both steps either by moving the sample with respect to the focal point or by moving the focal point while the sample is fixed. The resolution of the depth measurement is limited in part by the translational device used for scanning. To achieve high resolution, most existing confocal imaging systems require a stable, high-resolution 3D translational device. In general, this device is a mechanical stage that tends to be slow and expensive.

One long-standing goal for improving the performance of the confocal microscope is to increase the scanning speed while maintaining its high resolution. Many methods, other than using a faster and more expensive stage, have been proposed to improve the confocal scanning speed. One common alternative is a raster scan with galvanometric mirrors or acousto-optic deflectors, which allows the sample to remain stationary in the transverse plane, but which scans only a single point at a time. Alternatively, a rotating Nipkow disk\(^7\) consisting of an array of pinholes can be used to scan the transverse plane with multiple points in parallel. The parallel pinhole array improves the scan rate; however, the Nipkow disk has the disadvantages of a low illumination efficiency, high backscatter noise, and the requirement of mechanical rotation. Other methods also exist, such as that of the slit scan,\(^8\) which provides parallel measurements along one transverse axis; however, the other transverse axis still needs to be scanned. From these examples we reason that the performance (e.g., speed, stability, and the like) of the confocal microscope can be improved by reduction of inertial motion and through increased optical parallelism.

In recent years there has been growth in consumer optical microelectromechanical systems. As a result, the use of microelectromechanical systems has since also been researched in applications for confocal microscopy. The Texas Instruments DMD has been shown to provide multiaperture, programmable, transverse scanning for confocal imaging in both reflection-mode operation\(^9\) and in living-cell fluorescence imaging.\(^10,11\) In addition, we previously showed that it can be used in acquiring 3D measurements.\(^12\) We chose to use this device for our experiment, since the DMD is particularly suitable for transverse confocal scanning with its ability to perform parallel array scanning without need of translating the sample (i.e., the sample remains stationary). Details about the DMD are covered in Section 3.

The techniques mentioned above consider methods for transverse scanning only. Less research has been done in investigating longitudinal depth scanning. One promising technique for providing longitudinal scanning, though, is the chromatic scan, which uses the chromatic aberration of an optical system to provide focus-wavelength encoding.\(^13\)\(^-\)\(^15\)

In previous research Dobson et al. showed that chromatic scanning is a viable method, where the technique was improved by use of a diffractive lens illuminated with a tunable light source.\(^16\) In a different experiment Lin et al. combined chromatic scanning by using a white-light source with a transverse slit scan to create a single-shot 2D profilometer.\(^17\) The highly linear wavelength-to-depth relationship and the strong dispersion of the diffractive lens allows us to perform chromatic depth scanning by varying wavelength, eliminating the need for physical translation.

In the current experiment we used a combination of transverse DMD scanning and longitudinal chromatic scanning for the imaging and measurement of reflection-mode samples. These two techniques allow the profilometer to acquire 3D image data without the need for mechanical translation; in addition, the scan speed is improved while a high resolution is maintained.

3. Nontranslational Confocal Microscope System

The resolution of a confocal microscope is determined by the measurement system’s signal-to-noise ratio, which in turn depends on various factors, including calibration method, detector sensitivity, and system stability. System stability is affected by noise from vibration or inertial motion and is important to maintain at high scanning speeds. The microscope we developed is a stationary system, allowing highly stable 3D measurements to be made. Speed is also improved by introduction of optical parallelism in scanning.

The DMD-scanned confocal microscope method is similar in theory to one based on using a Nipkow disk for scanning. The micromirrors of the DMD can be arranged in a multipoint, parallel configuration to serve as an array of point sources and the corresponding array of conjugate point detectors. The pinhole pattern can be instantaneously changed by computer control. We call this dynamic configurability. The basic idea is to have illumination from \(\text{ON}\) mirrors of the DMD directed toward the sample while \(\text{OFF}\) mirrors divert light away from the sample. An array of
ON mirrors is imaged to a transverse plane on the sample, creating an array of bright point sources that is reflected and reimaged back to the same mirrors used as the point detectors. Depth discrimination of the confocal microscope is preserved when the pinhole points are spaced far enough apart to have negligible cross talk and retain the confocal property of rejection of scattered light. The array of ON mirrors is then turned OFF while the next set of mirrors at different \((x, y)\) locations is turned ON. If repeated rapidly with high-speed switching of the DMD micromirrors, a whole transverse \((x, y)\) plane can be digitally scanned by the array of point sources.

Conveniently, the DMD scanning method can be used in conjunction with the chromatic confocal depth-scanning technique. A tunable source illuminates the pinhole pattern, which is imaged through a diffractive lens onto the sample plane. The plane of focus is controlled by selection of the illumination wavelength. By scanning through a range of wavelengths, we can perform longitudinal depth scanning with the confocal microscope.

The combination of DMD and chromatic scanning allows us to perform a 3D scan and acquire 3D measurements with absolutely no mechanical translation of the system or sample. This makes measurements with the microscope extremely stable. Dynamic configurability of the DMD lets us immediately optimize signal power and speed of the microscope as needed when measuring different materials.

A. System Description

Figure 1 shows the setup of the nontranslational chromatic confocal profilometer. A tunable Ti:sapphire laser, operating in a wavelength range of 790–900 nm, is used as the principal light source for alignment and measurements. The vertically polarized laser beam is transmitted through a polarizing rotator to adjust for maximum transmittance through a polarizing beam splitter (PBS). The beam is then spatially filtered, expanded, and collimated.

After passing through the PBS, the laser beam is directed to the DMD surface plane with Mirrors 1 and 2. It is critical that the angles between the two mirrors be set such that, after reflecting from individual micromirrors in the DMD array, the light is parallel to the optical axis of the system (see Fig. 1). The optical field passing through the DMD is imaged by a combination of a refractive lens and a diffractive lens. The light reflected from the micromirrors in the DMD array (only for micromirrors in the ON state) passes along the ON path through collimating Lens 1, the diffractive lens \((f = 180 \text{ mm, } f/4 \text{ at design wavelength of 610 nm})\), and then through a \(\lambda/4\) retardation plate. The diffractive lens focuses different wavelengths of light onto different focal planes, allowing for depth scanning through wavelength tuning.\(^{12,13}\)

The operating wavelength of the microscope is controlled by a motorized tuner and monitored by a wavemeter (Burleigh Wavemeter, Model WA-2500) with a \(\pm 0.02\)-nm sensitivity. Although we did not have the equipment available, a higher tuning rate and sensitivity can be achieved with an electro-optic tuner. The light then passes through Lens 2 (eyepiece \(6 \times\)) and a microscope objective lens to focus onto the surface of the object. Various microscope objectives are used in the system to evaluate its performance characteristics.

The light reflected from the object is traced back through the optical components onto the DMD surface. For the reflected light, the DMD serves as a detector pinhole array that filters out the light scattered from the out-of-focus part of the object and allows only the in-focus backreflected field to be directed to the detector. Because the backreflected light passes through the \(\lambda/4\) retardation plate twice, the returning light will be orthogonally polarized to the incident light. Thus the returning light is reflected by the PBS to be focused onto the CCD camera (Pulnix Model TM-7EX, 768 \(\times\) 494 pixels of 8.4 \(\mu\)m \(\times\) 9.8 \(\mu\)m) by imaging Lens 3. We use two computers to operate the system, one to control the DMD engine for scanning and the other for image acquisition and processing.

B. Description of the Digital Micromirror Device

The Texas Instruments DMD\(^{18}\) is a planar array of 16 \(\mu\)m \(\times\) 16 \(\mu\)m mirrors that are bistable at \(\pm 10^\circ\) normal to the chip. Each individual micromirror acts as an ON–OFF switch by either reflecting light toward the optical axis of the microscope system (ON pixel) or by reflecting light away from it (OFF pixel). The controller circuits for the DMD convert an SVGA video signal from a computer graphics card into the proper signal to switch each of the 800 \(\times\) 600 mirrors in the array to their correct positions. Transit time between the ON–OFF states is 20 \(\mu\)s, and the entire DMD chip can be refreshed at a video rate. By means of controlling the video signal delivered from the graphics card, individual micromirrors can be set to their ON–OFF positions, creating any arbitrary pattern of pixels on the chip. We tested various scan patterns (e.g., arrays, lines, and points) and used different...
sizes of pinhole points. The switching speed of the DMD is limited by a video driver rate of 56 Hz. Each pixel of the DMD is time multiplexed at 8 bits per red–green–blue color, which we can use for equal division of the driving speed to 1/6 the standard video driver rate. The general pinhole pattern that we use for measurements in this paper is an array of micromirrors with a spacing of every sixth pixel in the vertical and the horizontal directions, which is scanned in a parallel, raster format. Thus we can scan a complete frame by using this pattern at a rate of \( \sim 9.3 \) Hz. The availability of faster drivers would allow us to increase the total scanning speed.

C. System Operation

The configurability of the microscope is achieved by computer control over the DMD scan pattern; this feature allows the user to optimize the performance of the microscope (e.g., balancing speed versus signal power of the measurement). For example, with weakly scattering objects, the distance between OFF mirrors can be small, whereas strongly scattering objects may require increasing the distance between the mirrors in the ON state. With this control, we can change the scan pattern and rate dynamically to suit our application. At the output plane, the CCD camera is used to acquire the detected confocal image, which has been scanned and integrated over the entire field of view. By controlling the DMD, if the signal is weak, we can increase the detected intensity by opening more holes (e.g., slit scan) but at the cost of a lower resolution, since there is more cross talk.

As another capability of our microscope we use the OFF-path pixels of the DMD for separate imaging of the sample in bright-field mode (see Fig. 1). Since in general there tend to be many more OFF pixels than ON pixels for a confocal system, the direct imaging system can be easily implemented. This improves the user control of the microscope by helping to locate where on the sample we want to perform the measurement.

The signal that can reach the CCD plane is weak because of the scattering noise and attenuation from various optical components, especially the DMD itself. The reflected image will contain noise and losses that are intrinsic to the geometry of the system and the DMD chip. These noise sources include diffraction that is due to the periodic structure of the mirrors and backscatter from the mirror surfaces and chip surface. It is important in our setup to block the optical noise and to improve the signal-to-noise ratio. The PBS filters much of the scattering noise from the DMD surface, since most of the scattered field is horizontally polarized, whereas the measurement information is vertically polarized on returning through the \( \lambda/4 \) plate. In addition, the interference noise generated by the periodic structure of the DMD surface is also periodic and can be eliminated by use of a spatial filter (Iris and 0-Stop) placed in the back focal Fourier transform plane of imaging Lens 3. Finally, the moiré interference pattern that is created by the spatial periodicity mismatch between the DMD and the CCD array is removed by time integration of the detected CCD image while the DMD scans over the entire field of view.

4. System Calibration and Characterization

The way 3D measurements are acquired is by scanning through a 3D volume on the sample object and recording the detected confocal intensity for each point. In our system we scan the microscope through a series of depths by tuning the laser wavelength. At each depth plane the DMD performs a confocal transverse scan while we record the detected intensity pattern from the CCD. For each \((x, y)\) position the depth plane of maximum detected intensity defines the surface depth location. From calibration data, measurement values then can be enumerated and 3D images rendered.

A. Chromatic Scanning

For system characterization we measured the wavelength-to-depth coding and the longitudinal PSF. The chromatic dispersion properties of a diffractive lens can be characterized by the function of its focal length versus wavelength. When the wavelength tuning range is much less than the design wavelength \([i.e., (\lambda - \lambda_d) \ll \lambda_d]\), the focal length of a diffractive lens follows the linear relation\(^{16}\):

\[
f(\lambda) \equiv 2f(\lambda_d) - f(\lambda_d)\lambda/\lambda_d.
\]  

The wavelength-to-depth coding is expressed as a deviation of the focal-point position, at a wavelength \(\lambda\). During calibration, we turn ON one central DMD pixel that coincides with the optical axis. For each wavelength that is tuned, we scan an ideal reflective object (i.e., a mirror) and record the object position that results in a maximum detected intensity, which is the corresponding focal plane. The measurement result seen in Fig. 2 shows a linear relation, where a linear least-squares curve fit of the experimental data.
data gives the wavelength-to-depth mapping of the system for each microscope objective used:

\[ D_{40 \times (\mu m)} = 1585.41 - 1.8912 \lambda_{(nm)} \]  
\[ D_{60 \times (\mu m)} = 734.90 - 0.8762 \lambda_{(nm)} \]  
\[ D_{100 \times (\mu m)} = 458.80 - 0.547 \lambda_{(nm)} \]

From Fig. 2 we can also see that, with a wavelength tuning range of 48.3 nm, the focus position changes a total of 42.3 and 26.4 \( \mu m \) for the 60\( \times \) and the 100\( \times \) objectives, respectively. A larger scanning longitudinal field of view is possible with the full wavelength tuning range of as great as 100 nm for the Ti:sapphire laser, but it is not necessary for our measurements.

B. Point-Spread Function

The longitudinal PSF is an important characterization of the confocal imaging system. It allows us to compare the quality of different microscope objectives, although it does not define the actual limit of confocal depth resolution. We compare the PSF of the confocal microscope that uses chromatic scanning to that which uses mechanical scanning. For the conventional, mechanically scanned, confocal measurement the longitudinal PSF is normally measured by means of scanning a mirror in depth through the focal plane of the objective while recording the detected intensity at each depth location. We obtain our measurement by turning on one micromirror in the DMD array and measuring the intensity of light at the corresponding pixel at the CCD camera while moving a planar mirror object through the confocal microscope’s object plane. The planar mirror object is mounted on a mechanical stage that uses a micrometer (Newport Model DM-13) with \( \pm 0.07-\mu m \) position resolution. Figure 3(a) shows the measured longitudinal PSF for the conventional confocal system. From the PSF, we can acquire its FWHM.
value. For a single ON pixel, we estimate the FWHM by linear interpolation of the PSF data. The FWHM value is found to be 1.94 μm for the 60× Olympus, f/0.80, and 1.03 μm for the 100× Leitz Wetzlar, f/0.90 objectives.

For the longitudinal PSF of the chromatically scanned confocal microscope, we set a single ON pixel, as done previously, and then find and place a mirror object in the corresponding focal plane of the objective lens for a specific center wavelength. We then measure the intensity of light detected on the CCD camera while scanning the wavelength of the laser (±0.02-nm wavelength tuning resolution) around the specific wavelength. The longitudinal PSF of a single ON pixel for the chromatic case is characterized by an intensity profile approximated as a sinc-squared function. From Fig. 3(b), for the 60× objective, we estimate a wavelength tuning FWHM of δλ = 3.36 nm in wavelength that corresponds to 1.84 μm in depth. For the 100× objective we estimate a wavelength tuning FWHM of δλ = 1.85 nm corresponding to 0.99 μm in depth. From these characterization plots we can see that the conventional mechanically scanned and the new chromatically scanned confocal microscopes have similar longitudinal PSF characteristics that provide comparable performance.

C. Depth Resolution

Depth resolution is the ability of the microscope to measure and distinguish between closely spaced depth variations of the sample surface. As mentioned above, the PSF does not solely define the microscope depth resolution. If a center-of-mass technique is used to find depth location, the measurement resolution can be greatly improved beyond that defined by the FWHM of the PSF. The precision of the center-of-mass measurement depends on the detected signal-to-noise ratio; i.e., the noise level can create uncertainty in the position of the center of mass. This in turn affects the resolution of the measurement. Then the uncertainty of our measurement is the error in measuring the correct wavelength in addition to the error in locating the correct depth value from our calibration fit. If the wavelength-to-depth coding for the calibration is an ideal linear relation, the resolution of our measurements can be defined by a standard deviation σ from the linear fit. We find that the resolution σ = 0.54 μm for the 40× objective, σ = 0.33 μm for the 60× objective, and σ = 0.39 μm for the 100× objective. The resolution does not improve while increasing from a 60× to a 100× objective, meaning that we may
have reached the limit of resolution as determined by our calibration technique or equipment (e.g., micro-meter, wavemeter, mirror, CCD, and the like).

D. Transverse Field of View
Since the DMD is a 2D array, we are able to measure over a surface area of the sample without any translational scanning of the sample. The total surface area that can be covered depends on the optics used to image the DMD’s 800 × 600 pixels to the sample surface. The DMD size is approximately 1.3 cm × 1 cm, which is demagnified to a transverse field of view of 435 μm × 325 μm (approximately 30×) for the 60× objective and of 320 μm × 240 μm (approximately 40×) for the 100× objective.

5. Experimental Measurements
To demonstrate the capability of our confocal imaging system, we made quantitative measurements of various samples. The measurements were acquired by use of a step-by-step process in which a sequence of confocal images is recorded at different depth planes of the object. Thus each confocal image is a 2D array of intensity values detected by the CCD camera for a specific wavelength (which corresponds to a specific depth). Figures 4(a) and 4(b) show images of the diffractive element taken when the confocal imaging plane is adjusted by wavelength tuning to the top (λ = 805.08 nm, corresponding to z = 1.35 μm) and to the bottom levels (λ = 802.61 nm, z = 0 μm) of the element, respectively. The (x, y) coordinate of the images corresponds to the respective location on the sample’s surface. The set of all confocal images gives each (x, y) surface location an array of intensity-versus-depth values. The depth position of each surface location is defined by the position of maximum intensity at each respective (x, y) point; we can calculate this point by finding the center-of-mass location of the intensity-versus-depth array. This method has previously been shown to provide high accuracy and resistance to system noise.17

Using the 100× objective lens, we measured the surface profile of a four-phase-level diffractive element. The sample was measured by both chromatic and conventional stage-scanned confocal depth-scanning schemes. We selected the every-sixth-pixel spacing configuration for the DMD transverse scan. In addition, we averaged 10 video frames for time integration to remove moiré noise, which leads to a measurement scan rate of ~3 Hz. If the DMD software driver rate can be increased by a factor of 10, the 3D confocal scan can be performed at a video rate.

Table 1. Comparison of Profile Measurements for Four-Phase-Level Diffractive Element

<table>
<thead>
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<th>Profilometer</th>
<th>Level 1 (μm)</th>
<th>Level 2 (μm)</th>
<th>Level 3 (μm)</th>
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<td>0.90</td>
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<tr>
<td>Stage-scan confocal</td>
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<td>Dektak</td>
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<td>0.846</td>
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Fig. 6. Experimental results of measuring the integrated-circuit chip (Rozier 10/95 Photonic SRAM) with a 100× objective: (a) image of the chip when the confocal plane is adjusted to the bottom surface (λ = 810.99 nm, z = 0 μm), (b) to the middle plane (λ = 813.09 nm, z = 1.15 μm from bottom), and (c) to the top surface (λ = 815.54 nm, z = 2.49 μm from bottom).
In Fig. 5(a) a 3D mesh plot is shown that is reconstructed from 14 consecutive chromatic confocal images that have been scanned through the depth of the four-phase-level sample with a $\Delta \lambda = 0.19 \text{ nm}$ wavelength tuning, which corresponds to a $\Delta z = 0.10 \mu \text{m}$ from Eq. (4). For comparison we used a Dektak profilometer to measure the same optical element, and the resulting 2D surface profile is shown in Fig. 5(c). However, Fig. 5(b) shows a 3D mesh plot that is reconstructed from 14 consecutive confocal images scanned through multiple depths by a mechanical stage in $\Delta z = 0.1 \mu \text{m}$ steps. From Table 1 we see that the profiles of the sample measured by both the chromatic- and the stage-scanned confocal microscopes correspond well to one another. These measured values are also consistent with the Dektak results, indicating that the performance of our method is accurate and comparable with other existing surface-profiling techniques, except that we can perform a full 3D measurement without any translational scanning. The differences between the measured values are well within our resolution, where the differences are most likely from calibration error or measurement of a different location on the sample.

Using the same setup and parameters as in the previous measurement, we measured a Rozier 10/95 Photonic SRAM chip with chromatic scanning. Figure 6 shows the confocal image where (a) the confocal plane is adjusted to the bottom ($\lambda = 810.99 \text{ nm}, z = 0 \mu \text{m}$), (b) to the middle ($\lambda = 813.09 \text{ nm}, z = 1.15 \mu \text{m}$ from bottom), and (c) to the top ($\lambda = 815.54 \text{ nm}, z = 2.49 \mu \text{m}$ from bottom) of the chip. The fine structure inherent to each level of the chip can be resolved in its corresponding image. We also show in Fig. 7 the profile measurement of the SRAM chip where the depth position is coded in gray scale. The 3D reconstruction is acquired from 14 consecutive confocal images by use of $\Delta \lambda = 0.35 \text{ nm}$ wavelength tuning (corresponding to $\Delta z = 0.19 \mu \text{m}$).

6. Summary and Discussion

We have described a system design that uses a chromatic confocal depth scan and a DMD for transverse surface scan. The characteristic values of the confocal microscope, including longitudinal and transverse field of view, the PSF, measurement resolution, and the like, were measured. We have also resolved some of the technical issues required for improving the confocal imaging system to take into account noise created from the DMD (e.g., scattering and interference noise). We have performed measurements of samples, including a 3D profile of a diffractive element, by scanning over a volume in $x, y,$ and $z$, totally without any mechanical translation of the sample or the microscope. The measurement and the profile are of high resolution and accuracy, consistent with values found in a commercial profilometer. Furthermore, the nontranslational, chromatic confocal microscope is configurable, applicable to different sample materials, and can be developed.
to serve as an effective tool for profilometry in many new fields and environments in research and industry. The advantage of this system over other confocal systems is that it is stable, since no translational motion is needed to measure and profile a 3D object. The chromatic confocal microscope using DMD scanning is potentially fast. If we improve the DMD driver speed, and increase the chromatic scan rate e.g., by using a color filter wheel or electro-optics to tune the wavelength, real-time (i.e., video-rate) 3D measurements can be made on samples that are either moving or changing. By using the dynamically configurable DMD for scanning, we can configure the source and detection pinhole array to achieve the best signal and to reduce the cross-talk noise when measuring different samples. Additionally, we are exploring applications of this system in confocal fluorescence imaging of biological samples and in real-time applications.

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References