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Technical Assessment of Navitar Zoom 6000 Optic and Sony HDC-X310 Camera for MEMS Presentations and Training

Carl Diegert

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Carl Diegert
Data Analysis and Visualization Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-MS0822

Abstract

This report evaluates a newly-available, high-definition, video camera coupled with a zoom optical system for microscopic imaging of micro-electro-mechanical systems. We did this work to support configuration of three document-camera-like stations as part of an installation in a new Microsystems building at Sandia National Laboratories. The video display walls to be installed as part of these three presentation and training stations are of extraordinary resolution and quality. The new availability of a reasonably-priced, cinema-quality, high-definition video camera offers the prospect of filling these displays with full-motion imaging of Sandia's microscopic products at a quality substantially beyond the quality of typical video microscopes. Simple and robust operation of the microscope stations will allow the extraordinary-quality imaging to contribute to Sandia's day-to-day research and training operations.

This report illustrates the disappointing image quality from a camera/lens system comprised of a Sony HDC-X310 high-definition video camera coupled to a Navitar Zoom 6000 lens. We determined that this Sony camera is capable of substantially more image quality than the Navitar optic can deliver. We identified an optical doubler lens from Navitar as the component of their optical system that accounts for a substantial part of the image quality problem. While work continues to incrementally improve performance of the Navitar system, we are also evaluating optical systems from other vendors to couple to this Sony camera.

ACKNOWLEDGMENTS

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INTRODUCTION

We report on a technical, but qualitative evaluation of a newly-available, high-definition video camera (Sony HDC-X310) coupled to a zoom optical system (Navitar System 6000). The evaluation is based on qualitative assessment of images of a sample micro-electro-mechanical systems (MEMS) part. Adequate performance imaging this part would have provided a basis for proceeding with more detailed and quantative evaluation. The result could have been a configuration for three document-camera-like stations that are to be acquired and installed in a new Microsystems building at Sandia National Laboratories.

Video display walls of extraordinary quality are part of the three presentation and training stations currently under construction in Sandia's new Microsystems building. The new availability of a reasonably-priced, cinema-quality, high-definition video camera offers the prospect of filling these displays with full-motion imaging of Sandia's microscopic products at a quality substantially beyond the quality of typical video microscopes. Simple and robust operation of the microscope stations will allow the extraordinary-quality imaging to contribute to Sandia's day-to-day research and training operations.

MATERIALS AND METHODS

Optimizing image quality for effective understanding of MEMS parts is partly science and partly art. We have found that using Differential Interference Contrast (DIC) imaging is often remarkably effective in showing topography and other detail in these difficult, highly reflective devices. To perform the testing described in this report we first set selected a sample MEMS part that is typical of the product to be imaged in Sandia's new Microsystems building. We then configured and optimized DIC imaging of this part to obtain imaging that is typical of what has proven useful. Finally, we attempted to configure the relatively inexpensive Sony/Navitar system to retain as much of the utility of the imaging from the difficult-to-use, expensive research microscope system.

On 2-February-2006 we recorded images of the same sample Sandia micro-electrical-mechanical-system, MEMS, part using the two camera/microscope systems shown in Figure 1. The system for possible use in the new Sandia Microsystems building is on the left. It is based on a Sony HDC-X310 camera and an optical system from Navitar. We worked to optimize the imaging from this system, using imaging from the much more expensive and difficult-to-use system on the right. This reference system is based on a Sony HDC-F950 camera and a Zeiss Axioplan-2IE research microscope. Images from both systems are included in this report. Both cost and difficulty-of-use preclude replicating the reference system for use at the three stations in the new Sandia Microsystems building.

Figure 1. Two camera/microscope systems used to acquire images of a Sandia micro-electrical-mechanical-system, MEMS, part. The system based on the Navitar Zoom optic and Sony HDC-X310 camera is on the left. The system based on the Zeiss Axioplan2ie microscope and Sony HDC-F950 camera is on the right.

Camera/Microscope system based on Navitar Zoom Optic

Figures 2 and 3 show two configurations using a Sony HDC-X310 camera coupled to a system of parts from Navitar. These configurations are different in two ways:

- The microscope objective and the adapter to the objective differ. Figure 2 includes an Olympus 10X/0.30 UPlanFL objective. This objective has Royal Microscopy Society (RMS) standard threads (0.800x36T) and is coupled to the system using Navatar part 3-60187. Figure 3 includes a physically larger Mitutoyo 20X/0.42 objective. This objective has M26x36T threads and is coupled to the system using Navitar part 3-60160.
- Figure 3 includes a 2X magnifying lens, Navitar 1-6120, while Figure 2 has only air between the back of the common analyzer and the camera. Figure 2 does include a C-mount spacer that is not part of the Figure 3 configuration.

Early in our evaluation we learned that the long-working-distance objective from Mitutoyo was not compatible with the Navitar DIC prism. All imaging from the Navitar systems in this report were acquired either with the configuration exactly as shown in Figure 2, or with the system shown in Figure 3 where the Olympus objective and its adapter from Figure 2 replace the Mitutoyo and its adapter shown in Figure 3. That is, we acquired all Navitar-based images in this report using the Olympus objective

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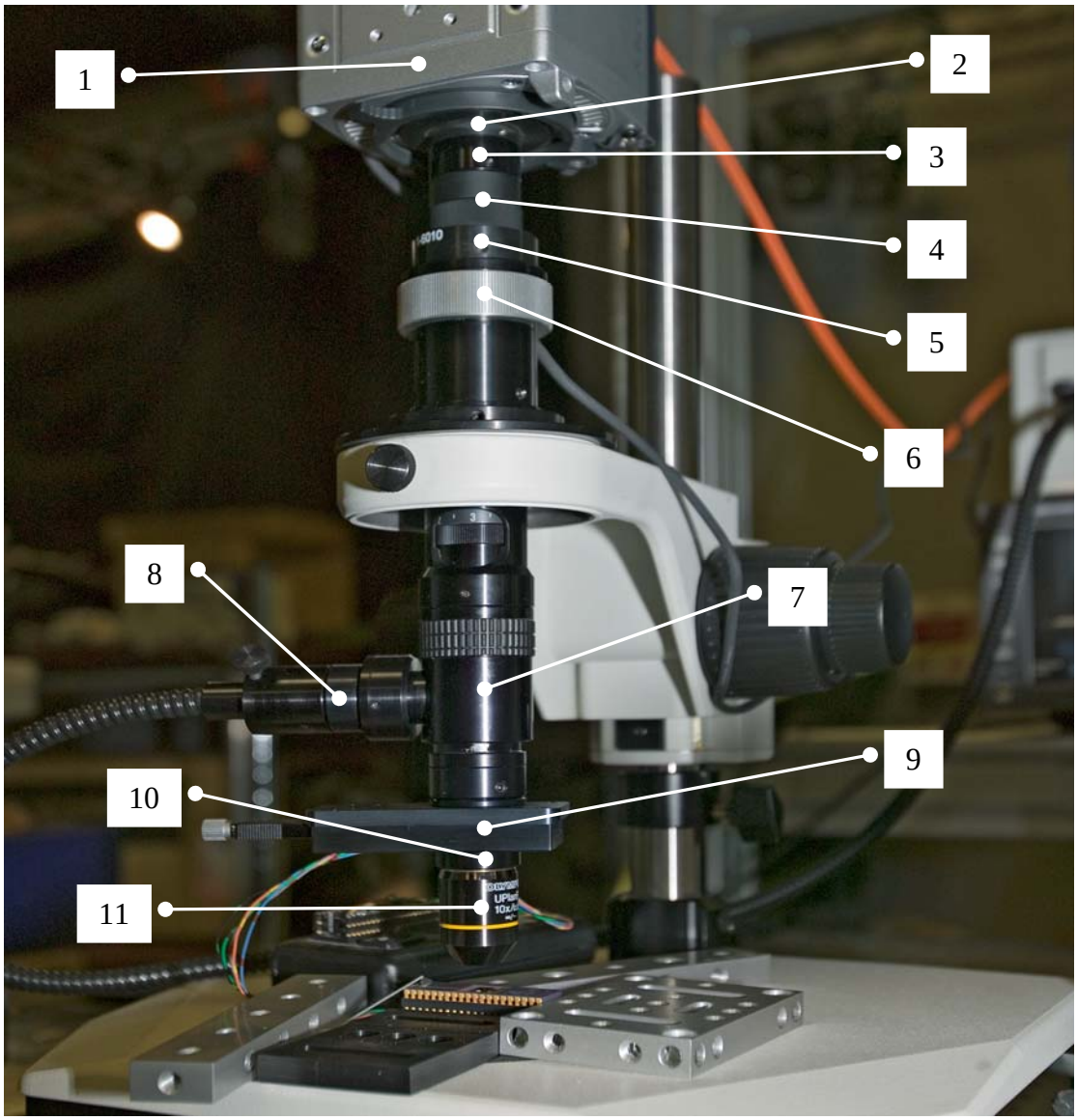

Figure 2. Camera/Microscope system based on Navitar Zoom 6000 optic with Olympus objective and with no 2X magnifier. The component parts are described in Table 1.

Table 1. Camera/Microscope components shown in Figure 2.

1	Sony HDC-X310 Camera
2	Adapter, Bayonet Hot Shoe 3-chip to C-mount (Navitar 2-12046)
3	Extension Tube, C-Mount (Navitar 3-11714)
4	Extension Tube, C-Mount, 20mm (from Schneider Optics Kit 21-060400)
5	Coupler, C-Mount (Navitar 1-6010)
6	Analyzer (Navitar 1-60816)
7	UltraZoom Super High Resolution Objective Coupling Lens (Navitar 1-60191)
8	Coaxial Polarizer, 8mm fiber input (Navitar 1-60812)
9	DIC Module (Wolaston Prism) (Navitar 1-63102)
10	Adapter, 0.800x36T to Navitar (Navitar 3-60187)
11	10X/0.30 Objective (Olympus UPlanFl)

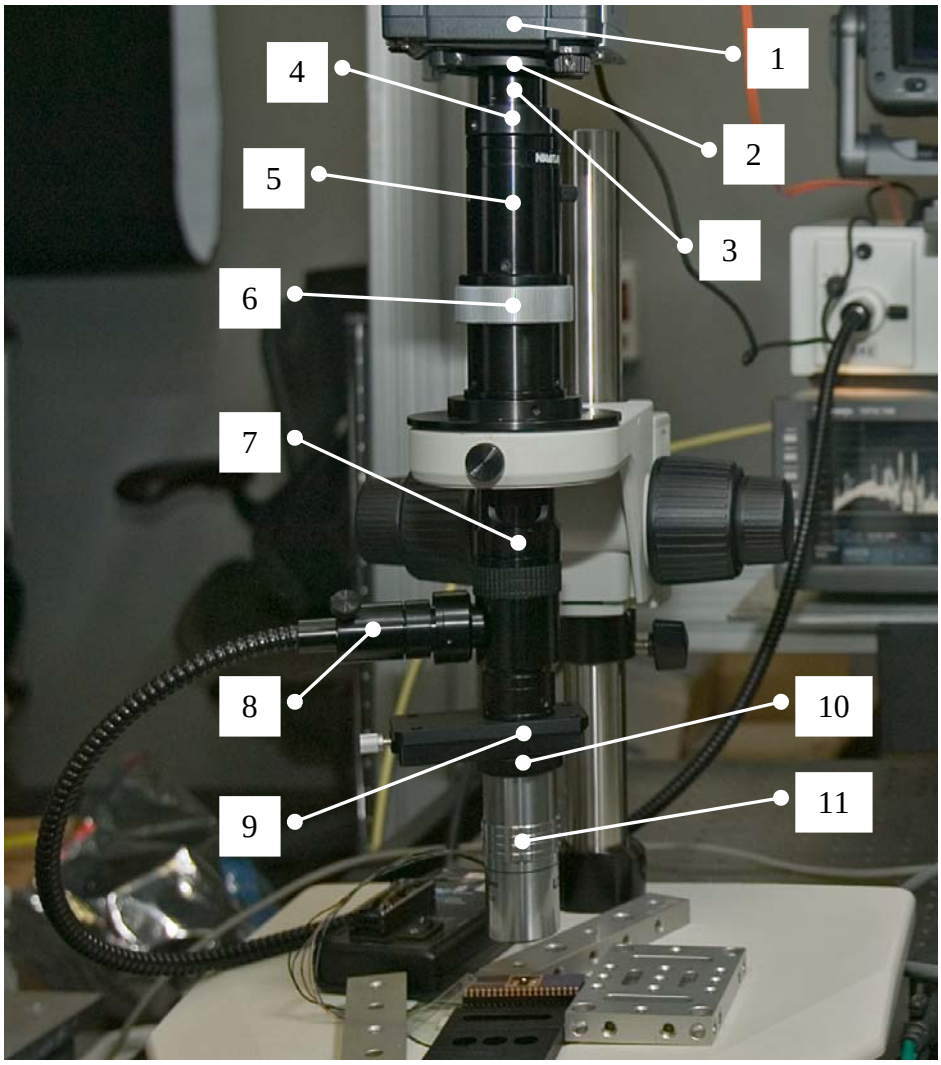

Figure 3. Camera/Microscope system based on Navitar Zoom 6000 optic with Mitutoyo objective and with 2X magnifier. The component parts are described in Table 2.

Table 2. Camera/Microscope components shown in Figure 3.

1	Sony HDC-X310 Camera
2	Adapter, Bayonet Hot Shoe 3-chip to C-mount (Navitar 2-12046)
3	Extension Tube, C-Mount (Navitar 3-11714)
4	Coupler, C-Mount (Navitar 1-6010)
5	Adapter, 2X Magnification (Navitar 1-6120)
6	Analyzer (Navitar 1-60816)
7	UltraZoom Super High Resolution Objective Coupling Lens (Navitar 1-60191)
8	Coaxial Polarizer, 8mm fiber input (Navitar 1-60812)
9	DIC Module (Wolaston Prism) (Navitar 1-63102)
10	Adapter, M26x36T to Navitar (Navitar 3-60160)
11	20X/0.42 Objective (Mitutoyo M Plan APO)

Camera/Microscope system based on Zeiss Axioplan 2 Research Microscope

We imaged the same MEMS part with both the Navitar-based systems shown in Figures 2 and 3, and with a Zeiss Axioplan 2 research microscope coupled to a Sony HDC-F950 cinematography camera. The HDC-F950 camera head is visible housed in Sony's T-adapter on top of the Axioplan 2 microscope on the right of Figure 1. A Zeiss HAL 100 halogen light coupled to the upper light path of the Axioplan 2 provided light for these images. Both polarizer and analyzer are part of an optical cube (Zeiss 1046-277) that we rotated into the optical path of the Axioplan 2 for this imaging. We obtained all images from the Axioplan 2 in this report using a 20X/0.50 Zeiss Epiplan NEOFLUAR HD DIC objective (Zeiss 1005-005) and its matched DIC prism (Zeiss 1053-083).

Images from the Axioplan 2 are included to provide a high-quality reference to guide optimization of the Navitar-based options, and to provide a benchmark to measure results we were able to achieve with the Navitar-based options. The expense and difficulty-of-use of the Axioplan 2 and HDC-F950 preclude their use in the presentation and training stations of Sandia's new Microsystems building.

Image Capture

Interface to both the HDC-X310 and the HDC-F950 camera is fully digital using serialized data on a 75-ohm coaxial cable as defined by the SMPTE292M standard, and often called described as a high-definition serial digital interface, HDSDI. We configured both cameras to capture full frames of video at 29.97 frames per second. That is, the capture was progressive and not interlaced. We cabled the cameras to a routing switcher. For the tests we set up three routes from each of these cameras. We routed the camera in use:

- to a Tektronix WFM700 Waveform Monitor,
- to a Sony BVM-F24 telecine video monitor, and
- to a Digital Video Systems Clipster system for uncompressed capture.

Both cameras send digital luminance and color components using 10 bits. We captured all of this information by configuring the Clipster to record the images in tiff-format files using 16-bits per component. Images in this report have been reduced to eight-bit-per-component colors. However, the full 16-bit, tiff-format files are archived with this report.

While still images are presented in this report, the application is for presenting moving images of operating MEMS parts. All image capture for this report was, in fact, accomplished at 29.97 frames per second. We arbitrarily chose to include the third frame in these image sequences for this report. Temporal fidelity of the camera and the HDSDI-based video displays and capture equipment is essentially perfect, and offers an important new capability for critically examining MEMS operation.

In-camera processing

Both cameras offer substantial in-camera processing using more precision than the 10-bits-per-component digital signal they deliver to their output. Configuration of this processing is possible using buttons on the cameras to walk through an elaborate system of menus and controls presented superimposed on the camera's video output (HDC-X310), or on a separate camera electronic viewfinder (HDC-F950). Optimization of in-camera processing is vastly assisted by using a specialized box with physical controls to adjust many of the critical parameters. The box we used for adjust both cameras, a Sony RM-B750, is shown in Figure 2. We used this RM-B750 to adjust color balance, master black level (roughly image contrast), shutter speed, and other parameters before each image capture.

Figure 4. Sony RM-B750 attaches to either camera and controls camera acquisition and processing parameters.

RESULTS

DIC Imaging using Long-Working-Distance Objectives

We had difficulty optimizing DIC imaging using the Mitutoyo objective shown in Figure 2. Navitar kindly set up a telephone conversation with their engineers, and we learned that Navitar does not recommend using their DIC component together with long working distance objectives like this Mitutoyo objective. They explained that the exit pupil that is characteristic of long-working-distance objectives interferes with proper operation of their DIC prism.

Positioning the 3-Chip Camera at the Image Plane

Lenses mount to the Sony HDC-X310 camera using a bayonet mount with a locking ring on the camera. Navitar advertises a part to mate to the Sony HDC-X310 as a *Bayonet Hot Shoe 3-Chip adapter*, part number 2-12046. Navitar was unable to supply this part for our testing. Instead they supplied an under-sized bayonet part that could lock to the camera, but demanded that we manually center the part in the camera before locking it into place. This part, as used in our testing, was not identified with a Navitar part number.

We obtained the highest-quality images from the Navitar-based systems when the Sony HDC-X310 camera was mounted behind the Navitar Zoom Lens (1-60191) with only the Navitar analyzer (1-60816) between the camera and the back of the zoom lens. To acquire an image of optimal quality, and to acquire images that remain in focus as the zoom of the Navitar 1-60191 is adjusted, the camera's CCD devices must be placed at the image plane formed by Navitar zoom lens.

Navitar was unable to supply parts to allow us to place the HDC-X310 camera at the proper distance from the back of the 1-60191. To get the camera at approximately the right position, we used a 20mm C-mount extension tube from a third party as shown in Figure 2.

The 20mm length of the C-mount extension tube was approximately correct, but did demand that we optimize focus after each change to the system zoom setting. For future work with this configuration we would substitute a focusing extension tube for the 20 mm, fixed-length tube, and would optimize adjustment of the focusing tube by trail and error. As a starting point, we would carefully measure the lengths of Navitar parts in a configuration that they recommend for a C-mount camera. We believe that this measurement is correct, as we set up such a configuration with a C-mount camera and observed that focus remained rather sharp over the entire range of zoom settings.

To substitute the Sony HDC-X310 for the C-mount camera, we need to reduce the length of the optical path from the back of the Navitar Zoom component (1-60191) to the camera. When the system is properly configured for a C-mount camera, the image detector (the CCD) is 17.526 mm behind the face plate of the camera's lens mounting flange. We believe that the Sony HDC-X310 camera increases this *back flange distance* to 38 mm, although the numbers in Table 3 are from casual sources. Certainly the imaging prism that is part of the HDC-X310 and sits between the lens mounting flange and the camera's CCDs demands a distance of more that 17.526 mm.

The decrease in distance we configured for our testing was obtained by replacing a two-inch Navitar tube from the C-mount configuration with our 20 mm C-mount extension tube plus the length of the Navitar extension tube (3-11714).

Table 3. Back flange distances (in air) for a few camera lens mounts.

C-Mount	17.526 mm	Typical single-chip CCD camera
CS-Mount	12.5 mm	Typical single-chip CCD with small chip
Sony 2/3-inch B4 Bayonet Mount	48 mm	There is also a ½-inch B4 mount, probably different back flange distance
1/2-inch Bayonet Mount – General	35.74 mm	Typical 3-chip video cameras not from Sony
Sony 14-pin hot shoe, ½-inch bayonet	38 mm	Canon calls this a SY14 mount

Coaxial Illumination

Figure 5 shows a full video frame captured from the configuration without the 2X magnification adapter, as shown in Figure 2. We captured this image with the zoom control of the Navitar 1-60191 set for minimum magnification (maximum field-of-view). It is easy to confirm that the failure of this system to fill this field of view is caused by failure of the coaxial illumination to fill the back aperture of the objective. We confirmed in telephone conversations with Navitar engineers that this is a limitation of their system, and that Navitar cannot provide components to provide components to illuminate the back aperture of these and of most other microscope objectives.

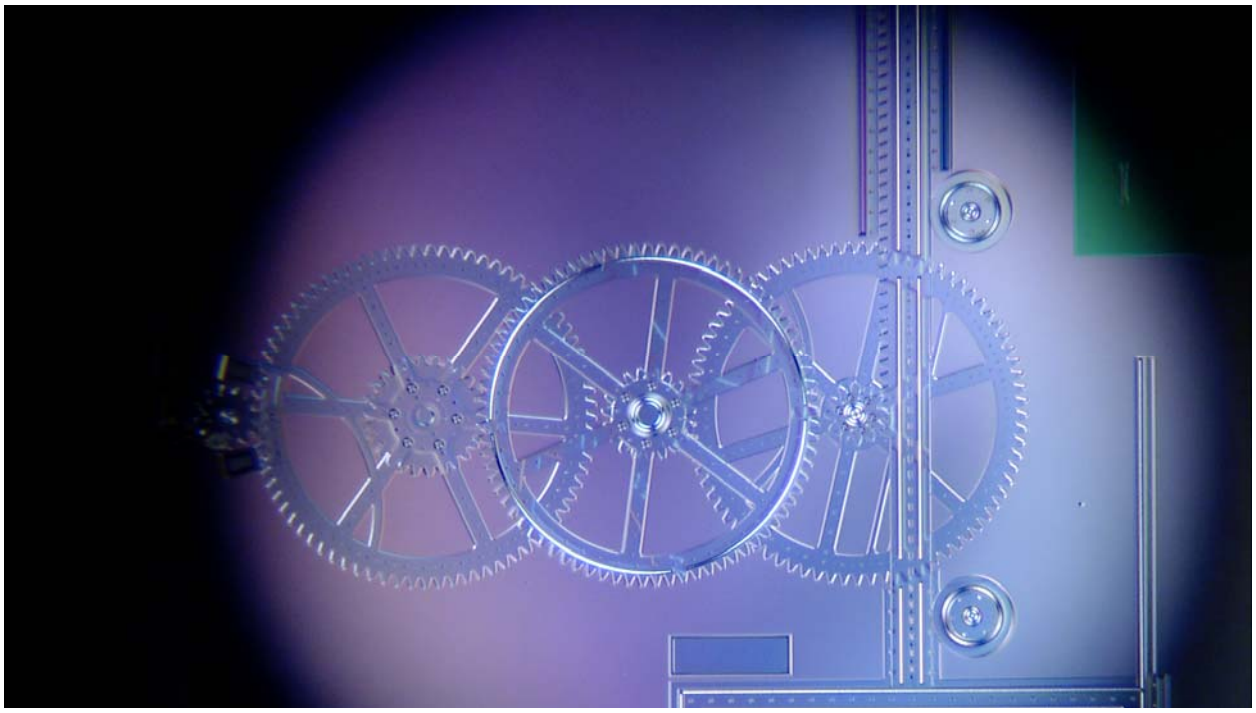

Figure 5. Image acquired through the Navitar-based system without the 2X magnifier, as shown in Figure 2. We adjusted the Navitar zoom lens for minimum magnification (maximum field of view) before acquiring this image. Navitar engineers confirmed that their coaxial illumination components cannot provide light to fill the camera's frame in this configuration.

Focus

Navitar includes what they describe as fine focus as part of the tested Zoom 6000 component, 1-60191. This mechanical focus adjustment is far too coarse to be usable at the magnifications provided by the systems tested here. We accomplished the testing by running the Navitar adjustment to its maximum extension where gravity could best hold its position. We focused the system using the microscope stand controls shown in Figures 2 and 3. This focus was sufficient for accomplishing the tests, but would not be adequate for day-to-day use of the system. To deploy a document-camera-style microscope station based on the Navitar Zoom 6000 it is likely best to lock down the position of the camera and optical parts using multiple clamps, and then accomplish focus by moving the sample using a micrometer-driven stage with three degrees-of-freedom.

Using 2X Magnifier to Fill Camera Frame

When Navitar engineers reported that they were unable to provide coaxial illumination to fill our camera's frame at minimum zoom, they offered to supply an adapter with a 2X magnification optical element so that the camera frame would be filled by their components, even at minimum zoom setting. If this proved satisfactory, we could reduce the overall magnification at minimum zoom by reducing the magnification of the objective.

We received the adapter with 2X magnification (1-6120) the next day and configured it into the system as shown in Figure 3. Unfortunately, the combined length of the Navitar analyzer (1-60816) and the adapter with the 2X magnification (1-6120) position the Sony HDC-X310 camera too far from the Navitar Zoom Lens (1-60191).

With the configuration shown in Figure 3 it is possible to focus over the entire range of zoom settings, but the distance between the objective and the MEMS sample must be substantially changed each time the zoom setting is changed.

Image quality Comparisons without DIC

Both the Navitar-based and the Zeiss Axioplan 2 systems provide for sliding the DIC (Wollaston) Prism out of the imaging path to easily record images without the DIC effect. Figures 6, 7 and 8 are samples of images obtained from the Zeiss Axioplan, and from the Navitar-based system with and without the 2x magnifier.

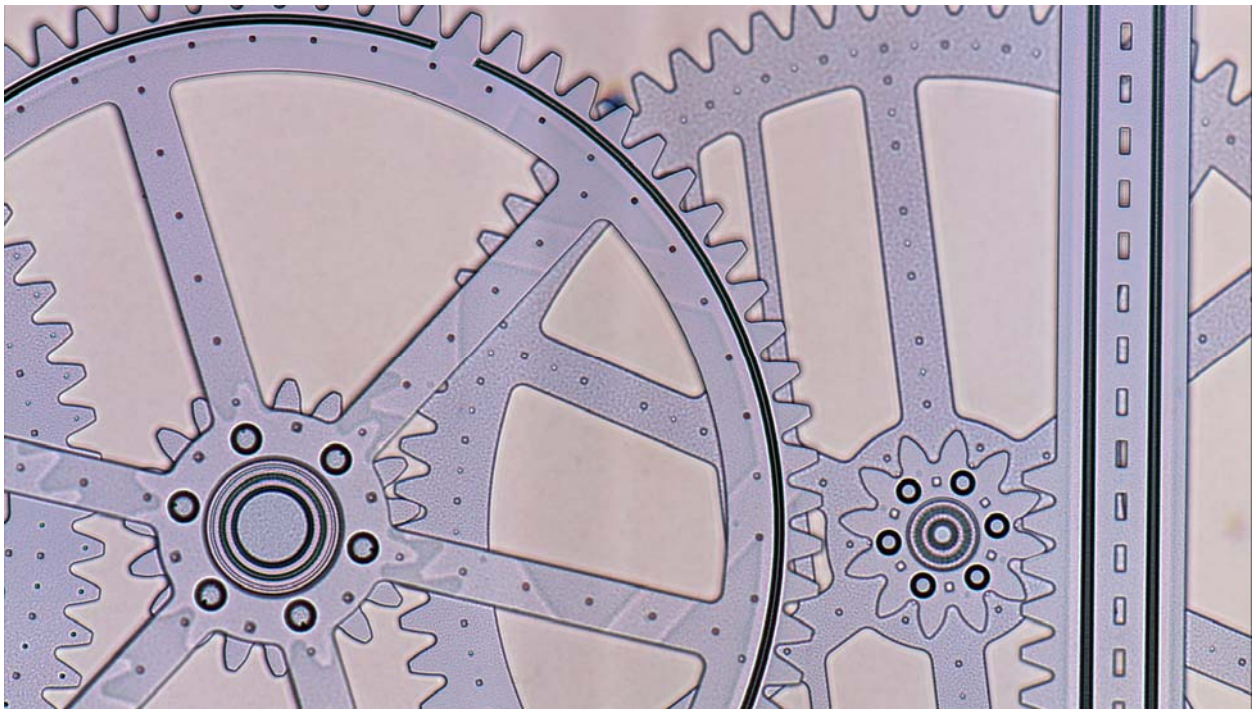

Figure 6. mage acquired through the Zeiss Axioplan 2 system without the DIC prism in the optical path.

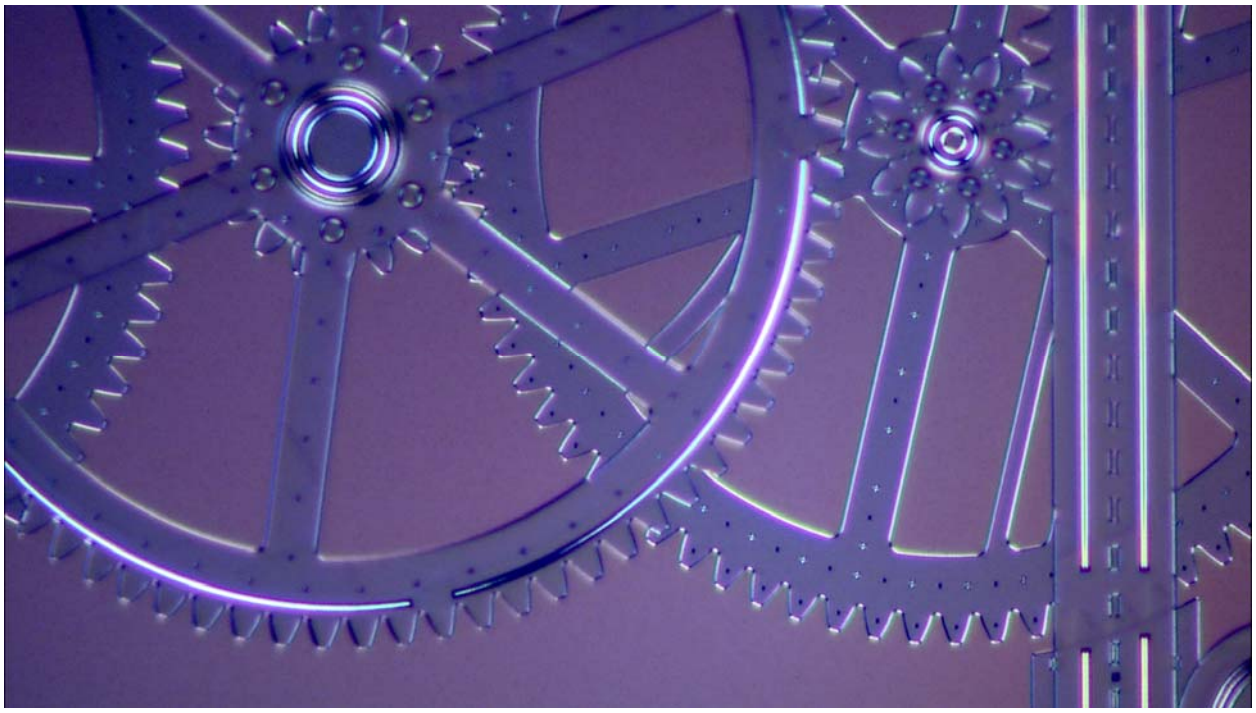

Figure 7. Image acquired through the Navitar system without the 2X magnifier, and without the DIC prism in the optical path.

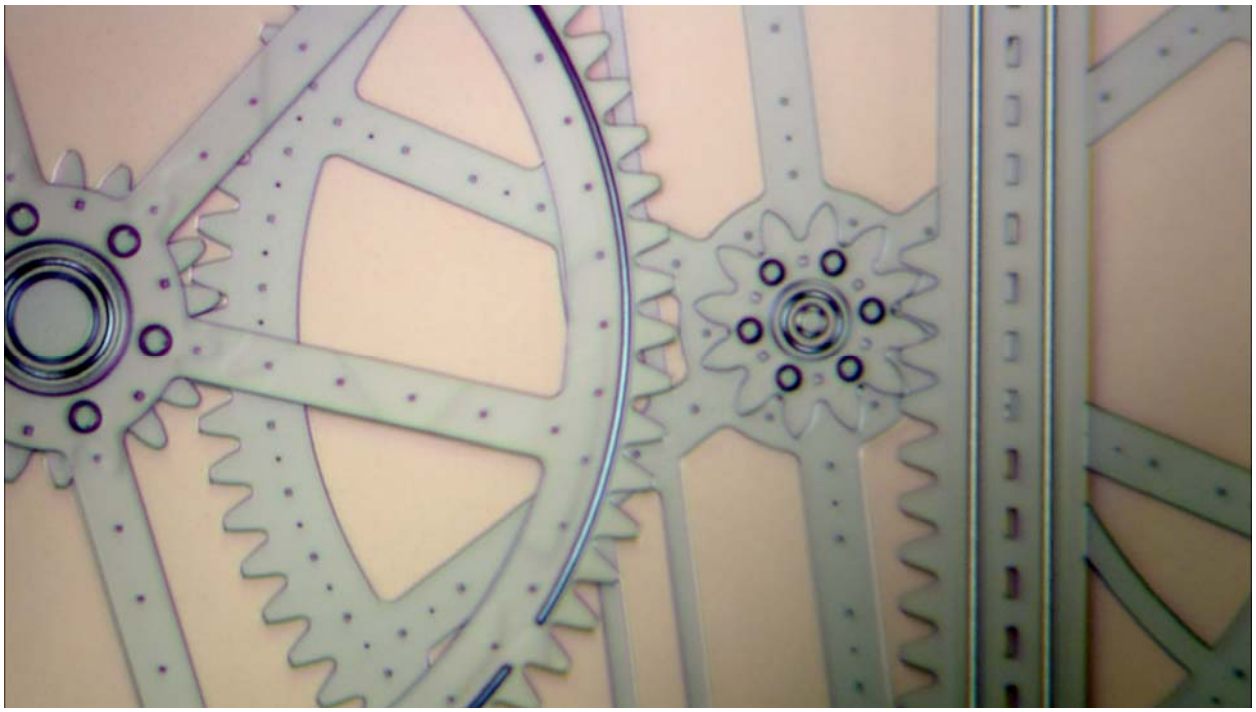

Figure 8. Image acquired through the Navitar system with the 2X magnifier, and without the DIC prism in the optical path.

Image quality Comparisons with DIC

Adjusting the position of the DIC prism in both the Zeiss Axioplan 2 system and the Navitar system yields a variety of image effects. To provide some flavor of what is possible this report presents six images, two from the Zeiss Axioplan 2, and two from each of the Navitar configurations (with and without the 2x magnifier). The two images in each of these three cases are taken at two different positions of the DIC prism. We placed the DIC in the first case to optimize the detail in the surface roughness of the gears. We placed the DIC in the second case to optimize the detail in the edges of elements at a depth where focus is good. These choices are highly subjective and are no substitute for hand-on work with these systems.

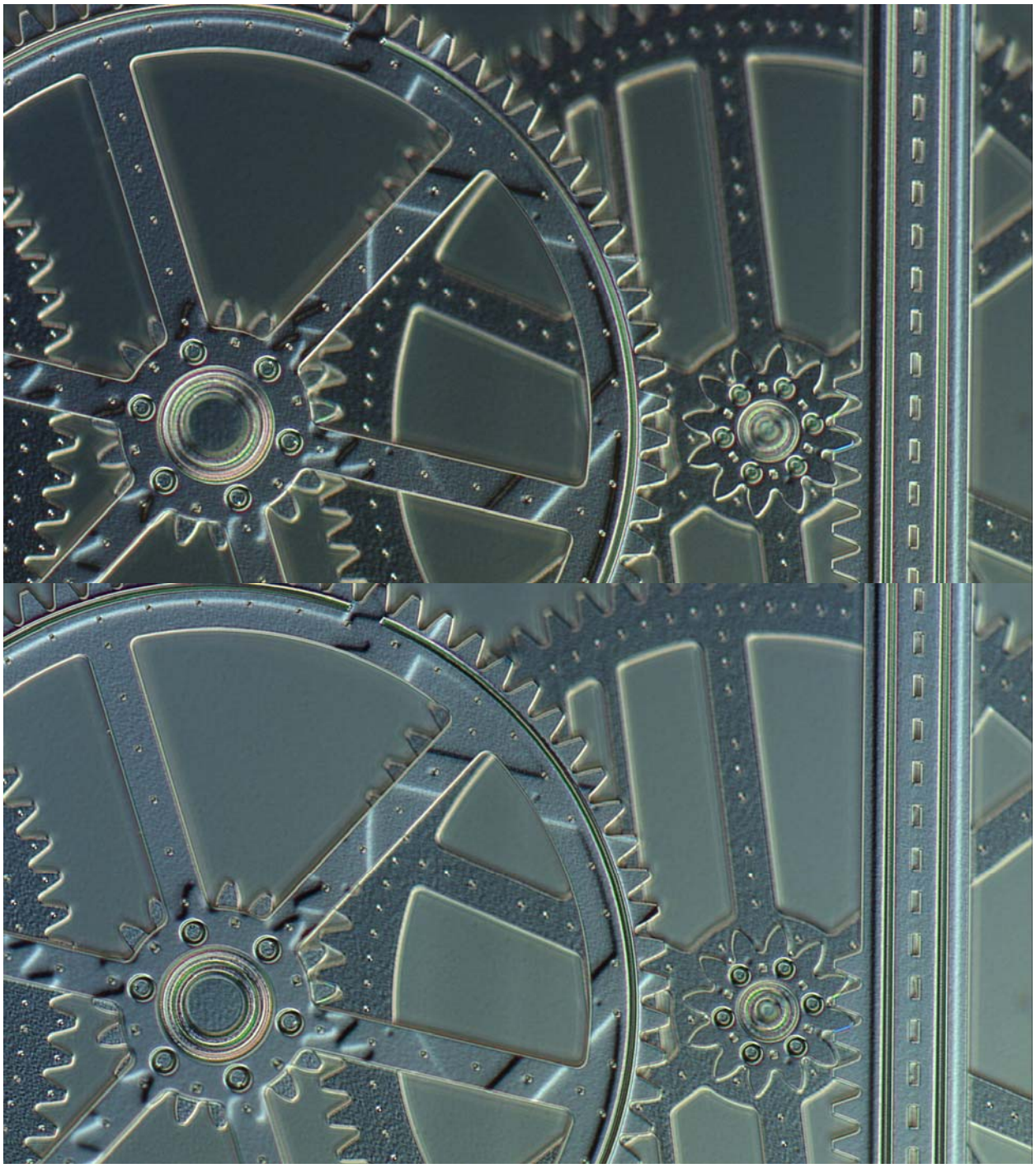

Figure 9. Image acquired through the Zeiss Axioplan 2 system with the DIC prism in the optical path. These two images show two possible positions for the DIC prism.

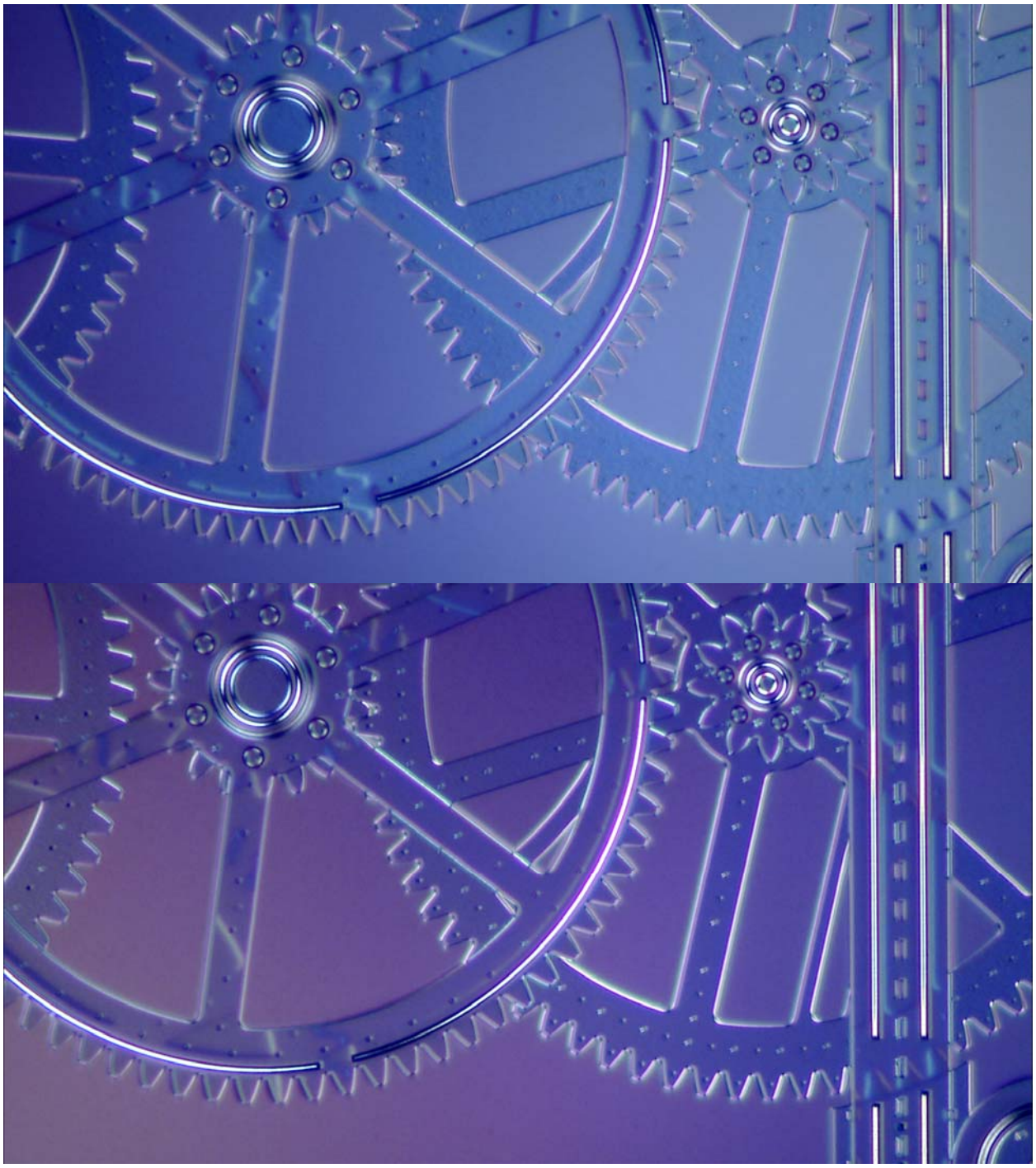

Figure 10. Image acquired through Navitar system without the 2x magnifier, and with the DIC prism in the optical path. These two images show two possible positions for the DIC prism.

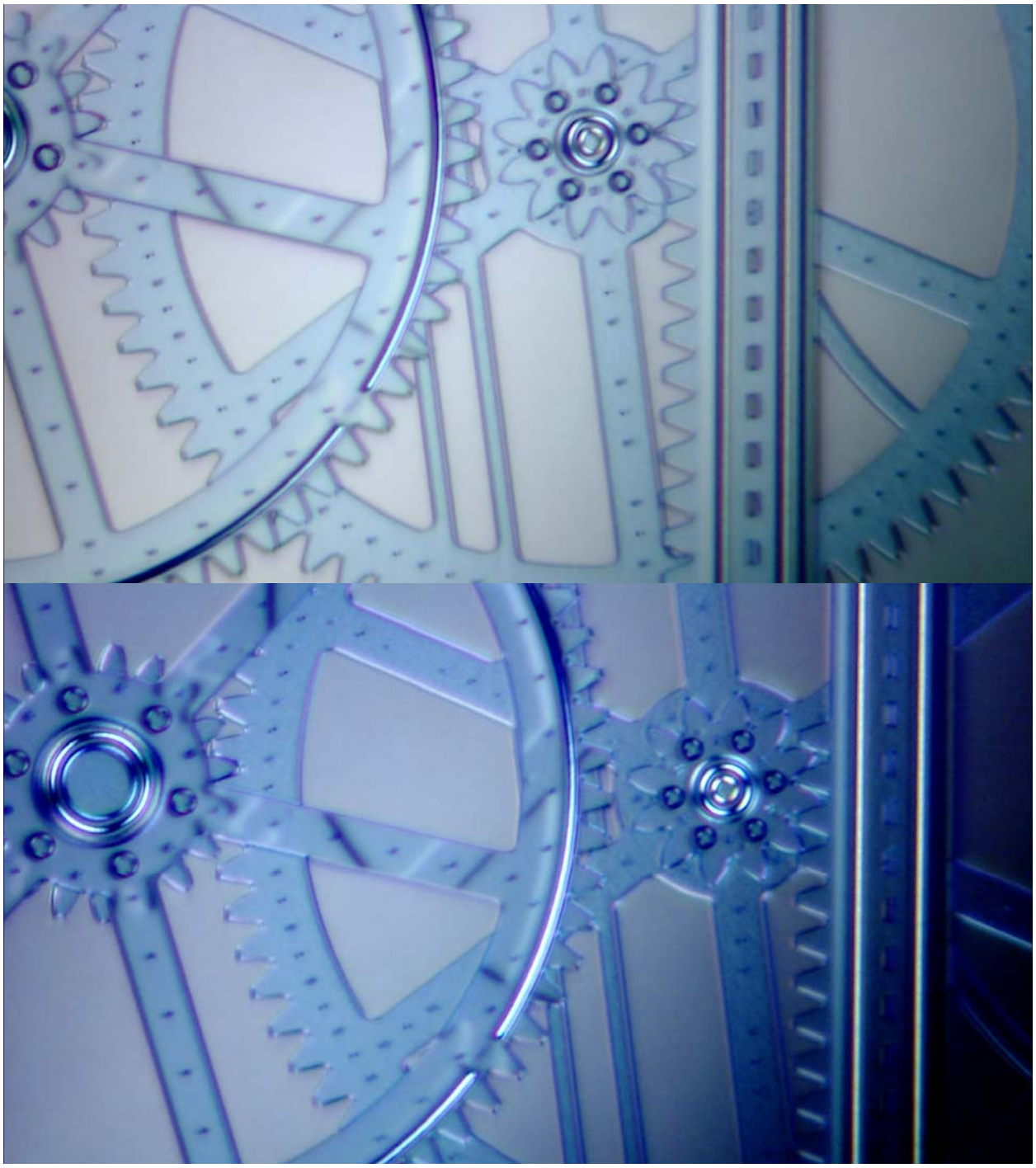

Figure 11. Image acquired through Navitar system with the 2x magnifier, and with the DIC prism in the optical path. These two images show two possible positions for the DIC prism.

DISCUSSION

Our goal is to configure a microscope station for presentation and training. For these purposes we sought to make the microscope station as robust and easy-to-use as a typical document camera. Imaging a sample MEMS part with the microscope objective a centimeter or more away from the part is substantially easier for a nervous presenter to accomplish than bringing the part to within a couple of millimeters of the objective. The long working distance greatly reduces the risk of damaging the MEMS part or of damaging the microscope objective. Unfortunately the Navitar DIC system does not work well with long working distance objectives.

The second problem with the camera/lens system comprised of a Sony HDC-X310 high-definition video camera coupled to a Navitar Zoom 6000 lens is the disappointing image quality qualitatively illustrated in this report. We determined that this Sony camera is capable of substantially more image quality than the Navitar optic can deliver. We identified Navitar's optical adapter with the 2X magnifier as the component of their optical system that accounts for a substantial part of the image quality problem. Improving the quality of this adapter may be as simple as making a shortened version available so that the camera can be moved closer to the parfocal image plane. We are hopeful that Navitar will make this part available, and that we can complete more testing and make an update to this report.

While work continues to incrementally improve performance of the Navitar system, we are also evaluating optical systems from other vendors to couple to this Sony camera.

A cooling fan is designed into the Sony HDC-X310 camera head. This fan certainly contributes softness to the imaging we obtained by causing vibration. It is also a source of acoustic noise that could be a problem in a quiet instructional or presentation setting. A final concern with this Sony camera is that the digital output includes a rather high level of additive noise in the luminance and color video components (video noise), even at low gain settings and with Sony's *mode 2* selected in their latest camera firmware.

With the Navitar coupled to the Sony HDC-X310, the problems with the Navitar optic dominated. We did not include any testing to quantify the fan and video noise problems contributed by the HDC-X310. If we can identify a more suitable optical solution to mate to the HDC-X310, then we will return to improve all aspects of the system performance, including the issues with acoustic and video noise in this camera.

Sony offers the same camera in two variations, with part numbers HDC-X310 and HDC-X300. We believe that the testing on the X310 version reported here applies to the X300. The fiber interfaces and remote camera control electronics that are part of the X310 version are not needed in the presentation and training stations, and we would therefore recommend that the less complex and less costly HDC-X300 be selected for this application.

DISTRIBUTION

Randy J. Brigham
Sony Electronics
7300 Summitview Dr.
Irving, TX 75063

Chris Meetze
Navitar, Inc.
200 Commerce Drive
Rochester, NY 14623

Mark Lubbers
Bender Associates, Inc.
5030 S. Mill Ave. Suite C-2
Tempe, AZ 85282

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