The Wonderland of Single-Lens Microscopes

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Abstract

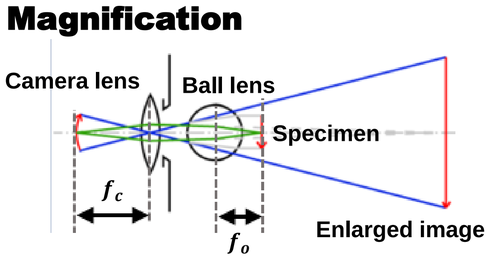
Leeuwenhoek had left several drawings of microorganisms in details his hand-made microscope consisting a glass bead in few millimeters with magnifying power 270X by placing the lens extremely close to the eyes. We doubted for Leeuwenhoek to distinguish specimens considering that so narrow field of view to observe and the resolution limit due to the limit of the numerical aperture. By analyzing the quality indicators of the image from test targets through the single-lens microscopes, composed of a glass bead of 5 mm and 3 mm in diameter, combined with a cellphone camera allowing for wider field of view and a illumination system with adjustable intensity, we reached maximum magnifying power 9.75X with fair resolution and tolerable aberration.

Introduction

Leeuwenhoek had left the observation records of animalcules through his hand-made microscopes. Let's recalling that the smaller the spherical lens, the greater the magnification, but the narrower the aperture, the lower the resolution. To achieve magnification 270X, the glass bead is required to be 1.85 mm in diameter. With the aberrations and the resolution limit, how much could we recognize in such a narrow field of view ?

Theory

Magnification



$$M_{system} = \frac{f_c}{f_0} \qquad f_0 = \frac{nd}{4(n-1)}$$

Figure 1: Magnification of image on the sensor of cellphone camera

Distortion

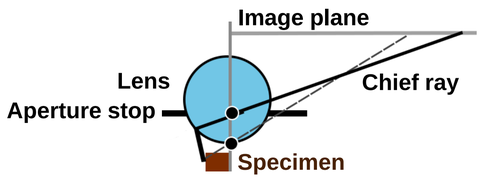
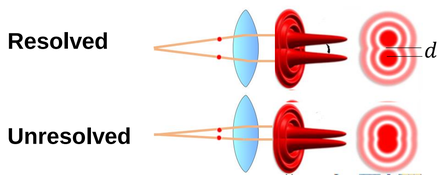


Figure 2: Pincushion distortion, larger magnification at the corner of the image, resulting from the light blocked out by the aperture stop, leading to shorter focal length.

Resolution



$$NA = \frac{nD}{2f} \qquad \text{resolution limit: } d = \frac{\lambda}{2NA}$$

Figure 3: Two point sources of light appearing as Airy diffraction patterns spaced closely will cause them difficult to identify.

Method

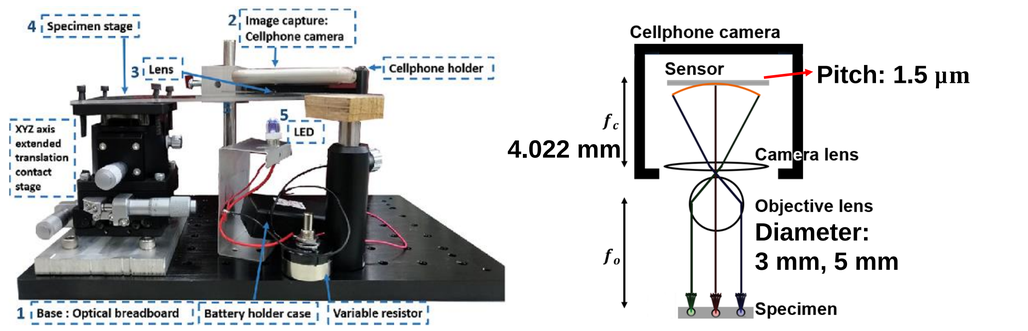


Figure 4 : Frame of single lens microscope and schematic diagram of the optical system

Analysis and Results

Quality parameters of lens

	Lens (3 mm)	Lens (5 mm)
Diameter of lens (mm)	3	5
Aperture	2.5 mm	2.5 mm
Numerical Aperture	0.55	0.375
Focal length (mm)	2.25	3.33
Resolution limit (μm)	0.5	0.73
Theoretical magnification	1.7876X	1.2067X
Theoretical resolution	161 line pairs /mm	181 line pairs /mm

Magnification

$$M = \frac{number\ of\ pixels \times number\ of\ pixels\ occupied\ by\ 0.05\ mm}{specific\ length\ of\ micrometer\ (0.05\ mm)}$$

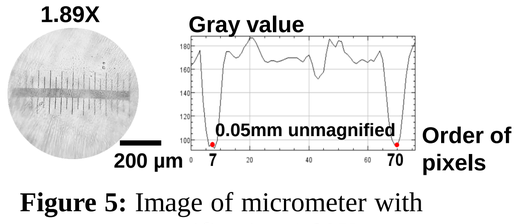


Figure 5: Image of micrometer with magnification 1.89X

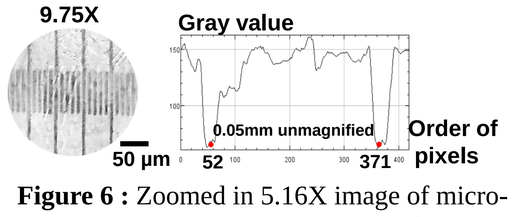


Figure 6 : Zoomed in 5.16X image of micrometer with magnification 9.75X

Distortion

Distortion is the magnification of the image varying with the field of view at a fixed working distance.

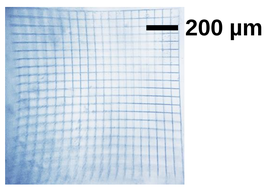


Figure 7: Image of grid with spacing 50 μm with distortion

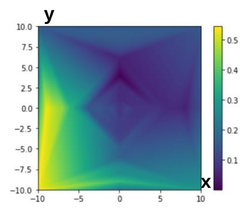


Figure 8: Distortion, different magnification throughout the field of view, is 16˙% on average.

Resolution & Modulation Transfer Function (MTF)

Figure 9: As spatial frequency increases, the images produced in microscopes appear as a composition of sinusoidally varying intensities that has reduced contrast, representing dark gray and light gray alternately instead.

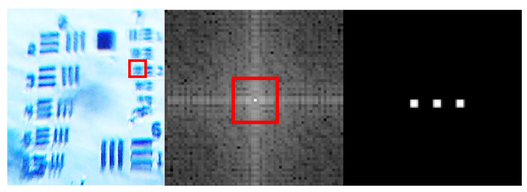


Figure 10: Best resolved pattern of element 3 in group 7 in 1951 resolution test target through lens of diameter 3 mm, with resolution 3.11 μm, analyzed from Fourier image of it.

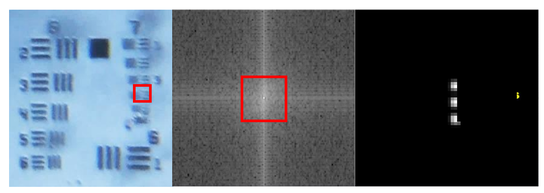


Figure 11: Best resolved pattern of element 4 in group 7 in 1951 resolution test target through lens of diameter 5 mm, with resolution 2.76 μm, analyzed from Fourier image of it.

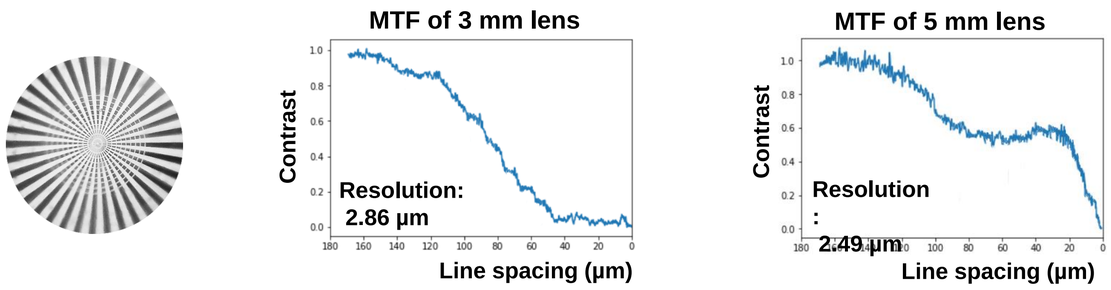


Figure 12: Figure on the left is image of Sector star applied to analyze MTF. The details of image cannot be distinguished beyond the cut-off frequency. For 3 mm lens, the closest details that can be resolved at spatial resolution 2.86 μm, and at 2.49 μm for 5 mm lens, inferring that resolution decreases with increasing diameter of lens.

Gallery of Microcosms and Sketching from Leeuwenhoek

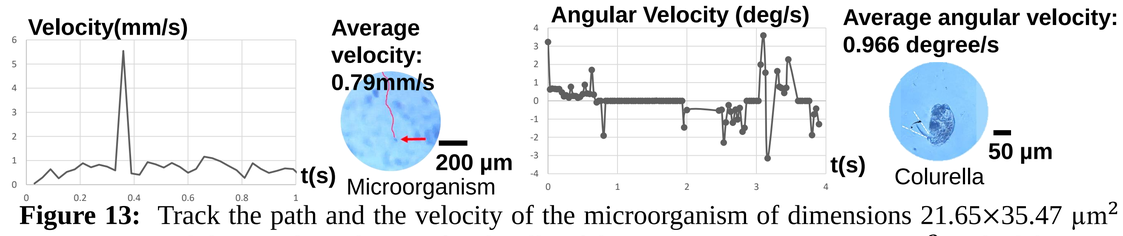
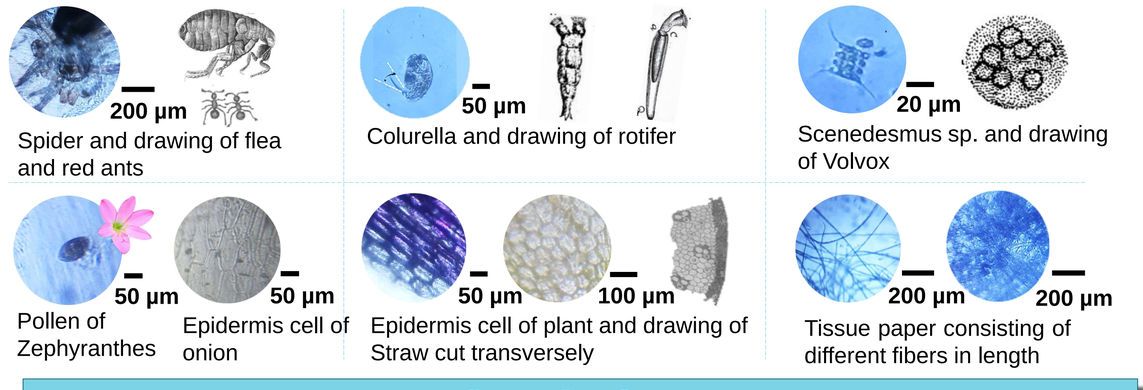


Figure 13: Track the path and the velocity of the microorganism of dimensions 21.65×35.47 μm^2 and the angular velocity of Colurella of dimensions 111.43 ×72.58 μm^2 in the lake.



Conclusions

1. Finest details of spacing 2.49 μm could be resolved when magnified through a lens of 5 mm in diameter, and 2.86 μm for a lens of 3 mm.
2. The details of specimens in scale of micrometer could be resolved even with a lens of 3 mm in diameter, therefore, we surmised that Leeuwenhoek indeed had observed and then to record those microorganisms by using single-lens microscopes.