Optical Instruments and Imaging: The Use of Optics by 15th Century Master Painters

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Abstract

We discuss some of the details of the optical technology that was known at the dawn of the Renaissance. We shown that it is quite easy to fabricate concave mirrors of suitable focal length, diameter, and resolution for 15th century artists to have used to project images. The information in this paper complements information on the actual optical evidence that we have presented elsewhere.

Introduction

In previous publications we presented some of the visual[1] and optical evidence[2,3,4] we have assembled that shows certain painters as early as c1425 used optical projections as aids for producing portions of some of their paintings. Here we address issues of optical technology. The period in question for this work is that prior to c1425, since that is the earliest date for which we have identified artifacts of the use of optics within certain paintings. In this paper we discuss both lenses and concave mirrors, since either could have been used to project suitable images.

Historical Background

There is considerable evidence that not only were suitable optics—both refracting and reflecting—available early in the Renaissance, but also that they were inexpensive. As shown in Fig. 1, Tomaso da Modena's 1351–52 paintings of 'Hugh of Provence' and 'Cardinal Nicholas of Rouen' contain, respectively, images of spectacles and a magnifying glass, and 'Isnardo of Vicenza'and 'St. Jerome' concave mirrors.

About the mirrors in two of these paintings Robert Gibbs writes[5] *"Isnardo da Vicenza is preparing his office; there is a reading glass (an enlarging-concave-mirror) on the shelf behind him."* Further, in a footnote to that sentence, Gibbs explains *"Mirrors, despite their inconvenient habit of reversing the text, were used alongside lenses to enlarge small and faded handwriting"*[6]. Gibbs continues in his footnote *"The use of mirrors for reading continued into the sixteenth century, and the second (not the first) representation, of a variant type set in a leather horn rather than on a fixed metal stand, appears on St. Jerome's shelf..."*.

In his extensive bibliography David Lindberg lists 61 texts on optics written in the years 1000–1425.[7] This shows that, contrary to popular perception, the period leading up to the Renaissance was a very active time of scientific activity. Knowledge developed during that period was quite extensive, as illustrated by the following passages from two 13th-century books:

Fig. 1. Details of four paintings by Tomaso da Modena in the Chapter House, Treviso, Italy, 1351–52. From left to right 'Hugh of Provence', 'Cardinal Nicholas of Rouen', 'Isnardo of Vicenza', and 'St. Jerome'.

> *…this is the concave surface of a paraboloidal body… The construction of such a surface proceeds as follows. Have a concave cone turned [on a lathe], the larger the better…*
> Roger Bacon, **De speculis comburentibus**, c1260[8]

> *What is proposed here can be proven experimentally. Indeed, in an iron mirror color appears weaker because the color of the iron, mingled with the reflected light…weakens the [resulting] reflected color. Make a spherical mirror as before [from clear iron]; smooth and polish its interior along the concave portion of its curvature…*
> Witelo, **Perspectiva (Book V)**, c1274~1278[9]

Witelo further describes the actual manufacture of a parabolic mirror from a concave piece of iron. Two equal parabolic sections were drawn on a rectangular sheet of iron or steel, and cut out. The parabolic edge of one was sharpened for cutting and that of the other made like a file for polishing. These sections were then used, with some unspecified mechanism to rotate them about their axes, to grind and polish the concave surfaces of the piece of metal so that it formed a parabolic mirror. As the above passages show, the tools and techniques for fabricating the necessary spherical — and the even more sophisticated parabolic — concave mirrors are described in texts as early as the 13th century.

Mirrors in Prose

Four pages of the 13th-century poem 'The Romance of the Rose' contain descriptions of what the book simply calls *"mirrors."* [10,11]. However, the shapes— flat, convex, or concave — are clear from the descriptions. In the paragraph starting at line 18247 Jean de Meun, the author of this portion of the poem, says that he won't bother giving details about the *"shapes of mirrors"* because *"Everything is written elsewhere in a book."* Starting at line 18039 he writes *"Alhazen…wrote the book of 'Optics'… There [the student] will be able to discover the causes and strength of the mirrors that have such marvelous powers…"*[12] Also, the fact de Meun mentions oblong images in one paragraph tells us they weren't limited only to simple convex mirrors at the time; they knew how to fabricate distorted ("anamorphic") ones as well. The introduction to the 1995 translation[10] says *"for nearly three hundred years [The Romance of the Rose] was one of the most widely read works of the French language,"* so this was a well known work during exactly the period in question.

De Meun refers to *"those who are masters of mirrors,"* indicating that there were specialists in such optical imagery at the time. The paragraph that starts at line 18163 says *"...Other [mirrors] make different images appear in different situations—straight, oblong, and upside down in different arrangements.... they make phantoms appear to those who look within. They even make them appear, quite alive, outside the mirror, either in water or in the air..."* This provides additional textural documentation that not only did concave mirrors exist as early as the 13th century, but also that they were being used for projecting images—images that are *"quite alive, outside the mirror"* is a beautiful description of an image projected by a concave mirror. By making the distinction between the *"phantoms"* that *"those who are masters of mirrors"* can make appear to people who look ***"within"*** a mirror, and those they can make appear *"quite alive, **outside** the mirror,"* we are given a description of both virtual and projected images produced by concave mirrors. Jean de Meun wrote those words in c1275; over 150 years before Jan van Eyck, one of the earliest painters who we have shown used optics for portions of some of his paintings.[1–4]

Cost and Availability of Optics

As for the cost and availability of quality optics by the mid-15th century, the historian Vincent Ilardi located correspondence dated October 21, 1462 between Duke Sforza of Milan and his Ambassador to Florence that answers this.[13] In his letter the Duke ordered three dozen pairs of eyeglasses to be made to three different sets of specifications. Based on typical travel time of the mail between those two cities, Ilardi estimated it took *"barely a week for the manual grinding and polishing of seventy-two lenses and fitting them into thirty-six frames."* Ilardi also points out that the average cost of 6.8 Soldi the Duke paid for each pair was quite modest, given that it was less than half the average daily wage of 17.2 Soldi that a mason earned at that time. According to the U.S. Department of Labor, the average daily wage of a construction worker now is ~$120, and today a pair of the least expensive, custom-ground glass reading spectacles costs ~$150, so the relative cost of custom optics 540 years ago was even less then than it is today.

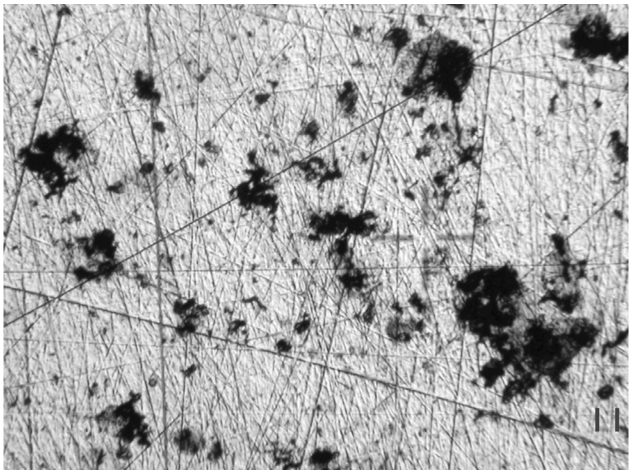

Fig. 2 Nomarski Differential Interference Contrast (DIC) micrograph of the surface of an iron mirror 201 days after polishing. The bars in the lower right corner of the image are 20 μm apart.

Metallic Concave Mirrors

As the passages quoted above show, the fabrication techniques for metal mirrors were known at the time, and it takes less time to make an appropriate concave mirror from metal than from glass. Metal is much softer than glass, so it requires less time to grind and polish, and when completed a metal mirror reflects light without requiring an additional shiny coating to be applied. However, unlike glass, mirrors made of iron, brass, bronze, silver, etc. all rust or tarnish, in each case forming opaque oxides or sulfides in a matter of years, if not months, if not periodically polished.

Fig. 2 shows a Nomarski Differential Interference Contrast (DIC) micrograph of the surface of an iron mirror approximately 7 months (201 days) after polishing. Although many scratches are quite apparent in the micrograph, this mirror projects a very nice image, showing that what scientists consider to be an "optical quality" surface is not required.

After polishing, this mirror was exposed to ~40% relative humidity for ~2 hours/day, and much less than that the rest of the time. The black-appearing blotches that cover approximately 16% of the surface are Fe_2O_3 (rust) patches. At this rate of formation, the entire surface will be covered by an opaque coating of rust in 3½ years. All metals that would have been used for concave mirrors in the Renaissance (iron, brass, bronze, silver, lead, tin, etc.) form opaque oxides or sulfides. Although only minor periodic polishing would have been required at the time to maintain their imaging qualities, the subsequent 600 years of oxidation means all such mirrors in museum collections today inevitably are very significantly degraded from their original condition.

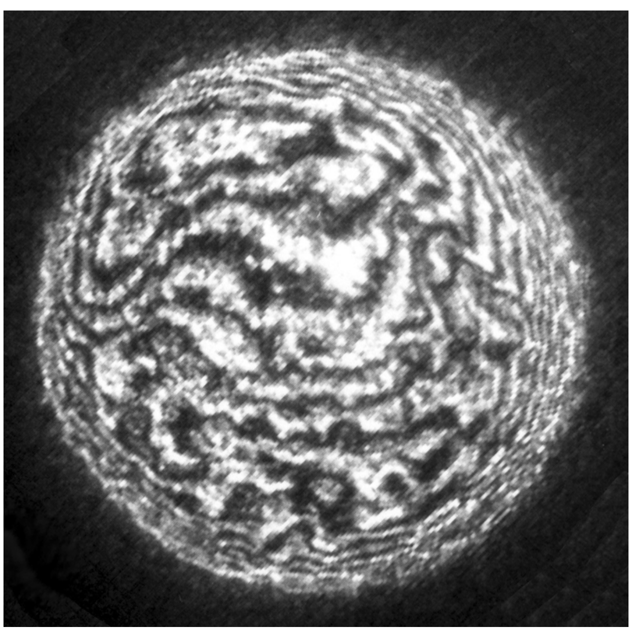

Fig 3. Optical interferogram of a 2.5 cm diameter brass concave mirror (courtesy Martin Valente).

We have fabricated several concave mirrors using technology that would have been available in the 15th century. To do this, we

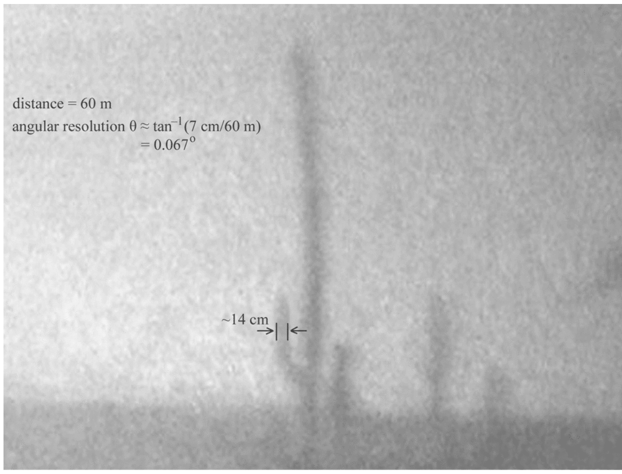

Fig. 4. Enlargement of a portion of an image projected by a 2.5 cm diameter brass concave mirror whose fabrication is described in the text.

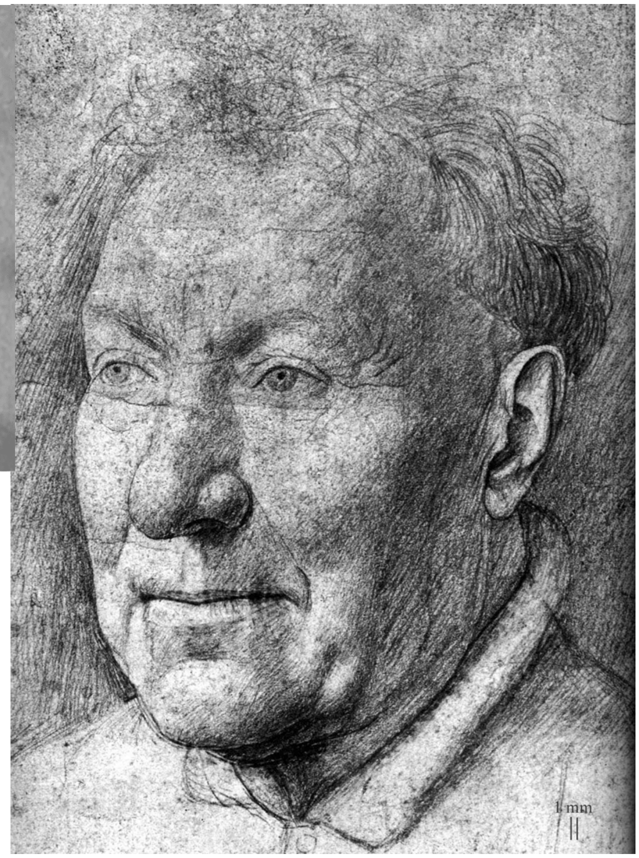

Fig. 5. Silverpoint drawing of Cardinal Albergati (detail), Jan van Eyck, 1431. The full drawing is 21.4×18.1 cm.

used only five grades of grinding and polishing compounds along with pieces of metal. As Fig. 1 shows, artisans were grinding glass spectacles by the 14th century, so they had abrasive compounds at that time.

Figure 3 is an optical interferogram of a 2.5 cm diameter brass mirror we made in only 59 minutes using grinding and polishing compounds. As can be seen, the interference fringes are at least 2λ in the center of the mirror, and even worse than that at the edges. However, in spite of the relatively poor quality of the mirror indicated by this measurement, it projected the image in Fig. 4.

Figure 4 shows an enlargement of a small portion of the image projected by the brass mirror whose interferogram is shown in Fig. 3. The mottled background is an artifact of the resolution of the digital camera used to photograph the projected image (this is an enlargement of only a small portion of the photograph). Note that it is easy to resolve the 14 cm arm of the cactus from the adjacent ~18 cm trunk on the projected image, which means that two vertical bars of width ~7 cm that were located ~7 cm apart would be resolved at that same distance. From this measurement we calculate the angular resolution of this mirror to be at least 0.067°.

Figure 5 shows the significance of the resolution calculated in the previous paragraph. From the measured separation of the Cardinal's eyes on van Eyck's drawing, and the fact he is viewed at an angle of ~30 degrees to us, we calculate that this drawing was made at approximately 50% of life size. If van Eyck had used a lens of 50 cm focal length (i.e. one comparable to that we calculated had been used by Lorenzo Lotto[2]) to aid him in making this drawing, we calculate from the Lens Makers' Equation that the Cardinal would have been sitting 1.5 meters from the lens. If van Eyck's lens or concave mirror only had the angular resolution of the brass mirror used for Fig. 4, the laugh-lines on the Cardinal's face that were 1.8 mm apart on the Cardinal himself would have been resolved. Since the drawing is at 50%, this corresponds to only 0.9 mm on the projected image. The 1 mm scale at the lower right of this drawing shows that such a resolution would have been sufficient for van Eyck to have made this drawing from an image projected by such a lens.

Summary

To summarize, we have discussed some of the details of the optical technology that was known at the dawn of the Renaissance. Using only grinding paste and pieces of aluminum and brass, we have shown that it is quite easy to fabricate concave mirrors of suitable focal length, diameter, and resolution for 15th century artists to have used to project images. This information in this paper complements information on the actual optical evidence that we have presented elsewhere.[1–4]

Acknowledgments

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6. Note: when properly oriented, concave mirrors magnify the text without reversing it.

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11. We are grateful to Peter Schroeder, Professor of English at California State University, San Bernadino, for bringing the passages about mirrors in 'The Romance of the Rose' to our attention.

12. Abu Ali al-Hasan ibn al-Haytham (Alhazen or Alhacen). b.965 Basra d.1039 Cairo. His seven-volume 'Kitab al-Manazir' was translated into Latin as *Opticae Thesaurus Alhazeni* prior to the 14th century.

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