Ibn al-Haytham and the Origins of Computerized Image Analysis

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Abstract- **Ibn al-Haytham (Latinized as Alhazen or Alhacen) was born in Basra in 965 A.D. [354 A.H.], but produced nearly all of his work in Cairo's al-Azhar Mosque, where he wrote nearly one hundred works on topics as diverse as poetry and politics. Al-Haytham is primarily known for his writings on geometrical optics, astronomy, and mathematics, and for nearly four hundred years his treatment of the geometry of reflection from flat and curved surfaces has been known as "Alhazen's problem." However, as discussed in this paper, with his landmark seven-volume** *Kitāb al-Manāzir* **[*Book of Optics*], published sometime between 1028 [418 A.H.] and 1038 [429 A.H.], al-Haytham made intellectual contributions that subsequently were incorporated throughout the core of post-Medieval Western culture. His seminal work on the human vision system initiated an unbroken chain of continuous development that connects 21st century optical scientists with the 11th century Ibn al-Haytham. The noted science historian, David Lindberg, wrote that *"Alhazen was undoubtedly the most significant figure in the history of optics between antiquity and the seventeenth century."* Impressive and accurate as that characterization is, it significantly understates the impact that al-Haytham had on areas as wide-ranging as the theology, literature, art, and science of Europe.**

I. INTRODUCTION

Recently, the artist David Hockney reported visual discoveries within some of the best-known paintings of European art that affect long-held understandings of the development of Western art of the past 600 years[1]. In a collaboration combining the expertise and visual skills of one of the world's greatest artists[2,3] with the analytical skills of an optical physicist, we then developed the foundations of a new methodology for extracting information from complex, optics-based images[4,5,6,7].

Briefly, we showed that certain features within very well-known paintings (e.g. the chandelier in *The Arnolfini Marriage* by Jan van Eyck, as shown in Fig. 1) are based on optical projections. We determined that these optically-based elements of the paintings are "photorepresentations"[8]. Our discoveries show that optical projections were being used by artists over 150 years before Galileo brought an optical instrument, the telescope, to wide attention.

II. HUMAN VISION AND COMPUTERIZED IMAGE ANALYSIS

A. Background

In the context of computerized image analysis, after an image is captured by a lens-based system, subsequent processing, including feature extraction, edge detection, image compression, etc., maintains the original encoding provided by the lens, as a flat field with an optically-imposed set of vanishing points. Images of interest can now contain over ten megapixels, with a continuing drive for even greater resolution. However, the encoding of these images is a fundamentally imperfect representation of human vision. Instead, when images are presented to observers in ways that mimic the way evolution has programmed our brains to function[9], humans can recognize images of remarkably low resolution.

That the mind of a painter is as intrinsically involved in the creative process as his hand makes paintings intrinsically complex to analyze. Although tracing projected images is known to have become a common technique by the 19th century [10], earlier use of optics has been difficult to identify and analyze, hindered also by the lack of interaction between art historians and scientists. In spite of this difficulty, the painter David Hockney and I recently identified optical evidence within a number of paintings demonstrating artists as early as Jan van Eyck (c1425) used optical projections as aids for producing portions of their images. While making these discoveries, Hockney and I developed fundamentally new insights into image analysis that I am now applying to problems in computerized image display and analysis.

Although I only briefly address it in this paper, no less important for understanding the evolution of post-c1425 painting, as well as certain modern applications of image analysis, is the indirect use of optics. Unlike an image

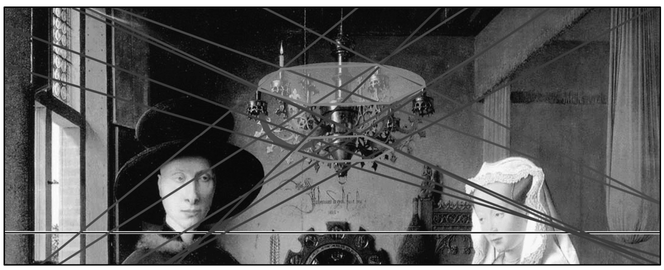

Figure 1. Jan van Eyck, *The Arnolfini Marriage*, 1434 (detail showing approximately 25% of the 81.8×59.7 cm painting). A summary of the evidence that the chandelier in this painting is based on optical projections is given in References [4,6].

† This paper originated from research supported by ARO grant W911NF0610359 and DARPA grant NBCH1050008.

projected onto film, the human eye constantly adjusts its aim and focus as the mind constructs the scene it is viewing. As a consequence, humans do not simultaneously see part of a scene in focus and part out of focus. Hence, a simple example of the indirect use of optics is if an artist has painted a distant portion of a scene as if it were out of focus, replicating the depth-of-field of an image projected by a lens. Although modern humans have seen this effect countless times in the form of photographs, in movies, and on television, it is not an effect that is part of natural human vision.

The fact that psychology is as intimately involved in vision as the simple geometrical optics of the eye occupies a significant part of Ibn al-Haytham's (Latinized as Alhazen or Alhacen) seven-volume treatise on optics [11, 12], the first time this topic was addressed in a modern scientific fashion. However, as discussed below, although he explained images of the crescent sun projected by a *camera obscura* in his treatise, "The Shape of the Eclipse," this optical device did not play a role in his understanding of vision.

III. IBN AL-HAYTHAM'S INFLUENCE ON EUROPE

A. Background

The noted science historian, David Lindberg, wrote that "Alhazen was undoubtedly the most significant figure in the history of optics between antiquity and the seventeenth century"[12]. Impressive and accurate as this characterization of Ibn al-Haytham (Alhazen) is, it significantly understates the impact he had on areas as diverse as the theology, literature, art, and science of Europe. Work I am now doing on computerized image analysis can be rightfully seen as the latest link in an unbroken chain that connects 21st century optical scientists with our intellectual progenitor, Ibn al-Haytham; a span of almost 1000 years.

Records indicate al-Haytham wrote nearly one hundred works, many of which have not survived, and today he is primarily known for his writings on geometrical optics, astronomy, and mathematics. However, it is with his landmark seven-volume *Kitāb al-Manāzir* [Book of Optics], first published sometime between 1028 [418 A.H.] and 1038 [429 A.H.] that he made his most important contribution to the culture as well as the science of Medieval and Renaissance Europe.

B. Historical Theories of Vision

Al-Haytham's work *Kitāb al-Manāzir* [Book of Optics] was translated into Latin in the early thirteenth century[13], and had a profound influence on European intellectuals, including figures as diverse as the writer Geoffrey Chaucer, the theologian John Wyclif[14], and the scientific work on optics of Bacon, Pecham, and Witelo[15]. Al-Haytham's work was republished in Latin in 1572, after the advent of the printing press, and is explicitly referenced in the writings on optics by Kepler, Snell, and Fermat[12].

Prior to al-Haytham, theories of vision could be classified into one of three categories: extramission, intromission, or a combination of the two. Extramission theories required some sort of illuminating particles be emitted by the eye. Euclid is one well-known scholar associated with this category of theory. Although there are obvious flaws with extramission theories, they do get the geometry right, with a one-to-one correspondence between points on the object and points on the eye. To elaborate one important connection between al-Haytham and western scholarship, Euclidian geometry, as influenced by al-Haytham's writings, is taught in every American and European school to this day.

Intromission theories of vision, with Aristotle as a prominent proponent, had objects continuously sloughing off replicas of themselves that then traveled to the eye of the observer. These theories avoided one obvious problem of extramission, that of near and far objects simultaneously being visible the moment the eye is opened, but at the expense of introducing other difficulties. Plato was a proponent of a combination of these theories, having light from a source like the sun, along with some sort of short-range emission from the eye, activate the air to let replicas travel to the viewer.

The genius of Ibn al-Haytham was not that he recognized there were problems with all existing theories of vision, since others before him had realized this as well. His genius lay in the fact that he found the solution that had eluded the best minds of antiquity. As mentioned previously, he recognized the crucial role of psychology (or how the mind interprets the world), and realized that to understand vision we must understand not only the geometrical optics of the eye, but

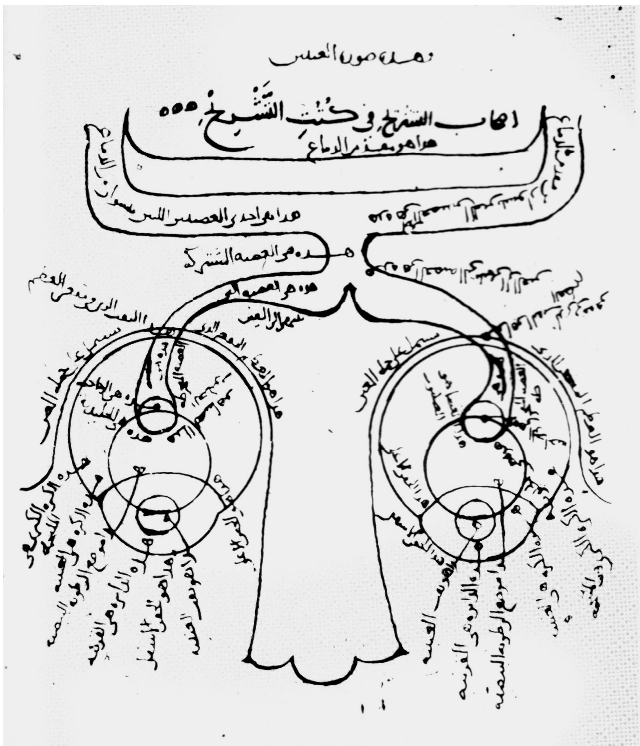

Figure 2. Ibn al-Haytham's description of the human visual system. From a 1083 [475 A.H.] copy of his *Kitāb al-Manāzir* in the Süleymaniye Library, Istanbul.

also the psychological processes that interpret what the eye collects.

Al-Haytham did get one important aspect of vision wrong. The fact that an image projected by a lens is upside down and flipped right-to-left apparently was more than he could accept in a theory of vision, even though it is contained within his optical formalism. However, Leonardo da Vinci also failed to accept this when he approached the problem much later. Five hundred years later, Kepler directly followed al-Haytham's formalism to its inevitable and logical conclusion in developing the theory of the retinal image. The 1572 Latin translation of al-Haytham's, *Opticae thesaurus: Alhazeni Arabis…* is explicitly referenced in the writings on optics by Descartes and Fermat as well as Kepler.

C. *Medieval European Optical Scientists*

The Latin translation of the *Kitāb al-Manāzir*, 'De Aspectibus', translated sometime prior to the 1230s, and the proposals contained within it are used in the optics manuscripts *Perspectiva* by Roger Bacon (c1265), *Perspectiva* by Witelo (c1275), and *Perspectiva communis* by John Pecham (c1280). Although today we think of these scholars as optical scientists, they approached their work as theologians. In each case their interest in optics was motivated by their interest in vision, which in turn was motivated by religious belief. In essence, they hoped that developing an understanding of physical vision would provide them with insights into spiritual vision. Hence, the developments in geometrical optics that came from their studies were actually incidental to their religious drive to understand spiritual vision.

D. *Medieval European Theologians*

The onset of the Protestant Reformation is typically dated to 1517, when the priest Martin Luther published his '95 Theses' criticizing the Christian 'Catholic' Church. Luther, however, built directly on the efforts of the 14th century priest, John Wyclif, who is credited with being the intellectual progenitor of the Reformation. Like his fellow priests of the time, Wyclif used optics in his theology. For example, he classified spiritual vision as direct, refracted, and reflected, and referred to al-Haytham by name in discussing the seven deadly sins in terms of the distortions in the seven types of mirrors analyzed in 'De Aspectibus'. As shown in Fig. 4, Wyclif even used the Arabic word for parabolic mirror, *mukephi*, in his Latin text for 'De Eucharista', written in 1382.

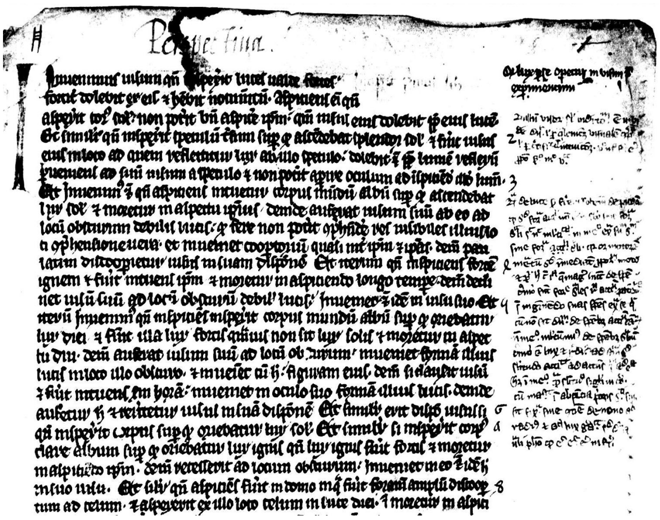

Figure 3. Excerpt from the first page of al-Haytham's *Perspectiva*, 14th century (Sloane MS 306, fols 1-177, British Library, London).

E. *Medieval European Literature*

Turning from religion to literature, one of the most widely read works in the French language for 300 years after its publication in c1275 was the epic poem *Roman de la Rose* [Romance of the Rose] by Guillaume de Lorris and Jean de Meun. Four pages in this poem describe the properties of mirrors, with the text exhibiting a surprisingly non-trivial understanding of optics. One short passage from these four pages makes its debt to al-Haytham (Alhazen) quite clear:

> *"Alhazen, the nephew of Hunain, was neither a fool nor a simpleton, and he wrote the book of 'Optics', which anyone who wants to know about the rainbow should know about. The student and observer of nature must know it and he must also know geometry, the mastery of which is necessary for the proofs in the book of 'Optics'."*

One hundred years later Geoffrey Chaucer produced his *Canterbury Tales* (written over the period 1387–1400), the first major piece of literature in the vernacular English language. Chaucer, too, was influenced by his understanding of the content of al-Haytham's works on vision and optics, as is clear from the following passage:

Then they referred to many a learned tome
By Aristotle and by Alhazen
And Witelo and other learned men
Who when alive had written down directives
For use of cunning mirrors and perspectives,

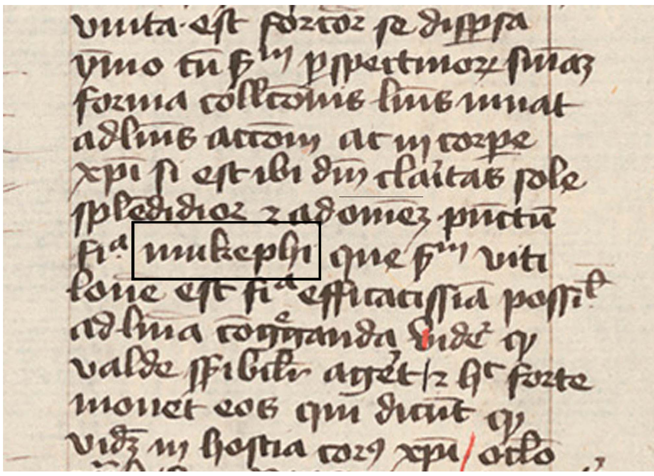

Figure 4. Excerpt from 'De Eucharistia' by John Wyclif, 1382, transcribed by Kourim of Bohemia in 1404–05, National Library of the Czech Republic. I have added a black box to highlight the Arabic

As anyone can tell who has explored
These authors.

F. *Renaissance European Art*

Al-Haytham not only had a direct influence on the development of European science, theology, and literature, but it can also be argued that he has had at least an indirect influence on art theory and art practice.

As Greenstein points out [16], Guerruccio di Cione Federighian translated al-Haytham into Italian in the 14th century, and portions of it were incorporated by Ghiberti in Book 3 of his *Commentari*. In this book, which was incomplete at the time of his death, Ghiberti attempted a theoretical understanding of the arts, relying heavily on optics.

Recent discoveries reveal al-Haytham's indirect influence on Western European art as well. The painter David Hockney in his book *Secret Knowledge* [1] made fascinating observations about some of the best-known paintings of European art that affect long-held understandings of the emergence of realism at the dawn of the Renaissance. Building on these observations, Hockney and I developed the foundations of a new methodology for extracting information from complex, optics-based images. Briefly, we showed that certain features within very well-known paintings (e.g. the chandelier in *The Arnolfini Marriage* by Jan van Eyck) are based on optical projections. In addition to van Eyck (c1430), we have found evidence of the use of optical projections within works by later artists, including Bermejo (c1475), Holbein (c1530), Caravaggio (c1600), de la Tour (c1650), Chardin (c1750) and Ingres (c1825). These examples demonstrate a continuum in the use of optics by artists from c1430, arguably initiated as a result of Ibn al-Haytham's influence, until today.

IV. SUMMARY

Ibn al-Haytham's intellectual contributions are intimately threaded throughout the core of post-Medieval Western culture. It is indeed unfortunate that each academic discipline today is largely unaware of the overall scope of his influence.

ACKNOWLEDGMENTS

I gratefully acknowledge David Hockney for the many invaluable insights into imaging gained from him in our collaboration that investigated paintings from over 1000 years of European art. These insights provided the foundation for ongoing work subsequently being pursued with David Graves, resulting in locating documents related to the early use of optics by artists, the origin of which we have traced to the writings of Ibn al-Haytham.

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[3] "...His drawings and etchings are among the deftest of this century; posterity may well acclaim him the greatest of modern portraitists."
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[8] I use the word "photorepresentation" to avoid the reader drawing the incorrect conclusion that elements within these paintings are effectively photographs. Even through a projected image is on the surface in front of him, the artist, unlike a piece of photographic film, is free to use artistic judgment to trace portions of it exactly as projected, alter other portions to suit his taste, and ignore yet other parts of that projected image entirely. Consequently, these paintings are not simply composites of accurate tracings.

[9] The visual systems of primates have evolved over 30–50 million years to the point where the human visual cortex occupies over one-third of our brain mass. As a result, even 20,000-years ago humans were able to produce remarkably realistic images (e.g. the cave paintings at Lascaux, France). In contrast, cuneiform tablets from 5000 years ago show that even by that date our mathematical abilities had yet to advance beyond counting.

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[14] al-Haytham and his optics are described in the c1275 epic poem *Romance of the Rose*, which for the next 300 years was one of the most widely-read works in the French language, and in Chaucer's c1400 *Canterbury Tales*, the first major piece of literature in the vernacular English language. The 14thC theologian John Wyclif, whose writings were an important precursor to the Protestant Reformation, used al-Haytham's writings on physical vision to help explain his own doctrine of spiritual vision.

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