Did the great masters use optical projections while painting?
Perspective comparison of paintings and photographs of Renaissance chandeliers

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Abstract

Recently it has been claimed that as early as 1420 some European artists constructed their paintings by optically projecting images onto their supports (canvas, oak panel, etc.) and then tracing or painting over these projections. Because projected images obey the laws of perspective, a powerful test of this claim centers on analyzing the geometric accuracy of key Renaissance paintings.

This paper investigates new techniques for analyzing the perspective accuracy of paintings. Notably, we focus on a portion of a painting central to the debate of the theory: the chandelier in Jan van Eyck's "Portrait of Arnolfini and his wife." Despite the high level of visual realism of the painting, the technique proposed here highlights large geometric inaccuracies that are very hard to explain as arising from the optical projection route.

The contribution of this paper is two fold: i) we present a projective geometry-based technique for detecting and measuring geometric inaccuracies in paintings, and ii) we demonstrate that in the Arnolfini portrait the source of those inaccuracies lies in the imaging process, as opposed to the manufacturing of the actual chandelier. The results presented in this paper cast serious doubts on the validity of the claim that optical tools were employed in painting the Arnolfini portrait.

Introduction

The contemporary artist David Hockney has recently claimed that some early Renaissance painters used concave mirrors to project (inverted) images of real scenes onto their supports (canvas, paper, oak panel, …) which they then traced or painted over, and that this was an important source of the increase in visual realism in European painting around 1420—the *ars nova* or "new art" at the beginning of the Renaissance. Hockney and his collaborator thin-film physicist Charles Falco have broadly and repeatedly pointed to the splendid chandelier or *lichtkroon* (Dutch, "light crown") in Jan van Eyck's "Portrait of Arnolfini and his wife" (1434) as central evidence in support of the optical projection theory [1]. Specifically, Hockney points out that there is no underdrawing for the chandelier and claims further that the image "is in perfect perspective" [2] and, apparently feeling that such accuracy cannot be achieved by eye, argues that the execution of the painting was helped by optical projections.

The Arnolfini portrait is an excellent test case for the projection theory, in part because the painting has been the subject of extensive physical and art historical analysis. Most importantly, there exist many surviving chandeliers in museums that can serve as comparisons. Historical documentation shows that chandeliers, candelabras and other decorative metalwork (known as *dinanderie*) were created with at least the *intention* of ensuring physical symmetry or regularity, and are rich in visual information relevant to test for projections.

This paper introduces a technique for detecting and measuring geometric inaccuracies in paintings. Notably, we focus on the Arnolfini chandelier, where the estimation of geometric distortions is achieved by geometrically registering different arms of the chandelier and measuring the residual misalignment of the arm shapes. Our technique reveals large inaccuracies throughout the arms.

The second contribution of this paper is determining the source of error: *i.e.,* are these imperfections due to an inaccurate imaging process (the painting process) or are they due to actual imperfections in the shape of the manufactured chandelier? In order to give an answer to this question we apply the accuracy analysis developed for the Arnolfini chandelier to a number of digital photographs (optical projections) of similar chandeliers and candelabras in museum collections. The photographs were taken from a vantage position similar to that of the Arnolfini chandelier. We found that the implied inherent deformation in the Arnolfini chandelier is considerably larger than that of photographs of surviving metalwork. This deviation can be explained only as arising from an inaccurate painting process, a result that casts serious doubts on the validity of the optical projection claim. Finally, we demonstrate that talented realist painters can achieve the level of perspective coherence and accuracy found in the Arnolfini portrait entirely "by eye," that is, without the help of optical projections.

In Sect. I we introduce the basic mathematics of homographies and plane-induced image registration. In Sect. II, we apply digital image registration to detect and measure geometric imperfections in the painted chandelier. The analysis of photographs of a represent-

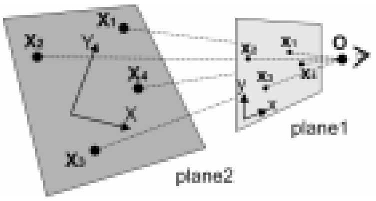

Figure 1: *A homography-based mapping between points X_i on plane 2 and points x_i on plane 1.* ***O*** *denotes the centre of projection.*

tative sample of surviving 15th-century *dinanderie* is conducted in Sect. III. Finally, in Sect. IV we judge the abilities of contemporary realist painters in the absence of optical aids by testing the perspective of paintings of elaborate chandeliers done "by eye". We find the accuracy comparable to that in the Arnolfini painting.

The facts that: i) the geometric inaccuracies in the Arnolfini painting are significantly larger than those measured in photographs of comparison dinanderie, ii) that artists can achieve comparable accuracy "by eye," and iii) that there is no corroboratory documentary evidence anyone in the early Renaissance built such a projector, all lead us to reject the claim that Jan van Eyck employed optical projections when painting his marvelous portrait.

I. Background: Plane-induced image registration

The mirror-based projection at the basis of Hockney's claim would generate images that obey the laws of perspective, just as do projections in a photographic camera [5]. In this paper we test the optical projection theory by analyzing the accuracy of perspective in paintings purportedly made under such a projection. Notably, we compare planar portions of three-dimensional objects by digital image registration techniques. In order to do so we first need to introduce the mathematics of plane-based image registration.

The most general bijective point-wise mapping between two arbitrary planes (such as between two planar chandelier arms) is called a homography [5] and can be modeled algebraically by a 3 x 3 matrix **H**. If the homography **H** is known then the mapping of each point **x** on one plane to the corresponding point **X** on the second plane is defined by (Fig. 1)

$$\mathbf{X} = \mathbf{H}\mathbf{x} \qquad \text{(Eq. 1)}$$

where the two-dimensional points **x** and **X** are expressed as 3-vectors in homogeneous coordinates. The matrix **H** can be estimated from a set of four or more corresponding points. A thorough investigation of techniques for accurate homography estimation may be found in [5]. Given an image of two planar surfaces and the estimated homography **H**, it is possible to use Eq. 1 to register (warp) the image of one of the surfaces with respect to the other one [5]. If the two planar objects are identical and **H** is error-free, then corresponding features on the registered images would overlap *perfectly*. The next section employs this plane-based registration technique to remove the perspective distortion introduced by the imaging process and compare actual shapes of arms in the painted chandelier.

II. Perspective analysis of the Arnolfini chandelier

The analysis in [6] has shown how the vanishing points induced by the geometry of the Arnolfini chandelier are largely inconsistent with the laws of linear perspective. These inaccuracies may be due to two main reasons: i) asymmetries in the shape or placement of the chandelier's arms or ii) inaccurate image formation process (the painting process). This section extends the geometric analysis of [6] by comparing the actual shapes of the chandelier's arms and estimating the inter-arm consistency. We achieve this goal by: i) registering different arms with respect to each other, and ii) measuring the residual misalignment, *i.e.,* the local distortion that is intrinsic to the shape of each arm.

In Fig.2 two arms of the Arnolfini chandelier were selected and isolated. After manually selecting a few (>4) corresponding image points (*e.g.,* tips of decorative crosses or "crockets"), one of the two arms was warped (via the estimated **H**) to be aligned with the other one (Fig.2d). Perfectly identical arms and a perfect imaging process would give rise to perfect alignment of features in Fig.2c and Fig.2d. However, the superimposition of the two images (Fig.2e) shows large misalignments. It must be stressed that the quality of registration depends also on the selected reference points (for **H** computation). Thus, here we repeated the experiment several times, with different selected reference points and found consistently inaccurate image alignment. Figure 2e shows the results of one typical iteration: Corresponding points in the cruciform structure atop each arm are misaligned by as much as 3 cm; the decorative crockets beneath (two such crocket correspondences are marked in white) are offset by as much as 8 cm in the space of the Arnolfini room (where we assume the scale of the chandelier is that given in [8]), or 20% the distance from the central axis.

Figure 3 illustrates a different way of measuring the geometric misalignment. Figure 3a and 3b show the Canny edges [3] detected from the images in Fig.2d and Fig.2c, respectively. Figure 3c is the symmetrical Chamfer map [4] which is constructed by taking each edge map (*e.g.,* Fig.3a) and, for each point, computing the minimum distance from each edge in the second edge map (*e.g.,* fig 3b). In the Chamfer map, darkness of points is proportional to distance and therefore large misalignments shows up as darker points. In this case, the average edge misalignment was estimated to be 12.6% of the image width. More robust misalignment metrics can be achieved by means of shape matching techniques such as [12].

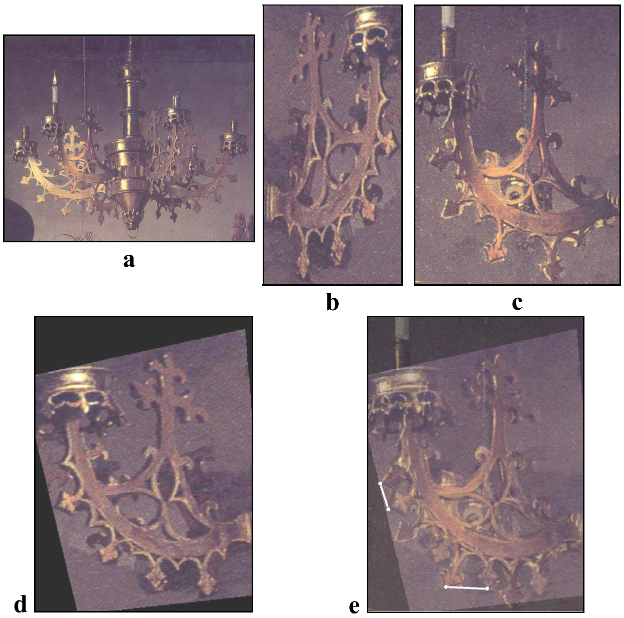

Figure 2: ***a)*** *The Arnolfini chandelier © National Gallery London.* ***b, c)*** *Two selected arms.* ***d)*** *Perspective correction of (b) for maximum correspondence with the (untransformed) arm in (c).* ***e)*** *Overlap of (c) and (d). The white bars mark some of the mismatching crockets. Offsets of this kind pervade the arms and indicate the large inherent variations implied by the optical projection claim. The same analysis performed on different arm pairs revealed similar results.*

In this section we have detected and measured inconsistencies in the shape of the Arnolfini chandelier. Now we need to understand the source of error, *i.e.,* are these inaccuracies due to a manual and thus imperfect imaging process or is the physical chandelier asymmetrical?

III. Perspective analysis of photographs of dinanderie

The question whether the painted chandelier is consistent with an optical projection thus comes down to whether we can expect the large variations measured in the Arnolfini chandelier also in photographs of physical chandeliers of the Renaissance. If that was the case then we would conclude that the observed inaccuracies are to be attributed to manufacturing imperfections rather than the imaging process (here we model photographic cameras with conventional pin-hole model, see Fig.1).

Thus we apply our error analysis technique to photographs of similar chandeliers in museum collections. Figure 4 shows the results for a cast of a 15th-century chandelier in the Barley Hall collection. After registration, the overlap image in Fig.4e shows quite an accurate alignment of the planar region of the photographed arms. Furthermore, it is clear that this chandelier was cast since the crockets show no evidence of hand attachment by soldering or rivets that might lead to variation in position along the arms. The casting procedure is expected to produce very little symmetry artifacts [7]. The edge-based measurements were also conducted for this example and the results are reported in Fig.5. The average misalignment in Fig.5c was measured to be only 3.15% of image width (to be compared with the 12.6% of fig 3c). The improved image alignment is also illustrated by the brighter values of the pixels in the Chamfer map (Fig.5c). The same experiment was repeated for many other photographs of existing dinanderie with very similar results.

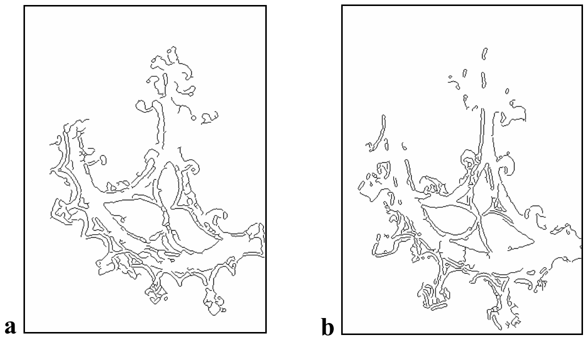

Figure 3: ***a, b)*** *Canny edges extracted from Fig.2d and Fig.2c, respectively.* ***c)*** *Symmetric Chamfer distance map between (a) and (b). Notice how large misalignments (darker pixels) show up in the bottom crockets and the cruciform structure atop.*

The fact that our analysis conducted on photographs of period chandeliers produce consistently smaller alignment errors than those in the Arnolfini portrait highlights the fact that *the main source of inaccuracy is due to the imaging process*, rather than to asymmetries of the actual painted objects. The historical records [7] (that due to space constraints cannot be discussed here) confirm the accuracy of the manufacturing techniques of the time.

However, in a painting the artist can alter the shape of an object even when optical projections are involved, but the question at this point would be: why would the artist purposely alter the positioning of the crockets in the chandelier's arms to deviate from the true optical image?

IV. Experimental painting

Underlying the arguments of Hockney and Falco is the assumption that good perspective cannot be easily achieved "by eye," that is, without the help of optical

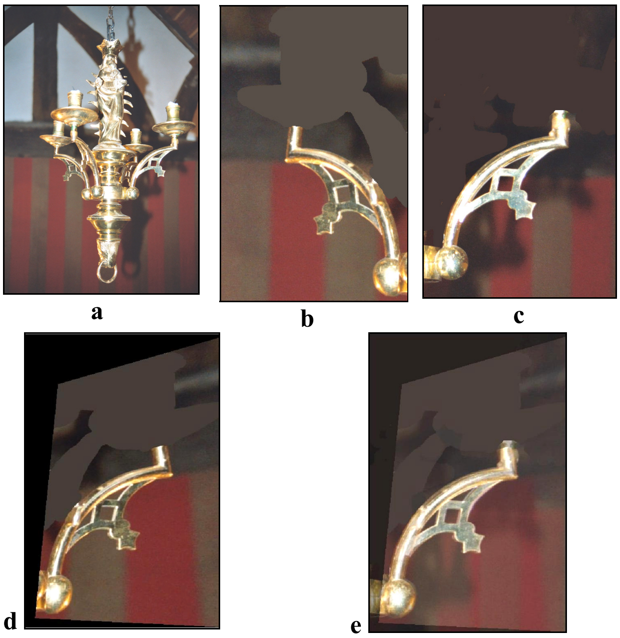

Figure 4: ***a)*** *A photograph of a cast of a 15th-century Bruges chandelier from the Museum of the Hospital of St. John in Bruges, Barley Hall collection.* ***b,c)*** *Two selected arms.* ***d)*** *Perspective correction of arm in (b) for maximum correspondence with the arm in (c).* ***e)*** *Overlap of (d) and (c). Features of the transformed arm (d) and the original arm (c) correspond extremely well, with corresponding points differing by less than 1 mm in the space of the room, too small to be seen here.*

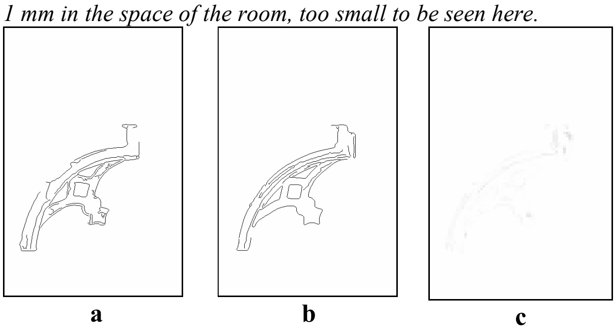

Figure 5: ***a, b)*** *The extracted Canny edge images for Fig. 4c and Fig. 4d.* ***c)*** *The symmetric Chamfer distance map. The good alignment between the two arms is expressed here by the fact that the Chamfer distance map is quite bright (bright points correspond to small misalignments).*

devices. To test their assumption, as part of our research, British realist painter Nicholas Williams painted two chandeliers entirely "by eye." Figure 6 shows one of the two chandelier paintings he realized for us. Our perspective analysis applied to this painting resulted in a good but, as expected, imperfect alignment of arms. The average measured deviation was about 8.55% the image width, of the same order of magnitude as that of van Eyck's chandelier. This experiment confirms that realistic-looking structures can be painted merely by eye, without the help of optical tools of any sort.

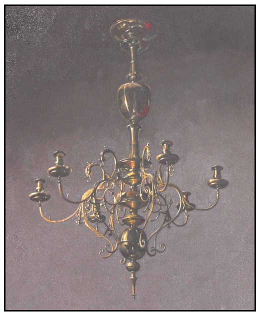

Figure 6: *Nicholas Williams, "Chandelier 2" (2003) oil on canvas. The elaborate and realistic-looking geometry of this painting was constructed entirely by eye. No optical tool and no perspective constructions of any sort were employed here.*

V. Conclusions

This paper has presented a new technique for the analysis of geometric accuracy in paintings. Notably, the rigorous perspective analyses, error measurements and painting experiments presented in this paper demonstrate that the chandelier painted in the Arnolfini portrait shows a degree of geometric inconsistency which is typical of "eye-balling" painting, and considerably larger than that observed in true optical projections (such as photographs). These results and the lack of supporting documentation lead us to reject the claim that the chandelier in the Arnolfini portrait was created by means of optical projections. Our results comport with the growing scholarship questioning Hockney's projection theory, in particular for Jan van Eyck [11] and his contemporary Robert Campin [6]. This paper represents one further proof of how computer vision techniques can help give answers to interesting debates in art history.

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