Quantitative Analysis of Artists' Characteristic Styles through Biologically-Motivated Image Processing Techniques: Uncovering a Mentor to Johannes Vermeer

Minseo Kim and Jeounghoon Kim

Graduate School of Culture Technology, KAIST (Korea Advanced Institute of Science & Technology), 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea
{artmin,miru}@kaist.ac.kr

Abstract. This study was designed to improve the limitations of traditional analysis of artworks by quantitatively analyzing artworks through biologically-motivated image processing techniques that reflect visual information processing mechanisms of human vision. As the first step to achieve this goal, this study addressed one of the important questions in art history, uncovering a mentor for 'an artist who remains forever unknown' Johannes Vermeer, by adopting three interdisciplinary research methods of cognitive science, art history, and engineering. We performed orientation, radial frequency, and color analyses with the artworks for comparing the artistic styles of Vermeer and other artists who have been presumed to be his mentor. The results from three analyses have led us to the conclusion that a person who had the strongest influence on Vermeer is Gerard Ter Borch. This conclusion was strongly confirmed by verifying the research methods with an additional comparison of artistic styles between Rembrandt and Carel Fabritius, whose master-pupil relationship has already been revealed. This study is believed to provide a new perspective on uncovering previously unknown mentor of Vermeer, and the research methods adopted here can be applied to other related research issues in art history, such as authenticity debates on masterpieces, by quantitatively archiving artists' characteristic styles.

Keywords: Johannes Vermeer, Visual Information Processing, Orientation Analysis, Radial Frequency Analysis, Color Analysis.

1   Introduction

Artwork analysis requires a macroscopic framework and methodology, reflecting both art historical approach and scientific technique. Yet majority of artwork analysis relies heavily on either historical evidence or highly subjective appraisal, and many limitations have been addressed in appreciating artworks with conventional analytical methods. The scientific methods of investigation such as X-ray photography, infrared photography, pigment analysis, and radiocarbon dating have also limitations due to the possible danger of irreparable damage on the artwork. Artwork analysis, therefore, stands in great need of non-destructive analysis and objective methodology that can lend support to subjective appraisal, and moreover, collecting artist's distinct styles of

painting and constructing a database are certainly needed for continuous application. We thus combined the traditional art appraisal with image processing techniques to standardize the artworks analysis. We defined the elements that most clearly manifest the artist's individuality and developed quantitative analysis of the elements and created a scientific reservoir of the individual artist's signature elements. As the first step to achieve this goal, we studied on uncovering Johannes Vermeer's mentor who remains largely unknown to art historians. Johannes Vermeer is well-known for highly realistic portraits and genre-paintings. However, his life and a question of who had the strongest influence on him still remains a mystery. Thus, this paper will focus on the study of the art historical background of Vermeer and other artists and provide a practical solution by introducing quantitative analysis of artists' painting styles through image processing techniques.

2   The Art-Historical Analysis of Johannes Vermeer

Johannes Jan Vermeer (1632-1675) is typical of the Delft School owing to his special techniques such as his expression of light, realistic interiors, and poetical descriptions of people. Presumably, he began his artistic training around 1645-47, later joining the Guild of Saint Luke as a master in 1653. The reason why this date is regarded as important is that Vermeer's early paintings are often embroiled in authenticity debates. Thus, it is important to identify who had the most influence on Vermeer because doing so helps to reveal Vermeer's stylistic development and distinguish replicas from original artworks. So far, five artists who are Abraham Bloemaert, Carel Fabritius, Gerard Ter Borch, Leonaert Bramer, and Rembrandt have been presumed to Vermeer's mentor through art historical records [2].

Fig. 1. Vermeer's artistic styles
(from left, sfumato, pointillès, depth, complementary colors, poetical face)

Vermeer's painting techniques are categorized according to the characteristics of human visual information processing. There are four components, which account for form (sfumato, pointillès), depth (various directions of lines), face, and color (complementary color) (Fig. 1). First, sfumato is a drawing style without lines or borders, in the manner of smoke or beyond the focus plane. Vermeer always regarded shadow is more important than lines for separating different objects. As a result, he mixed elaborative lines and blurry lines. Second, pointillès is a light expression technique in which points are formed on a polished or metallic surface. Vermeer specially used the pointillès technique on unreflecting surfaces, including bread, cloth, and baskets, showing clearly that he added new interpretations and appreciation to the usual pointillès method. Third, geometrical spaces made by various directions of lines – horizontal, parallel, and diagonal - give an illusion of space like a glimpsing through a keyhole. Fourth, complementary colors were used to emphasize the effects of light and to enhance the vividness of the quality of the materials. In particular, complementary pairings of yellow ocher

and cobalt blue were the most representative characteristic of Vermeer. Fifth, Vermeer's faces in his artworks have been considered as poetical faces because they are involved in a type of mental activity. Vermeer tried to express important moral lessons or social critiques through his paintings. To do so, he always included a descriptive context.

3   The Quantitative Analyses of Artworks

For the quantitative analyses of Vermeer' artworks, an image dataset was built from the various websites. The main purpose of this was to minimize the source-dependency of the images and to verify that the images were analyzed and characterized based on the actual visual content rather than other artifacts which may be a feature of the image given its source [4]. As a result, the image dataset contains 535 images from six different painters, and each painting is normalized to 256 X 256 pixels without changing the aspect ratio. Also, most images were converted from color to grayscale except for those used in the color analysis.

3.1   Orientation Analysis

The orientation analysis was based on Vermeer's distinctive lines, including sfumato and pointillès styles and various directions of lines. This analysis compares and analyzes the styles of lines in the artworks of Vermeer and other artists who have been suggested as his mentors. To select artists' characteristic line styles quantitatively, line orientations were analyzed utilizing Gabor wavelets, which have been used to simulate configurations of the receptive fields of visual cells in human visual brain.

In this analysis, the Gabor wavelet applied four scales (2, 4, 8, and 16) and six orientations (0°, 30°, 60°, 90°, and 120°) and yielded the Gabor energy, which is defined as the sum of the squared values obtained by convolving Godd and Geven [3]. The Gabor energy refers to the average value which does not exceed the standard error (± 2 SE) and is regarded as the representative value of each artist's style of lines. For a comparative analysis of the Gabor energy, a t-test was used to determine whether Vermeer's Gabor energy is similar to that of the other artists. The results showed that 'Gerard Ter Borch and Vermeer [$t(29)=.537$]' and 'Carel Fabritius and Rembrandt [$t(22)=-.895$]' are not statistically significant, unlike other relationships of artists. This result may therefore be considered as evidence that Gerard Ter Borch's artistic style is similar to that of Vermeer. Also, the result showing that Rembrandt and Carel Fabritius, who are known to have had a master-pupil relationship, have similar artistic styles verifies the reliability of these analyzing methods.

3.2   Radial Frequency Analysis

A radial frequency analysis exhibits and compares styles of faces in the artworks of Vermeer and other artists. To extract characteristic face styles of artists' works quantitatively, faces are analyzed by adopting radial frequency, which has been used in simulating configurations of the specialization of visual cells pertaining to curved shapes and actual faces. The use of radial frequency can create various closed circle

figures by adding two or three circles or can abstract basic components by disassembling a closed circle figure. In this analysis, artist's faces are compared in terms of the distribution of the radial frequency components. As a result, 'Gerard Ter Borch and Vermeer [t(19)=-.948]', and 'Leonaert Bramer and Vermeer [t(19)=-.926] are not statistically significant, unlike other relationships of artists. This result may therefore be considered as evidence that Gerard Ter Borch and Leonaert Bramer have artistic styles similar to Vermeer's artistic style. Also, 'Carel Fabritius and Rembrandt [t(42)= .342]' and 'Leonaert Bramer and Rambrandt [t(49)= -1.628] ' additionally show similar artistic styles, these facts verify the reliability of these analyzing methods because they are known to have had a close relationship.

3.3   Color Analysis

A color analysis is valuable due to the fact that Vermeer used complementary colors to emphasize the effect of light in his paintings. Accordingly, this analysis exhibits and compares cobalt blue and yellow ocher in the artworks of Vermeer and of other artists. For the color analysis, RGB-coded images are transformed into the CIE L*a*b color space format because the CIE L*a*b corresponds very well to the perceptual differences of their appearances [1].

$$\Delta E = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2} = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2} \qquad (1)$$

To discriminate the characteristic colors of artists' works quantitatively, colors were analyzed in terms of complementary color differences based on the Euclidean distance $(\Delta E)(1)$, which has been used when simulating configurations of opponent coding information processing in research on human color perception. Because the Euclidean distance is generally regarded as equal in terms of color within $\Delta E= 0.5$-1.2, the analysis is judged by this criteria. The result of the analysis shows that 'Gerard Ter Borch and Vermeer' used perceptually equal colors in the 'Yellow ocher analysis [$\Delta E=0.8590$]' and in the 'cobalt blue and yellow ocher analysis [$\Delta E=0.5276$]'. Leonaert Bramer has also been presumed to be Vermeer's mentor by reason of the similarity of Cobalt blue, but this analysis shows that Vermeer's cobalt blue is most similar to that of Gerard Ter Borch, even if it does not show a perceptually equal color.

4   Results and Conclusion

This study offered important implications and gave direction to future research on Vermeer and the Delft School. First, the converging results of these three analyses (table 1) show that the most influential mentor of Vermeer is Gerard Ter Borch. In addition, the fact that Rembrandt and his pupil Carel Fabritius have a similar artistic style verifies the reliability of these analyzing methods. Actually, many studies shows that Vermeer was influenced by Gerard Ter Borch's genre scenes [5]. Second, the similarity of faces in radial frequency analysis between Leonaert Bramer and Rembrandt is full of suggestions in terms of their closeness. Finally, the difference

between Leonaert Bramer's and Vermeer's cobalt blue will provide new implications for art history. Thus, this study provides a practical solution to the addressed issue in this paper by introducing quantitative analysis of artists' painting styles through image processing techniques.

Table 1. Results of analyses (✔: Similarities between the artistic styles of different artists)

	Orientation analysis	Radial Frequency analysis	Color analysis
Vermeer	Bloemaert Bramer Fabritius **Ter Borch ✔** Rembrandt	Bloemaert **Bramer ✔** Fabritius **Ter Borch ✔** Rembrandt	Bloemaert Bramer Fabritius **Ter Borch ✔** Rembrandt
Rembrandt	Bloemaert Bramer **Fabritius ✔** Ter Borch Vermeer	Bloemaert **Bramer ✔** **Fabritius ✔** Ter Borch Vermeer	Bloemaert Bramer Fabritius Ter Borch Vermeer

5   Implications

This study suggests a new vision for unsolved questions in art history as well as debates on the authenticity of masterpieces and offers a great potential to be applied for quantifying information on drawing styles into a database. An interdisciplinary approach of engineering, cognitive science, and art history adopted here by utilizing biologically-motivated image processing techniques is believed to contribute to a systematic analysis of artworks and would be very informative for future studies.

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