Results of the study of the possibility of replacing the Gia GemSet, designed for evaluating the color of precious stones, with digital simulators for automated control systems

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Abstract. Currently, the quality of precious stones is assessed by the organoleptic method. To identify their color experts use a set of Gia GemSet imitators made of transparent acrylic plastic—a polymer with a high refractive index, and with its own GIA color space. The authors conducted research on the optical characteristics of the GIA GemSet set in order to study the possibility of replacing physical standards with digital simulators for automated control systems. The research was carried out using two methods: spectral and technical vision. Spectral measurements were performed using a USB4000 fiber-optic spectrometer. To determine the color characteristics of digital images, we used a proprietary hardware and software package. Based on the research results, a color body of the GIA GemSet for the case of a standard D65 source is constructed, which gives a visual representation of the characteristics of the set. The correspondence between the color coordinates of the samples obtained by the two methods is established, which confirms the possibility of automation of color of precious stones evaluation process.

1. Introduction
The quality of precious stones is traditionally evaluated by the size, weight (in carats), color, purity, as well as the type and quality of cut – for jewelry inserts [1]. Size and mass are determined by direct measurement methods and are objective indicators, while color and purity are evaluated by the organoleptic method and, as a result, are subjective. Considering the heterogeneity of color and structure of precious stones, these parameters are also the most difficult to determine. As a rule, to assess these indicators, experts use reference master-samples or measures-simulators, which, however, does not allow to exclude the factor of subjectivity.

The decision about the value of a gemstone depends on the objectivity and accuracy of the result of analysis, that is why researches [2–7] conducted by a different groups of scientists devoted to the automation of gems quality evaluation process are topical and very marketable.

This work is devoted to the research of the existing system of color evaluation of colored precious stones in Russian Federation and the possibilities of its translation into digital format.

Currently, in our country, three Atlases are used for evaluating the color of precious stones (PS): the Atlas of the Gemological Institute of America (GIA) and the corresponding sets of color standards GIA GemSet; a set of color measures-PS simulators, registered in the State register of measuring instruments (MI) No. 20855-01 dated 20.12.2000. (further – a set of imitators from the measuring
instruments state register) [8]; a set of World of Color cards produced by GemGuide, reproducing possible PS colors similar to the Munsell color system.

The GIA Atlas is physically implemented as sets of GIA GemSet reference samples: a complete (GIA GemSet Hue Set) containing 324 samples, and a truncated (GIA GemSet Hue Wheel Version) containing only 50 samples. The GIA color code contains symbols for three components: hue, lightness, and saturation. The main drawback of the GIA color Atlas and GemSet standards is that they do not have any quantitative data, and therefore they are intended solely for evaluating the color of PS by an expert based on visual comparison. However, the GIA GemSet standards can be digitized and become the basis of a similar, but already digital, PS color classifier.

The set of color PS simulators contains 50 samples (31 samples to describe the hue, 7 samples to describe the hue and 12 samples to describe the saturation), manufactured according to the technical documentation of GIA GemSet (GIA Gem Instruments, USA). The same terminology is used to describe the color as in the GIA Atlas. In fact, the set of imitators from the MI state register is a truncated Gia Atlas (GIA GemSet Hue Wheel Version). The Atlas contains not only physical PS simulators, but also their color and chroma coordinates in the colorimetric system SIE-XYZ 1931. for two standard lighting sources (A-type and C-type). Thus, theoretically, this Atlas can be used to implement quantitative analysis.

2. Materials and methods

For the experimental study, the GIA GemSet set was used, which contains 50 samples (31 shades, 2 sets of 6 saturation, and 7 hues).

Experimental studies were conducted in 2 stages:
1. Measuring the spectra of flat and faceted parts of GIA GemSet samples using compact USB-4000 fiber-optic spectrometer.
2. Measurement of flat and faceted parts of samples of the GIA GemSet set using Hardware and Software Complex for automated assessment of the quality of colored stones (HSC), shown in Figure 1 and described in detail in [9].

The HSC is based on the principles of technical vision and image processing. There are two modes of operation: reflection and transmission.

2.1 Spectral Measurements

The spectra were calculated based on the law of changes in the spectral transmittance and optical density depending on the thickness. In that case, of homogeneous transparent object, the transmittance coefficient $\tau$ is determined by the ratio of the passed radiation $P_t$ to the amount of radiation incident on the object $P_0$:

$$\tau = \frac{P_t}{P_0}. \quad (1)$$

In addition, the transmittance coefficient $\tau$ of a homogeneous transparent object can be described using the absorption coefficient $k_\lambda$ which does not depend on the thickness of the object and describes the property of the object's material:

$$\tau = \exp\{-d \cdot k_\lambda\}, \quad (2)$$

where $d$ is thickness of the object.

Consider transmittance coefficient of a homogeneous transparent object $\tau_1$ at the thickness $d_1$ to be known:

$$\tau_1 = \exp\{-d_1 \cdot k_\lambda\}. \quad (3)$$

Then the absorption $k_\lambda$ can be calculated as:

$$k_\lambda = \frac{1}{d_1} \ln \left(\frac{1}{\tau_1}\right), \quad (4)$$

Therefore, we can derive a formula for calculating the transmittance coefficient $\tau_2$ of an object made of the same transparent material, but with a thickness of $d_2$:

$$\tau_2 = \exp\left\{-\frac{d_2}{d_1} \cdot \ln \left(\frac{1}{\tau_1}\right)\right\} = \tau_1 \frac{d_2}{d_1} \quad (5)$$
Using spectral distributions for transmittance coefficients $\tau$ obtained for different thickness of samples and known spectral distribution of D65 light source, the color body of GemSet in CIE – XYZ 1931 could be modelled.

Color coordinates $\bar{X}$, $\bar{Y}$ and $\bar{Z}$ of a uniform transparent object are calculated in accordance with classical colorimetry rules:

$$
k_c = \frac{100}{\sum P(\lambda_i) \cdot \Delta \lambda}
$$

$$
\bar{X} = k_c \cdot \sum P(\lambda_i) \cdot \tau(\lambda_i) \cdot \bar{x}(\lambda_i) \cdot \Delta \lambda
$$

$$
\bar{Y} = k_c \cdot \sum P(\lambda_i) \cdot \tau(\lambda_i) \cdot \bar{y}(\lambda_i) \cdot \Delta \lambda
$$

$$
\bar{Z} = k_c \cdot \sum P(\lambda_i) \cdot \tau(\lambda_i) \cdot \bar{z}(\lambda_i) \cdot \Delta \lambda
$$

(6)

where $P(\lambda_i)$ is spectral distribution of D65 source radiation, reproducing the conditions of illumination by average daylight; $\bar{x}(\lambda_i)$, $\bar{y}(\lambda_i)$ and $\bar{z}(\lambda_i)$ – color addition curves in the $\bar{X}\bar{Y}\bar{Z}$ color measurement system according to the recommendations of the CIE 1931; $\Delta \lambda$ – wavelength increment.

Using calculated color coordinates $\bar{X}$, $\bar{Y}$ and $\bar{Z}$ chromaticity coordinates might be obtained:

$$
x = \frac{\bar{X}}{\bar{X} + \bar{Y} + \bar{Z}}
$$

(7)

$$
y = \frac{\bar{Y}}{\bar{X} + \bar{Y} + \bar{Z}}
$$

(8)

Based on the obtained values of color and chromaticity coordinates, color body reproducing elements of the GIA GemSet set was modelled.

To implement a comparison of the obtained data with the results of measurements on the HSC, the obtained color coordinates in the XYZ color space were recalculated to the color coordinates in the HLS space [10].

2.2 Hardware-Software Complex operation

Before each measurement cycle, the HSC was calibrated in two stages. Calibration with a uniform white background allows you to compensate uneven illumination of the analysis area and the influence of field aberrations of the lens. Photometric calibration using the white standard ensures the accuracy of color shades reproduction in the obtained images, taking into account the spectral characteristics of radiation sources and the spectral sensitivity characteristics of the camera's color channels.

![Figure 1](image-url)

**Figure 1.** Hardware-Software Complex: 1 – top light source, 2 – camera with lens, 3 – cassette for placing analysis samples, 4 – light scattering plate, 5 – bottom light source.

3. Results

The obtained spectral characteristics of Gia GemSet samples are shown in figure 2a.

The spectra were measured at the flat parts of the sample set to identify the material properties and further simulate the spectral transmission properties of the cut parts. Since cutting increases the optical
path of the light beam inside the material, the modeling of the optical properties of the cut part was reduced to modeling changes in spectral characteristics as the thickness of the material increases.

Figure 2. Spectral distributions of transmission coefficients of flat parts of GIA GemSet samples for (a) thickness 2 mm and (b) thickness 10 mm in the visible region of the spectrum.

Figure 3. GIA GemSet color body.
An example of the results of simulation of transmission spectra when increasing the thickness to 10 mm is shown in Fig. 2b.

Figure 3 shows the result of modeling the color body of the GIA GemSet set based on the calculation of color coordinates, calculated with use of previously obtained spectral distributions of reflection coefficients of samples with different thicknesses and using the reference D65 radiation source.

During measurement using HSC images for flat and cut surfaces of GIA GemSet samples were obtained and color coordinates in HLS (hue, lightness and saturation) color space were calculated. That color space was chosen as it describes the color similarly to the Munsell color Atlas, which GIA GemSet is the based on. The results are shown in Fig. 4.
As it seen from Fig. 4, images of samples of the GIA GemSet were obtained using the HSC under conditions of illumination with a uniform light flux, with or without glare on the surface of the samples. This effect was taken into account when processing images. The resulting images were transmitted to a personal computer, where they were processed using developed color detection algorithms.

4. Discussion

Figure 5 shows the results of comparing the results of calculating the color coordinates of the flat and cut parts of the Gia GemSet samples obtained by spectral measurements and using the HSC, on the example of Hue (H) coordinate of the HLS color measurement system.

![Figure 5](image)

**Figure 5.** Results of comparing Hue coordinates of the flat (a) and cut (b) parts of the Gia GemSet samples obtained by spectral measurements and using the HSC.

The figure shows that the results obtained have a high convergence for all elements of the GIA GemSet set – a tint circle (31 elements), a light series (7 elements), and two saturation series for red (6 elements) and blue (6 elements) shades – regardless of which part of the Gia GemSet set element is analyzed (flat or faceted). The maximum error is 5.3%. That maximum error occurs only for samples of two shades (purple "P" and reddish-purple "rP") when a strong glare appears. For the rest of the analyzed samples, the maximum error is 3.1%. Therefore, it can be concluded that replacing the GIA
GemSet, designed for evaluating the color of precious stones, with digital simulators for automated control systems is not just possible, but effective.

5. Conclusion
Thus, the obtained results indicate that it is possible to use digital color simulators (in the form of sets of color coordinates) instead of GIA GemSet samples which degrade over time. In addition, it was found that using the developed HSC, it is possible to replace visual analysis with an instrumental assessment.

6. References
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