

TEXTURE ANALYSIS OF A COATED SURFACE USING KEPLER'S PLANETARY MOTION LAWS

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to U.S. Provisional Application No. 61/901,503, filed on November 8, 2013.

FIELD OF THE INVENTION

[0002] The present invention generally relates to the use of Kepler's laws of planetary motion to relate spectral reflectances or colorimetric information from spectrophotometric angles and/or incident light sources to identify the proper pigment(s) to match both the texture and/or gonioapparent effect(s) occurring within an unknown target coating.

BACKGROUND OF THE INVENTION

[0003] In order to provide a proper color match via formulation or search engines (or a visual process) it is ideal to determine the correct pigmentation of the sample. It is clearly sensible that utilizing the same pigments or appropriate offsets of those pigments to an original sample will allow a formulation or search process to arrive at an apparent optimum solution. It is equally clear that excluding those pigments, either deliberately or inadvertently, from availability will result in a less than optimal color match.

[0004] Several formulation engines and methodologies attempt to encompass pigment selection and formulation via various algorithms simultaneously. Historically, pigment identification packages and formulation engines largely have taken a "brute" force, guess and check type of method to provide formulations and pigment information to their users. The combinatorial approach, or brute force method, is a frequently used method in which nearly all available pigments are combined in all the various combinations available given an end number of pigments desired in the final match. The combinatorial approach may utilize the Kubelka-Munk equation or a derivative thereof to generate the various formulations. Although there have been some methods which restrict the usage of some pigments given certain conditions to optimize the engine's speed, the end result is these formula

combinations are then validated against the sample and a selection (or a single) of formulas most nearly matching the sample are provided to the user. There are various forms of Delta E's or other colorimetric assessment algorithms used to determine the accuracy of the match compared to the sample.

[0005] The more elegant solutions require the user to submit a sample set of toners to a formulation engine, while the less elegant methods often select a predefined subset of toners to use. Neither of the approaches utilize a stepwise method and thus often result in non-optimal solutions. These methods have been typically burdensome for the users and lacked proper "intuition" to provide a streamlined method to a good solution for the user. Additionally, by the nature of this methodology, appropriate pigments necessary to match the sample can be excluded.

[0006] In a standard portable spectrophotometer, the incident light is generally set at an angle of forty-five (45) degrees from normal. The resulting spectral reflectances that can be gathered are generally in the same plane as the incident light and are on either side of the specular angle (equal and opposite angle to the incident light) as well as nearer to the incident light source itself.

[0007] New portable spectrophotometric devices offer a vast multitude of angular color response (spectral reflectance) data. Besides the addition of several new angles, including azimuthal, or out-of-plane, angles, many instruments also offer additional light sources with different geometries from standard. By way of example, the incident light source of a second illuminator may be located at fifteen (15) degrees from normal. The plurality of combinations of incident light and angular response cause an enormous amount of spectrophotometric data. There is however a lack of efficient methods to efficiently handle and analyze all of these data in a purposeful way. On the other hand also the new spectrophotometric devices capture only a part of the spectral response of the analyzed sample for selected illumination conditions.

[0008] Strategies have been recently developed using painted or virtual samples representing various textures and comparing those to unknown samples. These techniques require substantial user intervention and are significantly subjective which produces inconsistent results dependent upon the skill of the individual.

[0009] A simplified approach using limited multiangle, multiplaner when available, spectral data with or without a camera, color or otherwise, that can produce improved and simplified results for pigment characterization and sample properties is

preferable for speed and ease of use. Providing a simplified system which can accurately determine the pigmentation of a sample to be fed to a formulation engine or visual color matching process greatly improves speed and accuracy. Including the formulation engine in that same flexible system further improves performance, accuracy, and simplicity.

[0010] Thus, there is a need for systems and methods that may be used to efficiently evaluate all of the data and specific combinations of data from a spectrophotometer allowing in particular meaningful inferences regarding the texture and/or gonioapparent effect(s) of an analyzed unknown target coating.

[0011] Therefore the present invention aims to provide means which overcome or at least amend all or at least some of the afore-mentioned deficiencies of the prior art and enables in particular an efficient use of the data obtained from state of the art spectrophotometers, preferably providing at least an approximation of the complete spectral response, for a reliable, more precise color matching of target coatings having texture and/or gonioapparent effects. These objectives are attained by the computer-implemented method, the system, the apparatus and the non-transitory computer readable medium including software as described in the following.

SUMMARY OF THE INVENTION

[0012] In a first aspect, the present invention provides a computer implemented method. The method includes obtaining, using a processor, reflectance data from a target coating and calculating from the obtained reflectance data, using the processor, virtual color response data using at least one of Kepler's laws of planetary motion equation and/or at least one derivation of at least one Kepler's laws of planetary motion equation. The method also includes generating, using the processor and the virtual color response data, a coating pigmentation that is the same or substantially similar in appearance to the target coating.

[0013] In another aspect, the present invention is directed to a system. The system includes a database and a processor in communication with the database. The processor is programmed to obtain reflectance and/or colorimetric data from a target coating, calculate from the obtained data virtual color response data using one of at least one Kepler's laws of planetary motion equation and at least one derivation of at least one Kepler's laws of planetary motion equation, and generate, using the virtual

color response data, a coating pigmentation that is the same or substantially similar in appearance to the target coating.

[0014] In another aspect, the present invention provides an apparatus. The apparatus includes means for obtaining reflectance and/or colorimetric data from a target coating and means for calculating from the obtained data virtual color response data using one of at least one Kepler's laws of planetary motion equation and at least one derivation of at least one Kepler's laws of planetary motion equation. The apparatus also includes means for generating, using the virtual color response data, a coating pigmentation that is the same or substantially similar in appearance to the target coating.

[0015] In a further aspect, the present invention provides a non-transitory computer readable medium including software for causing a processor to: obtain reflectance and/or colorimetric data from a target coating; calculate from the obtained reflectance and/or colorimetric data virtual color response data using one of at least one Kepler's laws of planetary motion equation and at least one derivation of at least one Kepler's laws of planetary motion equation; and generate, using the virtual color response data, a coating pigmentation that is the same or substantially similar in appearance to the target coating.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 illustrates a process that calculates a pigmentation for a target complex coating making use of the present invention.

[0017] FIG. 2 illustrates a "standard view" of in-plane angles (solid arrows, -15°, 15°, 25°, 45°, 75° and 110° with respect to the specular reflection) and out-of-plane angles (dashed arrows) in a commercially available hand-held spectrophotometer.

[0018] FIGS. 3 and 4 illustrate examples of "top down views" of the arrangement depicted in FIG. 2 indicating how multiple angles and light sources may be envisioned using elliptical orbits.

[0019] FIG. 5 illustrates an example of the use of Kepler's laws of planetary motion data using a specific combination of angles to predict whether a target coating contains a gonioapparent effect.

[0020] FIG. 6 illustrates a system which may be used to identify physical property attributes of a coating mixture of a target sample according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] While the description herein generally refers to paint and/or coatings, it should be understood that the devices, systems and methods apply to other types of coatings, including stain and industrial coatings. The described embodiments of the invention should not be considered as limiting. A method consistent with the present invention may be practiced in a variety of fields such as the matching and/or coordination of apparel and fashion products.

[0022] The present invention may be used with or incorporated in a computer system that may be a standalone unit or include one or more remote terminals or devices in communication with a central computer via a network such as, for example, the Internet or an intranet. As such, the computer or “processor” and related components described herein may be a portion of a local computer system or a remote computer or an on-line system or combinations thereof. The database and software described herein may be stored in computer internal memory or in a non-transitory computer readable medium.

[0023] The present invention is directed generally to spectral and/or colorimetric analysis of coatings, and more particularly, but not by way of limitation, to devices, methods and systems for predicting and pigmenting a complex coating mixture containing metallic, pearlescent, and/or special effect pigments.

[0024] The present invention generally relates to a method and apparatus for identifying physical property attributes of cured complex coating (*e.g.*, paint) mixtures using Kepler’s laws of planetary motion as explained herein, using a processor, based on the spectral reflectance and/or colorimetric response or value from a spectrophotometer. The resulting dataset may be used to identify physical property attributes of cured complex coating (*e.g.*, paint) mixtures and/or to identify a coating pigmentation that is the same or substantially similar in appearance to the target coating.

[0025] The purpose of using Kepler’s laws of planetary motion methodology is multi-fold. First, in order to use all available angles within a given system, Kepler’s laws of planetary motion may be used to create an alternate bi-directional

reflectance distribution function (“BRDF”)-type analysis. This type of analysis does not exclude any angles, rather using all angles to create a hemispherical “map” or “fingerprint” of a particular coating, texture or pigment type, whether gonioapparent or not. This methodology may be used to pseudo-interpolate angular responses that are not physically captured by the instrument at hand. Second, Kepler’s laws of planetary motion may be used to evaluate only specific combinations of angles in order to achieve purposeful manipulations. Similarly, this includes the exclusion of specific singular angles or combinations of angles when a particular texture or effect is being sought after as included or not included in a target coating. Third, Kepler’s laws of planetary motion may be used to accommodate for and correct the potential assumption that the received spectral reflectance values are incorrect in some way. Some potential reasons for irregularity or abnormality of the spectral reflectance data, even if minor, may include incident light angle location, incident light fluctuation, aperture size, target coating surface non-uniformity, etc.

[0026] FIG. 1 illustrates a process that calculates a pigmentation for a target complex coating making use of the present invention. At step 10, data is gathered from, for example, a spectrophotometer and, at step 12, the data are sorted based on a secondary array of associated information. At step 14, Kepler’s laws of planetary motion data is calculated. Herein, individual measured reflectances or colorimetric information (for example, l, c, h, x, y, z, etc.) at specific physical angles, and/or the incident light angle, will act as foci in ellipses based on the physical layout of arrangement used to obtain the reflectance data, for example, a portable spectrophotometer.

[0027] FIG. 2 illustrates a “standard view” of in-plane and out-of-plane angles in a commercially available spectrophotometer. FIGS. 3 and 4 illustrate examples of “top down views” of how multiple angles and light sources may be envisioned using elliptical orbits where measured angular responses (FIG. 3) and/or one measured angular response in combination with the incident light angle (FIG. 4) act at the foci of the ellipse. Herein, the ellipses are created in a plane that represents a top-down projection along the surface normal of a hemisphere centered above the reflecting sample, wherein each intersection of an incident or reflected light with the surface of the hemisphere corresponds to a point in the plane.

[0028] In FIGS. 3 and 4, the squares 30 and 40 indicate an example of a point where the paths cross, which may be a “virtual” color response, meaning that no

physical data has been captured at the specific location, however the virtual response may be simulated or calculated based on Kepler's laws of planetary motion, as described herein. Elliptical paths of the color data need not necessarily cross in order to create a virtual color response. Additionally, the elliptical orbits of the color data may be conceptualized as the influence of the real, measured angular color data in relation to other data points, both real and virtual, within the spectrophotometric response. The virtual "hemisphere" of color data is different for each measurement. Therefore, the hemisphere is virtually mapped by interpolating virtual data points based on the Kepler calculation i.e., the focal point is a measured color data point. The other focal point is either another spectral angle or the incident light. Based on the two focal points, the ellipse (orbital path) can be calculated at any point. Thus virtually creating all those points in the orbital path that you never actually measured. They are not expected to be precisely in any plane except for the comparison plane between the two focal points. This comparison plane will change dependent upon when two points are being used as the focal points.

[0029] Although FIGS. 3 and 4 illustrate examples, a multitude of combinations are capable using the systems and methods described herein.

[0030] Kepler's first law of planetary motion states that "the orbit of every planet is an ellipse with the sun at one of the two foci." An analogous principle is applied to spectral reflectance and/or colorimetric data based on a spectrophotometer by creating an "orbit" for the relation of several angular responses with either the illuminant light source at one focal point and an angular color response at another focal point, or in which two different angular responses are used for the foci of the related ellipse. In the case where the illuminant light is used as one of the foci, it may be assumed at a singular (output) value along with its inherent location within the spectrophotometer. Using polar coordinates, angular responses within the spectrophotometer may be defined. Values may be calculated using the following equation:

$$r = \frac{p}{1 + \epsilon \cos \theta}$$

Equation (1)

where r and θ are the polar coordinates for the ellipse, p is the semi-latus rectum, and ϵ is the eccentricity of the ellipse. By solving for any of the variables, different Kepler's first law of planetary motion values may be calculated based on different

input data. In the case of wavelength-dependent spectral reflectance values, the calculations may occur individually for each wavelength and integrated at the end-usage point of the data. If using the polar coordinates directly from the spectrophotometer unit, these may be functions of at least one of: (1) a version of the angle reflected light, which may be dependent upon the incident light angle; (2) an indication of in-plane or out-of-plane as well as location within that plane; and (3) spectral reflectance value or colorimetric value at a particular wavelength.

[0031] Kepler's second law of planetary motion states that "a line joining a planet and the Sun sweeps out equal areas during equal intervals of time." In various embodiments, a planet and the Sun may be analogized to coloristic data as an angular response and the illuminant light source, or any combination thereof, including with and without the illuminant light source. For example, the Sun=foci can be a measured angular response (or incident light source) and the planet corresponds to a point on the elliptical orbit, i.e. signifies the virtual color response in a (not measured) angle. Using Kepler's second law, calculations may be completed using color data. The first equation is that for areal velocity, which takes into account the rate of change of the color based on its proximity to the illuminant light source or other chosen focal point. The areal velocity is defined as:

$$\frac{dA}{dt} = \frac{1}{2} r^2 \left(\frac{d\theta}{dt} \right)$$

Equation (2)

where A is the area of a triangle with a base of r and height of $r d\theta$, which may be related to color data as the reflectance or colorimetric data (r) at angle θ , and t is the time element, which can be utilized for color data as an element of physical relation to other points of color response, both real and virtual. A second equation from Kepler's second planetary law of motion is the angular velocity equation applied in relation to the areal velocity. The angular velocity is defined as:

$$\theta_{ang} = \frac{d\theta}{dt}$$

Equation (3)

where θ_{ang} is the angular velocity, and θ and t may be used to as describe the areal velocity. The last equation that will be discussed within Kepler's second law is that of mean motion, which is that of the planet around the sun. In the case of color, this can be analogized as the mean color or mean rate of change of color around the

hemisphere of spectrophotometric color response. The mean motion is defined as:

$$n = \frac{2\pi}{P}$$

Equation (4)

where n is the mean motion and P is the period of the elliptical orbit as described:

$$P = \frac{\pi ab}{0.5r^2\theta_{ang}}$$

Equation (5)

[0032] where a and b are related to the area of the elliptical orbit ($A = \pi ab$), and r and θ_{ang} can be employed as previously described. By solving for any of the variables, different Kepler's second law of planetary motion values may be calculated based on different input data. Kepler's second law of planetary motion may be used with respect to color to mathematically determine the rate of change of color over the entire visual response spectrum when observing a coating. In the case of wavelength-dependent spectral reflectance values, the calculations may occur individually for each wavelength and integrated at the end-usage point of the data. If using the polar coordinates directly from a spectrophotometer unit, these may be functions of at least one of: (1) a version of the angle reflected light, which may or may not be dependent upon the incident light angle; (2) an indication of in-plane or out-of-plane as well as location within that plane; and (3) spectral reflectance value or colorimetric value at a particular wavelength.

[0033] Kepler's third law of planetary motion states that "the square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit." For color data, the planet may be analogized to a real point of color response from a spectrophotometer and its related orbit may be analogized to the virtual color responses achieved where real physical data is not captured within the spectrophotometer. Kepler's third law is expressed as:

$$P^2 \propto a^3$$

Equation (6)

where P is the orbital period of the planet and a is the semi-major axis of the orbit, where the "orbit" may be defined for color by the specific related ellipses drawn based on one or multiple real spectrophotometric response captures and/or the illuminant light source. The related proportionality may be defined for individual scenarios and combinations of spectral reflectance and/or colorimetric data for all

color cases or for specific identification of texture subgroups, such as aluminums. By solving for any variable, different Kepler's third law of planetary motion values may be calculated based on different input data. In the case of wavelength-dependent spectral reflectance values, the calculations may occur individually for each wavelength and integrated at the end-usage point of the data. If using the polar coordinates directly based off of the spectrophotometer unit, these may be functions of at least one of: (1) a version of the angle reflected light, which may or may not be dependent upon the incident light angle; (2) an indication of in-plane or out-of-plane as well as location within that plane; and (3) spectral reflectance value or colorimetric value at a particular wavelength.

[0034] While FIGS. 3 and 4 illustrate examples of specific combinations of angles and/or illuminant light sources for consideration with Kepler's laws of planetary motion, in various embodiments any single or multiple combinations of angular data, both real and virtual, may be used with various forms of Kepler's laws. Additionally, other variables or overall calculations or transformations thereof within Kepler's laws of planetary motion may be used in place of or in conjunction with the first, second, and third laws as described herein. Singular, paired, etc. comparisons may provide a sizeable amount of information that can be used to understand texture. In various embodiments, the incident light angle, either from normal or from parallel, may be used within the coordinate definitions of other angular data. This may be useful when using data from multiple incident light angles or when including a comparison of the data received from the same physical receptor on a spectrophotometer, however the incident light came from multiple angles.

[0035] When using spectral reflectance data, the calculation may be made individually for each wavelength. In various embodiments, statistics, such as mean, median, and sum may be used to create a singular value out of multiple wavelength calculated Kepler's laws of planetary motion values. An individual specific wavelength or wavelengths may be compared using Kepler's laws of planetary motion analysis. This permits the study of the wavelength or wavelengths of maximum reflectance, and potentially secondary maximum reflectance, where a majority of color and/or texture is visibly perceived. An analysis of shifting maximum reflectances by wavelength may also be completed using Kepler's laws of planetary motion analysis.

[0036] At step 16 of FIG. 1 the calculated Kepler's laws of planetary motion values from the colorimetric or spectral reflectance data may further be empirically correlated to known characteristics in order to identify textures, primary flake types, or other appearance information in complex coating mixtures. To employ an empirical method, the Kepler's laws of planetary motion data points (eccentricity, semi-latus rectum, angular velocity, mean motion, areal velocity, orbital period, semi-major axis, etc.) are calculated for an empirical dataset and all desired combinations of angles, representative of the expected mixtures and colors that need to be or are desired to be handled in everyday situations. The empirical data set may be used to create a predictive correlation: $y = f(x)$, where y represents the desired characteristic for identification or a qualitative question regarding the target coating, and $f(x)$ is some function of x 's, where x is one or multiple variables using the Kepler's laws of planetary motion values calculated from a specific set or multiple sets of angular considerations. In various embodiments, certain situations, it may be desirable to limit the angular comparison sets to the specific that are most feature-defining for the particular characteristic that is being identified. The resulting function may be linear or non-linear as defined by the empirical data set.

[0037] FIG. 5 illustrates an example of the use of Kepler's laws of planetary motion data using a specific combination of angles to predict whether a target coating contains a gonioapparent effect. There is a clear division where the correlation using Kepler's laws of planetary motion data is roughly at or above zero, indicating a lack of gonioapparent effect, while values below zero indicate the use of a gonioapparent effect.

[0038] Once an empirical correlation has been determined, at step 18 of FIG. 1 it may be used to derive the predicted value for the target coating. This may be achieved by using the target coating's values for the x 's (eccentricity, semi-latus rectum, angular velocity, mean motion, areal velocity, orbital period, semi-major axis, etc.) and calculating the result for y (the texture effect). While examples here have been given for the content of a gonioapparent pigment, the methodology may be as specific as which gonioapparent pigment at which size flake of that pigment is present by iteratively choosing the most important single angles or combinations of angles for the Kepler's laws of planetary motion calculations and empirical correlations. The choice of angular comparisons and to what level they are combined may be used to create the best possible empirical correlation. The empirical correlations may also be

slightly improved by including other “non-Kepler” information, for example singular angle colorimetric data.

[0039] In various embodiments, the quality of the overall “map,” or “fingerprint,” approach and the quality of the empirical correlation approach may be dependent upon the quality of the input data. The quality of the input data may be dependent upon the quality of the instrumentation and the quality of the data set used to create a set of knowns for the overall map or the empirical correlation. While any quality of data from an instrument or an empirical data set will result in an answer, the answer may be improved with the use of a high quality instrument and a widely varied, high quality empirical data set.

[0040] The entire set of calculations described herein may be used in conjunction with a processor in order to facilitate the choice of specific angle combination as well as accommodate the volume of calculations required in order to derive and then use an empirical correlation using the Kepler’s laws of planetary motion data.

[0041] FIG. 6 illustrates a system 90 which may be used to identify physical property attributes of a coating mixture of a target sample in accordance with the present invention. A user 92 may utilize a user interface 94, such as a graphical user interface, to operate a spectrophotometer 96 to measure the properties of a target sample 98. The data from the spectrophotometer 96 may be transferred to a computer 100, such as a personal computer, a mobile device, or any type of processor. The computer 100 may be in communication, via a network 102, with a server 104. The network 102 may be any type of network, such as the Internet, a local area network, an intranet, or a wireless network. The server 104 is in communication with a database 106 that may store the data and information that is may be used by the methods of the present invention for comparison purposes. The database 106 may be utilized in, for example, a client server environment or in, for example, a web based environment such as a cloud computing environment. Various steps of the methods of the present invention may be performed by the computer 100 and/or the server 104.

[0042] In another aspect, the invention may be implemented as a non-transitory computer readable medium containing software for causing a computer or computer system to perform the method described above. The software can include various modules that are used to enable a processor and a user interface to perform the methods described herein.

[0043] It will be readily appreciated by those skilled in the art that modifications may be made to the invention without departing from the concepts disclosed in the forgoing description. Accordingly, the particular embodiments described in detail herein are illustrative only and are not limiting to the scope of the invention.

CLAIMS

1. A system for generating a gonio-effect coating pigmentation of a target coating, comprising:

a database for storing an empirical dataset, the dataset comprising empirically calculated data relating to a plurality of gonio-effect pigments;
a processor in communication with the database; and
a spectrophotometer in communication with the processor;

wherein the empirical dataset is generated by;

obtaining gonio-effect pigment reflectance data from the plurality of gonio-effect pigments; and

calculating virtual gonio-effect pigment colour response data from the gonio-effect pigment reflectance data for each of the plurality of gonio-effect pigments, wherein calculating the virtual gonio-effect pigment colour response data comprises applying at least one of Kepler's laws of planetary motion equation and at least one derivation of at least one of Kepler's laws of planetary motion equation, wherein the virtual gonio-effect pigment colour response data includes one or more eccentricity values, semi-latus return values, angular velocity values, mean motion values, areal velocity values, orbital period, and major axis values; and

the processor is programmed to generate the gonio-effect coating pigmentation of the target coating by:

obtaining, from the spectrophotometer, target coating reflectance data from the target coating;

calculating virtual target coating colour response data from the target coating reflectance data, wherein calculating the virtual target coating colour response data comprises applying at least one of Kepler's laws of planetary motion equation and at least one derivation of at least one of Kepler's laws of planetary motion equation, wherein the virtual target coating colour response data includes one or more eccentricity values, semi-latus return values, angular velocity values, mean motion values, areal velocity values, orbital period, and major axis values; and

generating, using the processor, based on the virtual gonio-effect colour response data and the virtual target coating colour response data, the gonio-effect coating pigmentation of the target coating, the gonio-effect coating pigmentation

being the same or substantially similar in appearance to the target coating, wherein generating the gonio-effect coating pigmentation comprises:

comparing the calculated virtual target coating colour response data to the virtual gonio-effect pigment colour response data stored within the empirical dataset.

2. A system according to claim 1, wherein comparing the calculated virtual target coating colour response data comprises correlating the virtual target coating colour response data to the virtual gonio-effect colour response data and predicting at least one texture feature of the target coating based on the correlating.

3. A system according to claim 2, wherein correlating the virtual target coating colour response data to the virtual gonio-effect colour response data comprises empirically correlating the virtual target coating colour response data to the virtual gonio-effect colour response data.

4. A system according to claim 2 or 3, wherein predicting at least one textural feature of the target coating based on the correlating comprises predicting, using at least one empirical calculation, at least one texture feature of the target coating based on the correlating.

5. A computer implemented method for generating a gonio-effect coating pigmentation of a target coating, comprising:

accessing, from a database, an empirical dataset stored in the database, the dataset comprising empirically calculated data relating to a plurality of gonio-effect pigments, wherein the empirical dataset is generated by;

obtaining gonio-effect pigment reflectance data from the plurality of gonio-effect pigments; and

calculating virtual gonio-effect pigment colour response data from the gonio-effect pigment reflectance data for each of the plurality of gonio-effect pigments, wherein calculating the virtual gonio-effect pigment colour response data comprises applying at least one of Kepler's laws of planetary motion equation and at least one derivation of at least one of Kepler's laws of planetary motion equation, wherein the virtual gonio-effect pigment colour

response data includes one or more eccentricity values, semi-latus return values, angular velocity values, mean motion values, areal velocity values, orbital period, and major axis values;

obtaining, from a spectrophotometer, target coating reflectance data from the target coating;

calculating virtual target coating colour response data from the target coating reflectance data, wherein calculating the virtual target coating colour response data comprises applying at least one of Kepler's laws of planetary motion equation and at least one derivation of at least one of Kepler's laws of planetary motion equation, wherein the virtual target coating colour response data includes one or more eccentricity values, semi-latus return values, angular velocity values, mean motion values, areal velocity values, orbital period, and major axis values; and

generating, using a processor, based on the virtual gonio-effect colour response data and the virtual target coating colour response data, the gonio-effect coating pigmentation of the target coating, the gonio-effect coating pigmentation being the same or substantially similar in appearance to the target coating, wherein generating the gonio-effect coating pigmentation comprises:

comparing, using the processor, the calculated virtual target coating colour response data to the virtual gonio-effect pigment colour response data stored within the empirical dataset.