GonioViewer 实验——视觉观察简化

GonioViewer Experimental — Visual Observation Simplified

目前，颜色测量是工业实验室中油漆或塑料分析中不可或缺的一部分。

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一种测量几何方法足以用于吸收性颜料和染料，要么直接在 45° 角照明并在正常情况下在 0° 角测量，要么用球体漫射照明测量。效果颜料的情况则不同，特别是干扰颜料不同。颜色、亮度、光度可以随着不同的观看角度而变化。因此，对相应的测量装置提出了特殊的挑战。

看看目前来自毕克、爱色丽和柯尼卡 – 美能达的多角度测量设备表明，它们使用的几何方法已经使用了近 30 年，是当时的标准。在照明侧对面的光泽角的一侧添加了一个新的几何构造。自 1992 年以来，我在出版物和讲座中基于许多实验反复展示这种几何 (-15° 方面），实验中照明角度和测量可以以 5° 的增量独立设置。这种几何形状和第二种照明被包括在 ASTM (美国测试和材料协会) 标准 E2539 中。在距离正常值 15° 处的第二次照明仅在 X-Rite MA98 中实现，后来在 MA-T12 中实现。

目视检查涂料面板时，用手将其上下倾斜。这是在视窗或合适的灯光间完成的。在这个过程中，照明的角度和观察 (测量) 的角度是不断变化的。这意味着在任何情况下都不采用测量仪器的几何形状。因此，仪器评估和视觉评估之间存在差异。测量仪器的一个小测点与面板的面积之间也存在差异。对于一个明信片大小的面板，当您将视图从顶部边缘移动到底部边缘时，会有一个 15 到 20° 的角度。这个角度大于镜面在 15° 和 25° 处的两个近光泽角。这对于具有较强

Nowadays, colour measurement is integral to paint or plastic analysis in industrial laboratories. One measurement geometry is sufficient for absorbent colours and pigments, either illuminated directly at 45° and measured at 0° in the normal or measured with diffuse illumination using a sphere. The situation is different for effect pigments, especially interference pigments. The colour, brilliance and brightness can change with different viewing angles. For this reason, special challenges are placed on the corresponding measuring devices.

A look at the current multi-angle measuring devices from BYK, X-Rite and Konica-Minolta shows that they work with geometries that have been used for almost 30 years and were the standard at the time. A new geometry has been added on the side of the gloss angle opposite the illumination side. I have repeatedly presented this geometry (-15° aspecular) in publications and lectures since 1992 based on many experiments with a laboratory instrument in which the angle of the illumination and the measurement could be set independently in 5° increments. This geometry and a second illumination were included in the ASTM (American Society for Testing and Materials) standard E2539. The second illumination at 15° from the normal was only realised in the X-Rite MA98 and later in the MA-T12.

When visually inspecting a painted panel, the panel is tilted up and down by hand. This is done at the window or in a suitable light booth. During this process, the angle of the lighting and the angle of observation (measurement) are

色移的干涉颜料是很重要的。

干涉颜料——应该插在这里——有一种载体材料，上面涂有一个或多个高折射层。一种常见的材料是天然的或人造的云母，例如，云母表面涂有高度折射的二氧化钛。入射光部分反射在表面上。在折射作用下，剩馀部分穿过二氧化钛层，并再次部分反射到云母的边界层。这部分使颜料平行于第一个反射部分。两者相互干扰，即如果光波的波峰遇到波谷，则产生的光波变大；如果波峰与波谷相遇，颜色就被理想地消去了。所产生的颜色取决于二氧化钛层厚度；随着层厚度的增加，最大值移动到更长的波长光谱范围。层厚由生产工艺决定，用户不能更改。

所产生的颜色也取决于光照的角度。从陡峭的照明到平坦的照明，颜色的最大值转移到光谱的较短波长范围。因此，干涉颜料可以通过改变照射角度来表征和描述。角度可以由用户改变。

我们开发了四个 GonioViewer 盒子，以减少视觉和仪器观察中观察场大小之间的差异，并使用适当的测量几何形状来满足干涉颜料的特性。它们是用 3D 列印工艺制作的，宽 23 厘米，高 16 厘米。所述半圆弧上设置相应几何形状的孔。在面板上方的盒子下面有一个开口，允许从不同的角度和几何形状观察它。

测量结果以 a*b* 图或反射曲线的形式显示。几何图形显示为照明角度和光泽度之差的组合 :45°/as25°= 45° 照明 / 25° 镜面 = 与光泽度之差 25°。

constantly changed. This means that in no case is one of the geometries of the measuring instruments adopted. There is therefore a discrepancy between the instrumental and visual assessment. There is also a discrepancy between a small measuring point of the measuring instrument and the area of a panel. With a panel the size of a postcard, there is an angle of 15 to 20° when you move your view from the top edge to the bottom edge. This angle is greater than the two near-gloss angles at 15° and 25° of the specular. This is significant for interference pigments with a strong colour shift.

Interference pigments — this should be inserted here —have a carrier material that is coated with one or more highly refractive layers. A common material of this kind is natural or artificial mica, which is coated with highly refractive titanium dioxide, for example. The incident light is partially reflected on the surface. Under refraction, the remaining part passes through the titanium dioxide layer and is again partially reflected at the boundary layer to the mica. This part leaves the pigment parallel to the first reflected part. Both interfere with each other, i.e. if the crest of the light wave meets the trough, the resulting light wave becomes larger; if the crest meets the trough, the colour is ideally cancelled out. The resulting colour depends on the layer thickness of the titanium dioxide: as the layer thickness increases, the maximum moves to the longer wavelength spectral range. The layer thickness is determined by the production process and cannot be changed by the user.

The resulting colour also depends on the angle of illumination. From steep to flat illumination, the maximum of the colour shifts to the shorter wavelength range of the spectrum. An interference pigment can therefore be

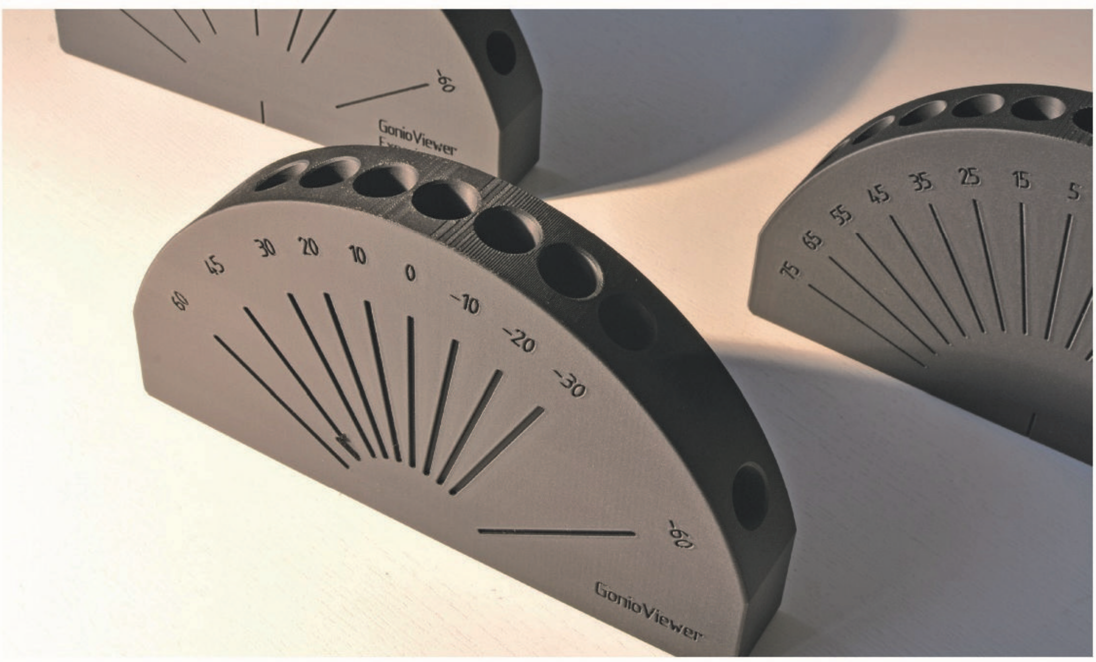

图1：GonioViewer 01具有与当前测量仪器相同的几何形状。额外的几何图形显示了新的干涉颜料的颜色梯度。
Figure 1: The GonioViewer 01 has the same geometries as the current measuring instruments. Additional geometries show the colour gradient of new interference pigments.

颜色测量 Colour Measurement

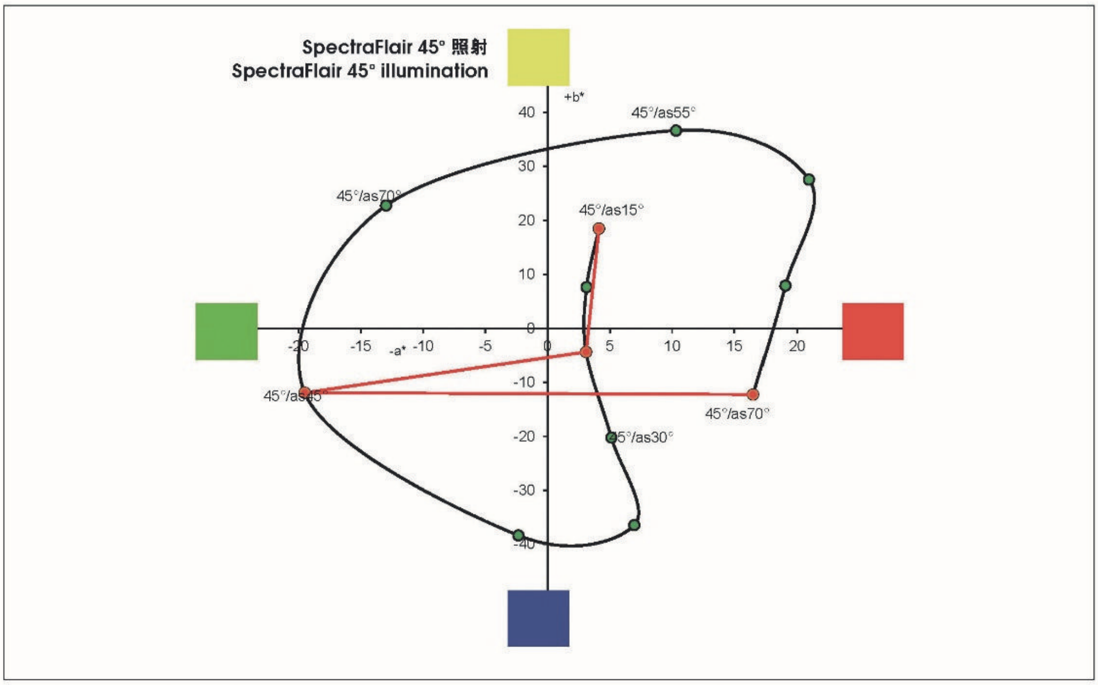

图2：新干涉颜料的颜色渐变示意图：红线反映了当前测量仪器的测量结果。颜色渐变显示了可以用GonioViewer 01观察到的彩虹（黑线与绿色测量点）。
Figure 2: Illustration of the colour gradient of the new interference pigments: The red line reflects the measurement results of the current measuring instruments. The colour gradient shows a rainbow that can be observed with the GonioViewer 01 (black line with green measuring points).

GonioViewer 实验 01

除了上述的干涉颜料，还有一些颜料的波状结构引起折射。入射光也在这里分裂，造成干扰。

在辐照为 45° 时，这些干涉发生在镜面 25° 处。在 25° 和镜面角度之间，这些颜料呈灰色或无色。从 25° 开始，它们最初呈现红色，然后是蓝色，绿色，最后随着与镜面的角度差异的增加而呈现黄色。这个彩虹出现在光泽度 25° 和 75° 之间。

常用的测量仪器在光泽度角 25° 和 75° 之间缺乏相应

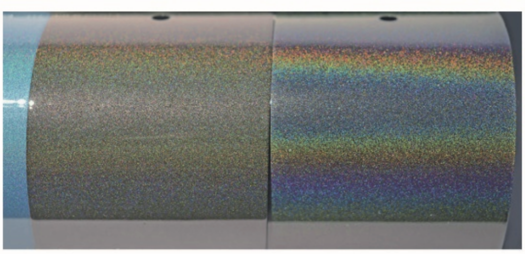

图3：这些色板清楚地表明，彩虹只在中心从25°的光泽角开始出现。
Figure 3: These painted panels clearly show that the rainbow only begins at 25° from the gloss angle in the centre.

characterised and described by changing the angle of illumination. The angle can be changed by the user.

We have developed four GonioViewer boxes to reduce the discrepancy between the size of the observation field in visual and instrumental observation and to fulfil the properties of the interference pigments using appropriate measurement geometries. They were produced using a 3D printing process and are 23 cm wide and 16 cm high. Holes in the corresponding geometries are arranged on the semi-circular arc. There is an opening under the boxes that lies above the panel, allowing it to be observed at different angles and geometries.

The measurement results are visualised either in the a*b*-chart or as reflection curves. The geometries are shown as a combination of the angle of illumination and the angle of difference from the gloss: 45°/as25° = 45° illumination/25° aspecular= 25° angle of difference from the gloss).

GonioViewer Experimental 01

In addition to the interference pigments described above, there are also pigments whose wave-like structures cause refraction. The incident light is also split here, causing interference.

These interferences occur from 25° of the specular at an illumination of 45°. Between 25° and the specular angle, these pigments are grey or colourless. From 25° they initially appear red, then blue, green and finally yellow as the angle of difference from the specular increases. This rainbow appears between 25° and 75° from the gloss.

颜色测量 Colour Measurement

的几何形状（**图 1**）。只有在 45° 时才能探测到彩虹的一种颜色。如果将 25°、45° 和 75° 的测点组合在一起，则会混淆（**图 2**）。只有在 35°，55° 和 65° 进一步测量几何形状的测量结果才能显示准确的颜色梯度（**图 3**）。

GonioViewer 01 在 45°、-15°、15°、25°、35°、45°、55°、65°、75° 和 105° 的光泽度角度的照射可以观察到颜色梯度（**图 4**）。

GonioViewer 实验 02

在视窗或灯光间进行视觉评估时，一个面板向或远离观察者和被观看者倾斜。照明角度和观测角度不断变化。在测量仪器中，照明角度是固定的，观测角度仅指该照明。在

Commonly used measuring instruments lack the corresponding geometries between 25° and 75° from the gloss angle (**Figure 1**). Only at 45° is one of the rainbow colours detected. If the measuring points of 25°, 45° and 75° are combined (**Figure 2**), the behaviour is confused. Only the addition of the measurement results of further measurement geometries at 35°, 55° and 65° shows the exact colour gradient (**Figure 3**).

GonioViewer 01 illuminates at 45°, at -15°, 15°, 25°, 35°, 45°, 55°, 65°, 75° and 105° from the gloss angle the colour gradient can be observed (**Figure 4**).

GonioViewer Experimental 02

During visual assessment at the window or in a light booth,

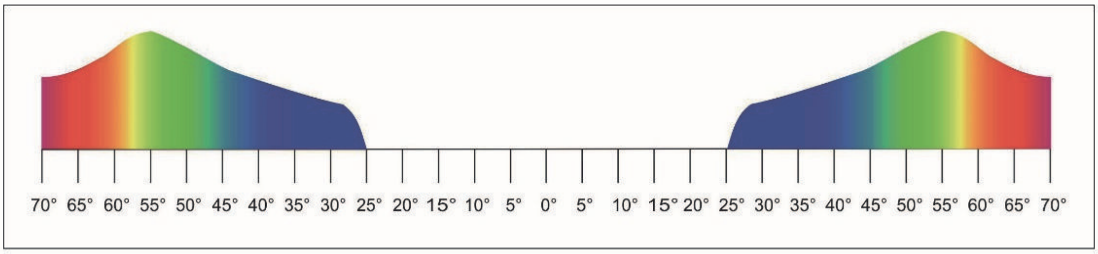

图4：0°光泽度角两侧的颜色示意图显示了从25°的蓝色到70°光泽度的绿色、黄色和橙色的颜色梯度。
Figure 4: The schematic representation of the colours on both sides of the gloss angle at 0° shows the colour gradient from blue at 25° via green, yellow and orange to red at 70° from the gloss.

向上倾斜 Tilting up

照射 Illumination	镜面反射 Specular	观察 Observation	差异 Difference	非镜面反射 Aspecular
15°	-15°	-15°	30°	0°
25°	-25°	-5°	30°	20°
35°	-35°	5°	30°	40°
45°	-45°	15°	30°	60°
55°	-55°	25°	30°	80°
65°	-65°	35°	30°	100°
75°	-75°	45°	30°	120°

向下倾斜 Tilting down

照射 Illumination	镜面反射 Specular	观察 Observation	差异 Difference	非镜面反射 Aspecular
15°	-15°	-15°	30°	0°
5°	-5°	-25°	30°	-20°
-5°	5°	-35°	30°	-40°
-15°	15°	-45°	30°	-60°
-25°	25°	-55°	30°	-80°
-35°	35°	-65°	30°	-100°
-45°	45°	-75°	30°	-120°

逆向：照明 <> 观察（交换 +-）
Reverse: illumination <> observation (exchange +-)

照射 Illumination	镜面反射 Specular	观察 Observation	差异 Difference	非镜面反射 Aspecular
15°	-15°	-15°	30°	0°
25°	-25°	-5°	30°	20°
35°	-35°	5°	30°	40°
45°	-45°	15°	30°	60°
55°	-55°	25°	30°	80°
65°	-65°	35°	30°	100°
75°	-75°	45°	30°	120°

图5：GonioViewer 02提供了当面板在视窗或灯光间倾斜时所采取的几何形状。由于光反转定律，向下倾斜时的几何形状与向上倾斜时的几何形状相对应。
Figure 5: GonioViewer 02 offers the geometries that are taken when the panel is tilted at the window or in a light booth. Due to the law of light inversion, the geometries when tilting downwards correspond to those when tilting upwards.

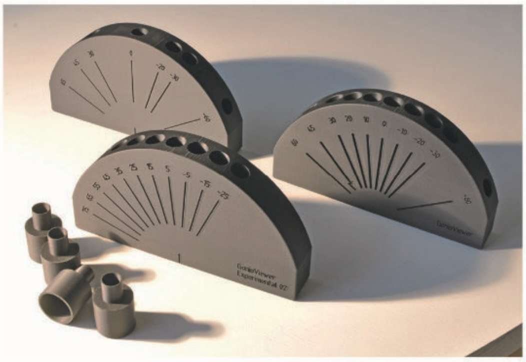

图6：带有灯适配器的GonioViewer 02。
Figure 6: The GonioViewer 02 with adapter for a lamp.

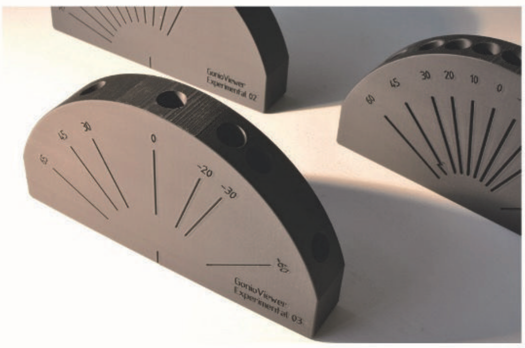

图7：测量仪器的照明角度为45°，观测角度为-60°、-30°、-20°、0°、30°和65°。GonioViewer 03再现了这些几何图形，以便可以在它们下面做出精确的判断。
Figure 7: The measuring instruments have an illumination angle at 45° and observation angles at -60°, -30°, -20°, 0°, 30° and 65°. The GonioViewer 03 reproduces these geometries so that precise judgements can be made under them.

这方面，目测评估和仪器评估之间没有对应关系（**图 5**）。

如果观察者以15°的照明角度握住面板，他会看到-15°的光泽度角。如果他现在将样板朝向他倾斜10°，则照明角度增加到25°。由于照明和观察者之间的角度保持不变（在本例中为30°），差异角度从0°增加到20°。当观察者继续向前倾斜时，照明角度和差角增加。

如果观察者将面板从起始位置向远离他的方向倾斜，则垂直于面板的法线将在照明方向上远离他，并且照明角度增加。然后照明移动到法线的同一侧作为观察。

使用GonioViewer 02，可以设置不同的照明角度，例如照明和观察之间的角度差异为30°或50°。然后从相应的镜面角度在30°或50°处进行观察。

由于光反转定律，向上倾斜的几何形状与向下倾斜的几何形状是相同的（**图 6**）。

GonioViewer 实验 03

GonioViewer 03 具有与测量仪器相同的几何形状：照

a panel is tilted towards or away from the observer and viewed. The angles of illumination and observation change continuously. With the measuring instruments, the angle of illumination is fixed and the observation angles only refer to this illumination. In this respect, there is no correspondence between the visual and instrumental assessment (**Figure 5**).

If the observer holds the panel at an illumination angle of 15°, he looks at the gloss angle at -15°. If he now tilts the sheet towards him at 10°, the illumination angle increases to 25°. As the angle between the illumination and the observer remains the same — in this case 30° — the difference angle increases from 0° to 20°. As the observer continues to tilt forward, the angle of illumination and the angle of difference increase.

If the observer tilts the panel away from him from the starting position, the normal, which is perpendicular to the panel, moves away from him in the direction of the illumination and the illumination angle increases. The illumination then moves to the same side of the normal as the observation.

With the GonioViewer 02, the illumination angle can be set differently, for example with a difference angle of 30° or 50° between illumination and observation. Observation then takes place at 30° or 50° from the corresponding specular angle.

Due to the law of light reversal, the geometries for tilting up are the same as for tilting down (**Figure 6**).

GonioViewer Experimental 03

The GonioViewer 03 has the same geometries as the measuring instrument offered: Illumination is at 45° and observation is at -15°, 15°, 25°, 45°, 75° and 110° from the specular angle (= aspecular line). In contrast to visual observation at a window or in a light booth, the field of view is about as small as the measuring field of a device (**Figure 7**).

With the GonioViewer 03, a panel can be assessed under the same optical geometries as with instrumental observation. In this respect, a direct comparison of the measured values with the visual impression is possible.

GonioViewer Experimental 04

The colour of an interference pigment is based on the one hand on the layer thickness of, for example, the highly refractive titanium dioxide. This layer thickness is determined by the production process as described above. On the other hand, it is determined by the angle of the incident light. Due to the law of interference, the colour changes to the short wavelength when the pigment or pigmented coating is illuminated at a flatter angle. The flatter the lighting, the higher the reflection compared to the reflection with steep lighting.

For visual inspection, hold the panel horizontally with an outstretched arm and illuminate it flat. Then move the panel parallel downwards and observe the colour change close to the gloss. This changes the lighting from a flat to a steep angle.

The GonioViewer 04 is used to track this movement and display it at an exact angle. It allows the illumination to be changed from 15° to 65° in 10° increments. Observations are then made at a difference angle of 15°. This corresponds to the observation angles from 0° to -50°.

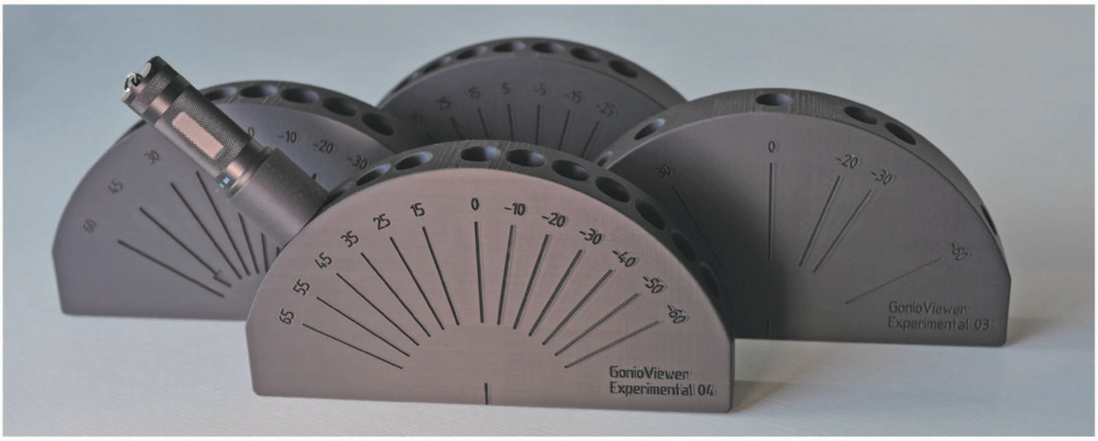

图8：干涉颜料在相同角度差异下从高光到平光照射表现出的色移。
Figure 8: Interference pigments show a colour shift when moving from steep to flat illumination at the same difference angle from specular.

明为 45°，观察为 -15°、15°、25°、45°、75° 和 110°，从镜面角度（= 镜面线）。与在视窗或灯光间的视觉观察相比，视场大约与设备的测量视场一样小（**图 7**）。

使用 GonioViewer 03，可以在与仪器观察相同的光学几何形状下评估面板。在这方面，测量值与视觉印象的直接比较是可能的。

The resulting colour gradient is referred to as the interference line. Ideally, it is described by the measurement results for the steep, classic and flat geometry: 15°/as0°, 45°/as15° and 65°/as15°. The current measuring devices can only describe this line to a limited extent. The X-Rite MA98 and the MA-T12 have a second illumination, whereby the two geometries 15°/as15° and 45°/as15° of the interference line

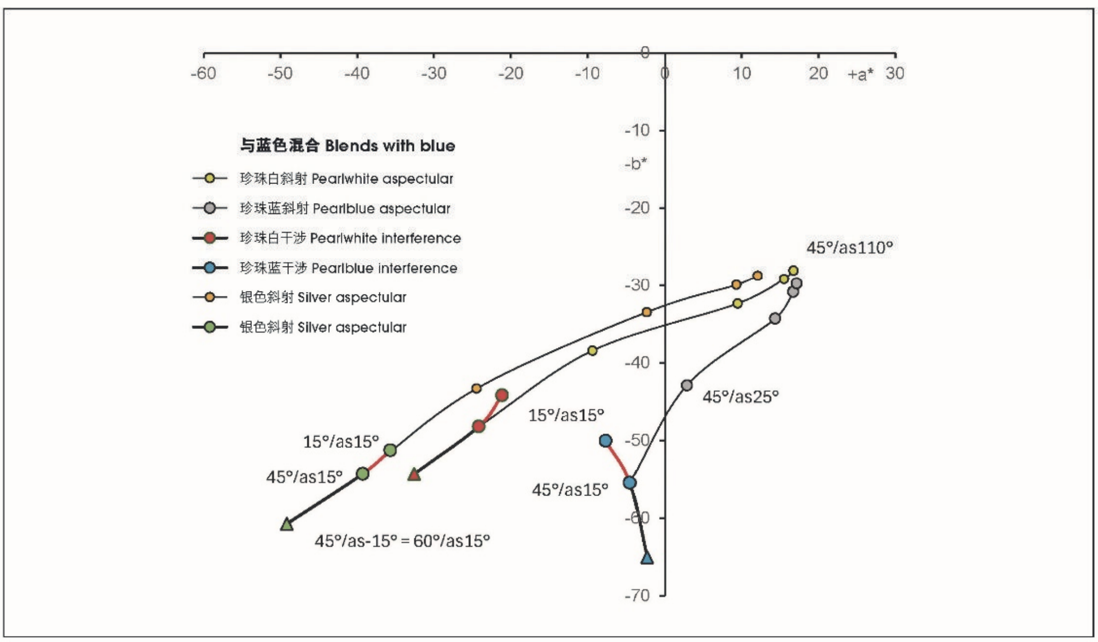

图9：相同的吸收蓝色颜料与不同的效果颜料混合:当与铝和白色干涉颜料混合时，干涉线（15°/as15°、45°/as15°女45°/as15°）作为镜面线（45°/as15°- 45°/as110°）的延伸。与蓝色干涉颜料混合，显示出一条远离谱线弯曲的干涉线。
Figure 9: The same absorbing blue pigment with different effect pigments: When mixed with an aluminium and a white interference pigment, the interference line (15°/as15°, 45°/as15°, 45°/as-15°) runs as an extension of the aspecular line (45°/as15° - 45°/as110°). Mixing with a blue interference pigment shows an interference line that bends away from the aspectral line.

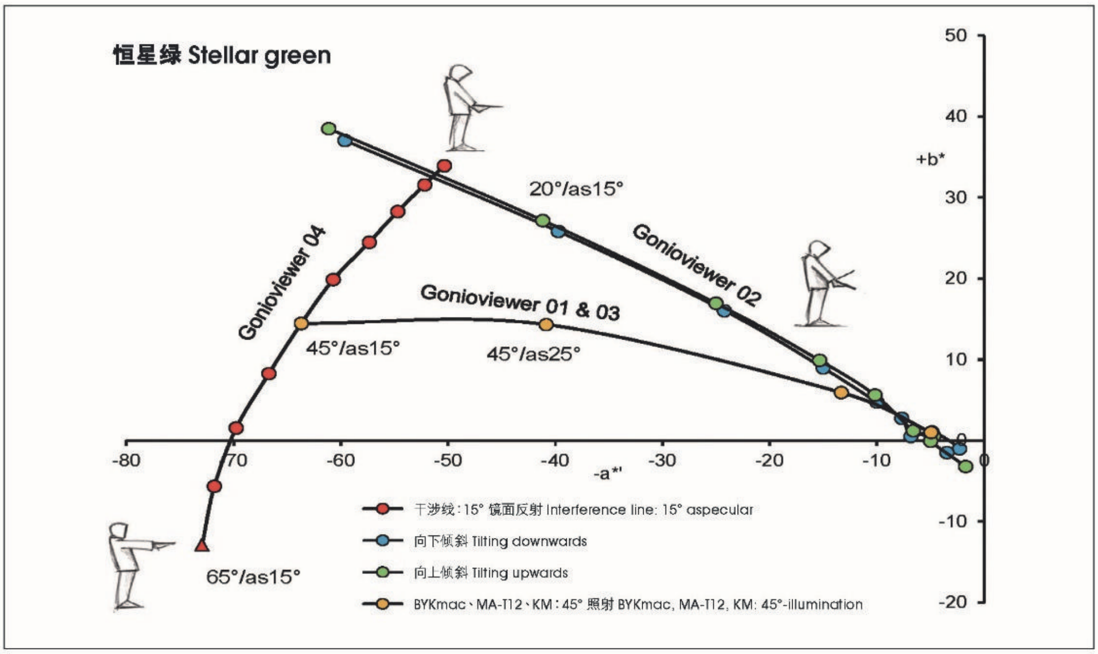

图10：以一种绿色干涉颜料为例，给出了不同的测量和观察结果。相应的GonioViewer也显示了:用橙色圆点的镜面线和GonioViewer 01和03(对应于当前仪器的几何形状)，用GonioViewer 02上下倾斜时的几何形状，用GonioViewer 04的干涉线（红点）。
Figure 10: The different measurements and observations are shown using the example of a green interference pigment. The corresponding GonioViewers are also shown: the aspecular line with orange dots and GonioViewer 01 and 03 (corresponds to the geometries of the current instruments), the geometries when tilting up and down with GonioViewer 02, the interference line (red dots) with GonioViewer 04.

GonioViewer 实验 04

干涉颜料的颜色一方面取决于，例如，高度折射的二氧化钛的层厚度。这一层的厚度是由上述生产工艺决定的。另一方面，它是由入射光的角度决定的。由于干涉定律，当以较平的角度照射颜料或颜料涂层时，颜色会向短波长方向变化。与陡峭照明的反射相比，照明越平坦，反射越高。

目视检查，保持面板与伸出的手臂水准，并平光照亮。然后将面板平行向下移动，观察接近光泽的颜色变化。这从一个平坦角度到一个陡峭角度改变了灯光。

GonioViewer 04 用于跟踪此移动并以精确的角度显示它。它允许照度以 10° 的增量从 15° 到 65° 变化。然后以 15° 的不同角度进行观测。这对应于 0° 到 -50° 的观测角度。

所产生的颜色梯度被称为干涉线。理想情况下，它由陡峭，经典和平坦几何形状的测量结果描述 :15°/as0°、45°/as15° 和 65°/as15°。目前的测量设备只能在有限的程度上描述这条线。X-Rite MA98 和 MA-T12 具有第二个照明，从而实现干涉线的两个几何形状 15°/as15° 和 45°/as15°。由于光反转定律，也可以使用 45°/as-15° 几何形状。45°/as-15° 对应于几何形状 60°/ as-15°。

对于没有二次照明的测量装置，45°/as-15° 几何形状也可用于表征干涉颜料：对于铝颜料或白色干涉颜料的混合物，镜面线从 45°/as45°、45°/as25° 和 45°/as15° 直接运行

are realised. Due to the law of light inversion, the 45°/as-15° geometry can also be used. 45°/as-15° corresponds to the geometry 60°/as15°.

For measuring devices without a second illumination, the 45°/as-15° geometry can also be used to characterise interference pigments: For mixtures with aluminium pigments or white interference pigments, the aspecular line runs from 45°/as45°, 45°/as25° and 45°/as15° directly on to the measurement result at 45°/as-15°. Coloured interference pigments are characterised by a colour shift when illuminated more flatly (**Figure 8**). As described above, the 45°/as-15° geometry corresponds to the 60°/as15° geometry due to the light reversal. The geometry illuminates flatter than the 45°/as15° geometry (**Figure 9**). The course of the aspecular line in the a*b* diagram then shows an anti-

表1：使观测成为可能的几何图形的汇编。
Table 1: Compilation of the geometries under which observation is possible.

Gonioviewer 实验 01 Gonioviewer Experimental 01

照射 Illumination	观察 Observation	非镜面反射 Aspecular
45°	-60°	-15°
45°	-30°	15°
45°	-20°	25°
45°	-10°	35°
45°	0°	45°
45°	10°	55°
45°	20°	65°
45°	30°	75°
45°	60°	105°

Remarks: red=new geometries

Gonioviewer 实验 03 Gonioviewer Experimental 03

照射 Illumination	观察 Observation	非镜面反射 Aspecular
45°	-60°	-15°
45°	-30°	15°
45°	-20°	25°
45°	0°	45°
45°	30°	75°
45°	60°	105°

Gonioviewer 实验 04 Gonioviewer Experimental 04

照射 Illumination	观察 Observation	非镜面反射 Aspecular
15°	0°	15°
25°	-10°	15°
35°	-20°	15°
45°	-30°	15°
55°	-40°	15°
65°	-50°	15°
45°	-30°	15°
45°	-20°	25°
45°	0°	45°
45°	15°	60°
45°	25°	75°
45°	35°	80°
45°	45°	90°
45°	55°	100°
45°	65°	110°

Gonioviewer 实验 02 Gonioviewer Experimental 02

照射 Illumination	观察 Observation	差异 Difference	非镜面反射 Aspecular
开始位置 Start position	15°	照射 Illumination/-15°	观察 Observation
15°	-15°	30°	0°
25°	-5°	30°	20°
35°	5°	30°	40°
45°	15°	30°	60°
55°	25°	30°	80°
65°	35°	30°	100°
75°	45°	30°	120°
开始位置 Start position	25°	照射 Illumination/-25°	观察 Observation
25°	-25°	50°	0°
35°	-15°	50°	20°
45°	-5°	50°	40°
55°	5°	50°	60°
65°	15°	50°	80°
75°	25°	50°	100°

到 45°/as-15° 的测量结果。彩色干涉颜料的特点是在较平坦的光照下发生色移（**图 8**）。如上所述，由于光反转，45°/ As -15° 的几何形状对应于 60°/ As -15° 的几何形状。该几何形状比 45°/ 15° 几何形状照明更平坦（**图 9**）。在 a*b* 图中的镜面线的过程然后显示逆时针弯曲向 45°/as-15° 几何。这种弯曲是彩色干涉颜料的典型特征（**图 10**）。

结论

使用GonioViewer实验，可以更准确地进行视觉评估。它们可以适应不同的要求：测量仪器的几何形状，在相同的光学条件下进行视觉评估。几何图形可以扩展到评估新的效果颜料的颜色梯度。通常在视窗或灯光间的目视检查也可以用 GonioViewer 模拟。相应的观察孔模拟窗户或灯光间的几何形状。GonioViewer 实验也可以用来精确地模拟干涉颜料的颜色梯度的几何形状，这可以通过移动平行于窗户或灯箱的面板来实现，而无需指定精确的几何形状（**表 1**）。总而言之，各种 GonioViewer 实验是理想的视觉评估方法。由于提供的几何形状，它们远远超出了测量仪器的可能性。

clockwise bend towards the 45°/as-15° geometry. This bend is typical for a coloured interference pigment (**Figure 10**).

Summary

With the GonioViewer Experimentals, visual assessment can be carried out more accurately. They can be adapted to different requirements: With the geometries of the measuring instruments, visual assessment is carried out under the same optical conditions. The geometries can be extended to assess the colour gradient of new effect pigments. The usual visual inspection at the window or in a light booth can also be simulated with a GonioViewer. Corresponding observation holes simulate the geometries at the window or in the light booth. A GonioViewer Experimental can also be used to precisely simulate the geometries for the colour gradient of an interference pigment, which could be achieved by moving a panel parallel to the window or light booth without specifying an exact geometry (**Table 1**). All in all, the various GonioViewer Experimentals are ideal for visual assessment. With the geometries offered, they go far beyond the possibilities of the measuring instruments.