Small objects in the spotlight

Visual perception is one of the most important senses of human beings. We associate the aesthetic value of an object with quality. For this reason, it is in the interest of many industries to be able to measure and control visual attributes. However, the objects are becoming more complex, and the need to measure small objects is increasing. To face this trend and to meet the requirements from industry, METAS developed a setup that allows to measure objects smaller than 1 mm in terms of their reflective characteristics from different angles.

Nina Basic

The visual appearance enriches our perception of the world. We can assess when a banana is ripe. Or pick the best strawberries at the market. Or recognize that a bowl of fruits in a furniture store is decorative. We identify the objects in our daily life based on their shape, size and visual attributes which are colour, gloss, transparency and texture. These visual attributes together define the appearance of the object. The CIE, International Commission on Illumination, defines the appearance as the «aspect of visual perception by which things are recognized».

The visual attributes are also very closely linked to the object's aesthetical value, to the sensation of quality and in the end to our wish to buy a certain product or not. Therefore it is essential to control the visual attributes for a variety of the industries, including automotive, cosmetics, paper, printing, packaging, coatings, plastics, food, fashion and textile, architecture, virtual reality, high tech, and 3D printing industries.

The challenge of measuring appearance

The measurement of appearance is not an easy task. All-in-one measurement is as of today not possible, thus it is divided into measurement of different visual attributes; colour, gloss, texture and translucency. Even with this division, the measurements are not trivial. With the emergence of novel materials, the task is becoming more and more complex.
The materials can be goniochromatic, meaning their colour changes depending on illumination and/or viewing direction. They can have very different levels of gloss, or exhibit sparkle (Fig. 1). These materials must therefore be measured at different viewing/illumination conditions, as well with spatial resolution.

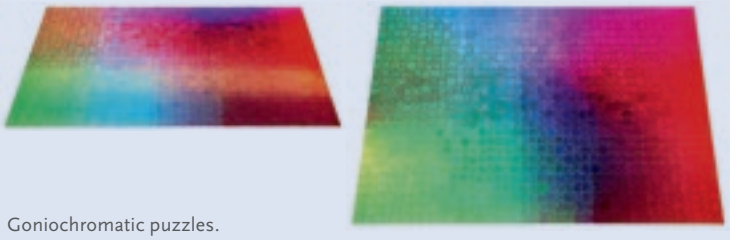
The measurements are performed using devices called goniospectrophotometers. A light source illuminates the object under one direction, while a detector measures the amount of light reflected from the object in another given direction. The first challenge of the measurements is its multidimensionality; the measurand, called bidirectional reflectance distribution function (BRDF), depends on the direction of observation, direction of illumination, wavelength, and polarization. When dealing with texture effects like sparkle, the BRDF also depends on the position of the measurement area on the object.

1: Examples of novel materials

Security feature on a Master Card.

Coffee cup with sparkle decoration.

Close up of the sparkle.

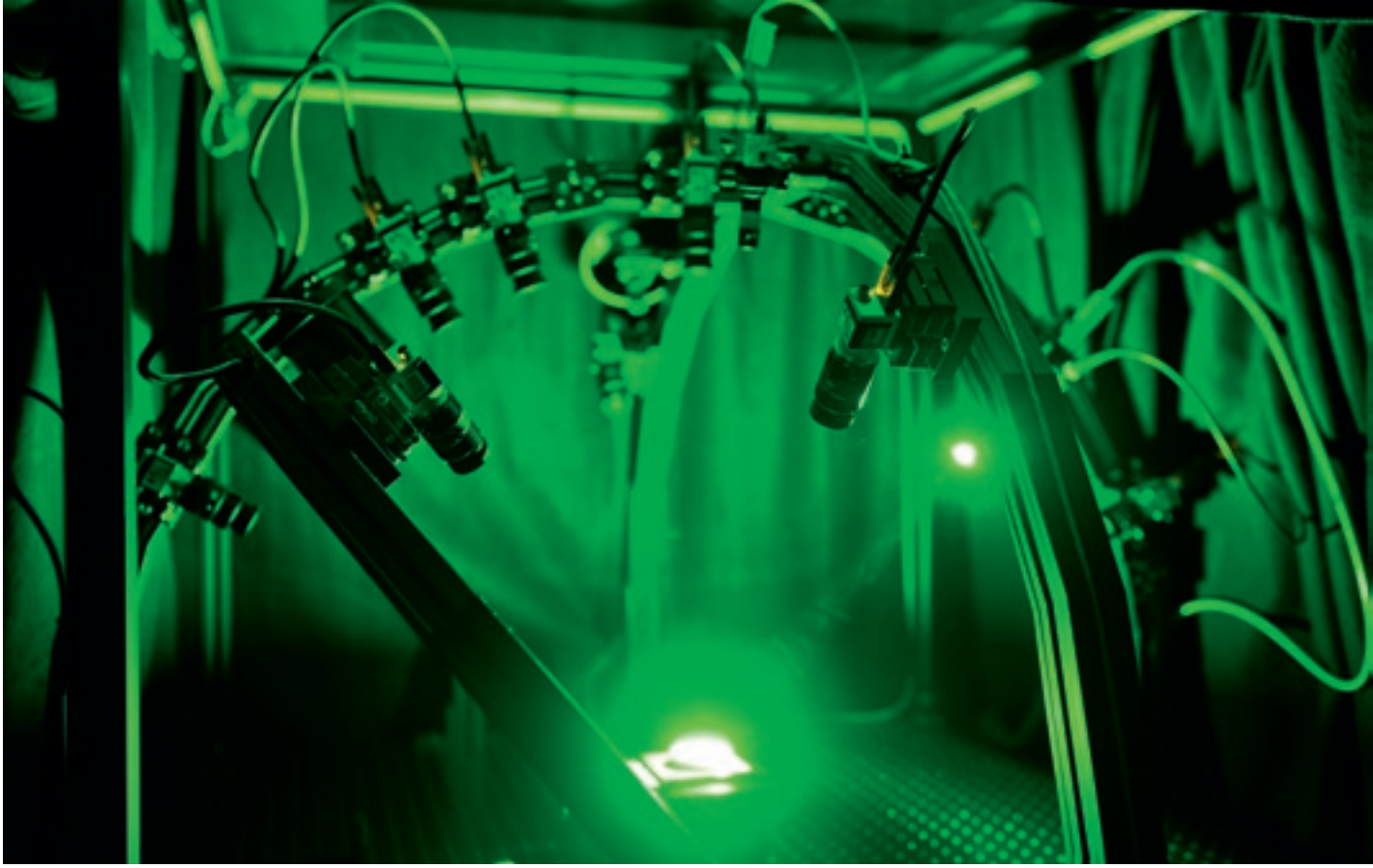


Goniochromatic puzzles.

The two different setups at METAS

To tackle the challenge of appearance measurements, METAS started a project in 2015 to build up the competence in the field. The goal of the project was the development and construction of a goniospectrophotometer, to provide the basis for the participation in third-party funded research projects, as well as providing services of appearance measurements.

During the project, two measurement setups have been built, called µBRDF and MARS (Fig. 2), designed to measure the reflectance of small objects, even smaller than 1 mm, having irregular shapes, at different directions of illumination and detection. This specialization addresses the particular needs of the Swiss industry.



2: BRDF measurement principle: a light source illuminates the object placed in the middle, while a camera (or multiple cameras, as in the photo) measures the amount of light reflected from the object.

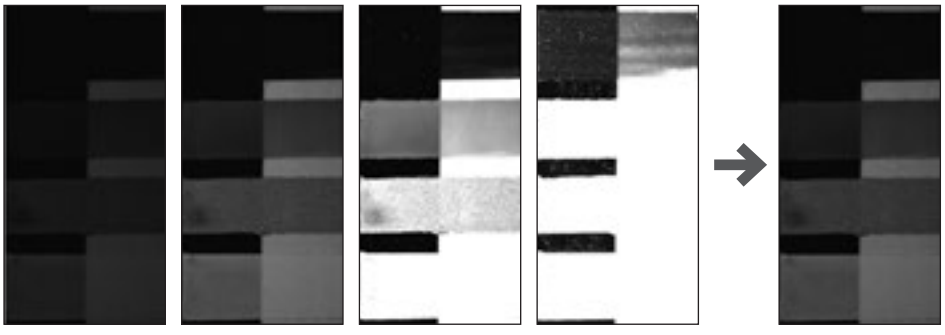
The measurement setups were designed to complement each other. The **m**ulti-**a**ngle **r**eflectance **s**etup (MARS) has limited number of measurement geometries but fast processing, while μBRDF is a universal setup with an almost arbitrary number of measurement geometries but slower processing.

The μBRDF setup consists of a white light source illuminating the object under a given direction, a sampleholder keeping the object at the correct position and orientation, and a camera measuring the amount of light reflected from an object in a given direction.

All three parts are mounted on a goniometer allowing us to change the direction of illumination and detection automatically during the measurement. The freedom to select any measurement geometry comes with long measurement time and large storage space. One measurement can easily include around 1500 measurement geometries, last 24 hours, and produce more than 400 GB of data.

The detection system of the μBRDF setup is based on a monochrome camera with an integrated filter wheel. The filters permit the measurement of luminance, as well as chromaticity coordinates. These represent the spectral reflectance of an object in a manner that is more similar to the human vision. Furthermore, the chromaticity coordinates can be converted into a variety of different colour spaces (e.g. RGB, *L a*b*). Instead of a camera, the μBRDF can utilize a spectrophotometer to measure the spectral BRDF of objects, not only the chromaticity coordinates. The storage space is in this case reduced because of the loss of spatial resolution.

MARS was designed to complement the μBRDF setup, measuring the spectrally and spatially resolved BRDF, with shorter measurement time. It consists of a spectrally tuneable light source that scans through the wavelengths, illuminating the object with different coloured light. In the post-processing, different wavelengths are combined together to obtain the spectral BRDF of the measured object. Instead of just one camera,



3: The cameras use HDR imaging, where the object is measured at different exposure times. Short exposure times (left) measure correctly the bright area, longer exposure times (left to right) measure correctly dark areas. Images with different exposure time are combined together in one HDR image (right).

as in the case of the μBRDF setup, MARS uses 10 cameras placed at fixed positions. The light source itself can be placed at three different illumination angles (15°, 45°, and 75°), allowing MARS to measure up to 30 measurement geometries. The 10 cameras measure in parallel, substantially reducing the measurement time; to 10 to 60 minutes per object, depending on the reflectance of the object.

The appearance setups enable BRDF measurements of objects using measuring surfaces ranging from below 1 mm up to 3 cm. The use of cameras as detectors allows us to measure multiple regions of interest (ROI) of an object at once. Furthermore, the ROIs can be selected/changed any time after the measurement. Due to the usage of high-dynamic range (HDR) imaging (Fig. 3), the setups also allow characterizing sparkle (bright spots on dark background). For this purpose, the object is measured at multiple exposure times and later combined into one HDR image. Short exposure times capture the correct values for bright areas, whereas long exposure times capture the values for dark areas.

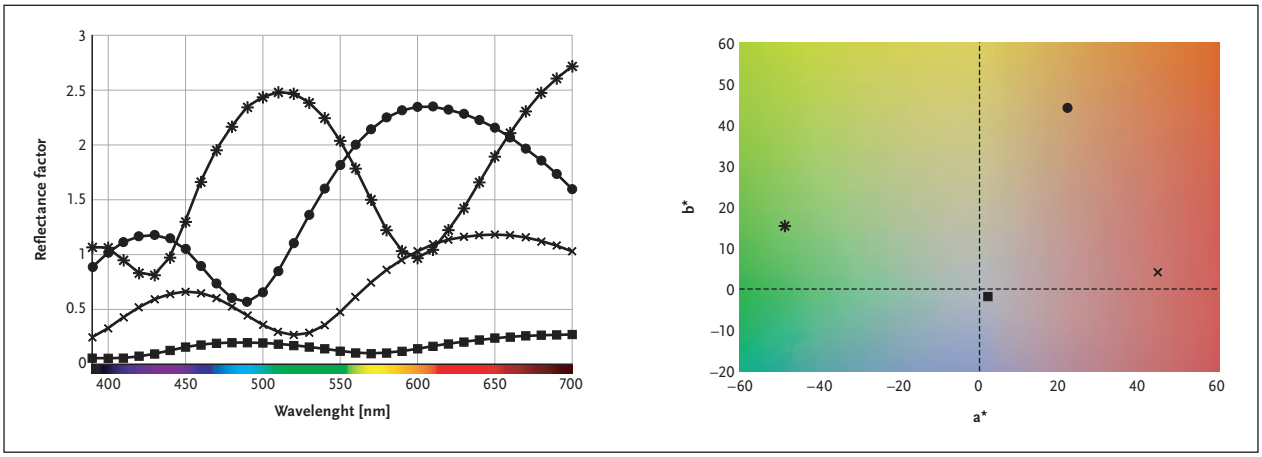
The BRDF measurement process is complex: cameras acquire images at multiple exposure times, multiple wavelengths, multiple measurement geometries, and multiple positions on the object. During the post-processing, the measurements are converted into a spectrum or chromaticity coordinates (Fig. 4) for a specific region of interest (Fig. 5). Each of these steps has an influence on the final result, therefore each of these steps has to be taken into account in the measurement uncertainty estimation. The measurement uncertainty is evaluated using a Monte-Carlo simulation for every ROI selected on the object

International activities and benefits

METAS is currently involved in two European research projects, as well as in two CIE technical committees related to the problem of appearance: the EMPIR projects, called BiRD and BxDiff, are a continuation of a previous EMPIR project, xDReflect, in which METAS was also involved. BiRD project is dealing with the development of guidance on the measurements of BRDF, gloss, visual texture (sparkle and graininess) and BRDF data arrangements. The BxDiff project's overall objective is to advance primary metrology in spectrophotometry by taking previously neglected uncertainty sources into account, and by developing new traceable spectrophotometric primary references. A total of more than 30 industrial partners, metrology and research institutes participate in both projects.

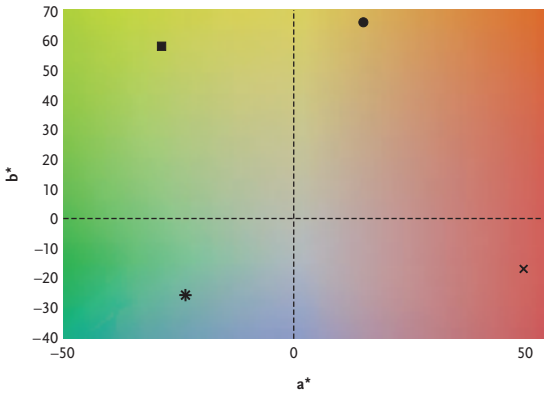
Closely related to the mentioned research projects are the two technical committees, in which METAS is involved. CIE TC2-85 aims to provide geometrical recommendations for the BRDF measurement according to the type of sample under investigation, while CIE JTC12 is aiming to provide a methodology to measure sparkle and graininess, and to develop a measurement scale.

In parallel with the ongoing research projects and technical committees, first services and demonstration measurements were carried out. Applications for spatially resolved BRDF measurements can be found, for example, in the watch and automotive supply industry, as well as in cosmetics and packaging technology. The manufacturers and users of the commercial instruments for appearance measurements can also benefit from our setups.



4: Spectra of a goniochromatic material (left) change significantly when the illumination and viewing direction change. This shift can also be represented in CIELAB colour space with colour coordinates *a*b** (right). The *a** axis represents the red-green component of the object, with red in the positive direction and green in the negative direction. The *b** axis represents the yellow-blue component, with yellow in the positive and blue in the negative direction.

5: Four patches of the mini colour checker are captured during one measurement. Any time after the measurement, multiple regions of interest (ROI) can be selected/changed on one object. The four selected ROIs on the mini colour checker (left) can further be represented in CIELAB colour space with colour coordinates *a*b** (right).



Future development at METAS

The measurement of appearance consists of many aspects, and normally one setup is not enough to capture everything. Thus, METAS is developing two new setups for appearance measurements. First, a diffuse reflectance setup, illuminates the object uniformly from all the directions, while a camera measures the amount of light reflected from the object under 0° or 8°.

The setup consists of a spectrally-tuneable light source, an integrating sphere to provide uniform illumination and a monochrome camera. It provides spectrally and spatially resolved diffuse reflectance measurements. METAS specialization is, as in the BRDF measurements, the measurement capability of small objects with irregular shapes.

The second measurement setup, which is currently still being developed, is intended for gloss measurements. Here, a white light source illuminates an object, while a detector measures the amount of reflected light in the specular direction.

Over the next few years, work at METAS will continue to focus on researching and improving the complex measurement of appearance.

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Kleinstobjekte im Rampenlicht

Visuelle Eigenschaften sind eng mit unserem Qualitätsempfinden verbunden. Für verschiedene Industriezweige ist es wichtig, die visuellen Eigenschaften ihrer Produkte wie Uhren, Kosmetika oder Baustoffe zu charakterisieren und bei der Produktion zu kontrollieren. Die Messung des Aussehens (engl. Appearance) – Farbe, Glanz, Textur und Lichtdurchlässigkeit – ist jedoch herausfordernd.

Mit dem Aufkommen neuartiger Materialien wird die Aufgabe noch komplexer. Goniochromatische Materialien ändern ihre Farbe je nach Beleuchtung und/oder Blickrichtung. Sie können zudem sehr unterschiedliche Glanzgrade aufweisen oder funkeln. Diese Materialien müssen daher bei verschiedenen Betrachtungs- und Beleuchtungsbedingungen sowie mit räumlicher Auflösung gemessen werden.

Die Messungen werden mit sogenannten Goniospektrophotometern durchgeführt. Eine Lichtquelle beleuchtet das Objekt in einer bestimmten Richtung, während ein Empfänger das vom Objekt reflektierte Licht in einer anderen Richtung misst. Die mehrdimensionale Messgrösse, die als bidirektionale Reflexionsverteilungsfunktion (BRDF) bezeichnet wird, hängt von der Beobachtungsrichtung, der Beleuchtungsrichtung, der Wellenlänge und der Polarisation ab.

Im Rahmen des Projekts «Appearance» wurden zwei Messplätze mit den Namen µBRDF und MARS gebaut, mit denen der Reflexionsgrad kleiner Objekte (kleiner als 1 mm) ortsaufgelöst gemessen werden kann. Diese Spezialisierung geht auf die besonderen Bedürfnisse der Schweizer Industrie ein, steht aber unseren Kunden weltweit zur Verfügung.

Petits objets sous le feu des projecteurs

Les propriétés visuelles sont étroitement liées à notre perception de la qualité. Pour divers secteurs, il est important de caractériser les propriétés visuelles de leurs produits comme les montres, les cosmétiques ou les matériaux de construction et de contrôler ces propriétés lors de la production. Mesurer l'apparence (appearance en anglais), par exemple la couleur, la brillance, la texture et la transparence, relève toutefois du défi.

La tâche devient encore plus complexe avec l'arrivée de matériaux innovants. Les matériaux goniochromatiques changent de couleur en fonction de l'éclairage et/ou de la direction du regard. En outre, ils peuvent disposer ou scintiller de degrés de brillance très différents. Ces matériaux doivent donc être mesurés sous diverses conditions d'observation et d'éclairage et avec résolution spatiale.

Les mesures ont été effectuées avec des goniospectromètres. Une source de lumière éclaire l'objet dans une direction déterminée tandis qu'un récepteur mesure la lumière reflétée par l'objet dans une autre direction. Le mesurande pluridimensionnel, désigné comme réflectivité bidirectionnelle (BRDF), dépend de la direction d'observation, de la direction d'illumination, de la longueur d'onde et de la polarisation.

Deux places de mesure, nommées µBRDF et MARS, ont été développées dans le cadre du projet Appearance. Ces places de mesure peuvent mesurer la réflectivité de petits objets (d'une taille inférieure à 1 mm) avec résolution spatiale. Cette spécialisation répond aux besoins particuliers de l'industrie suisse, mais elle est également à la disposition de notre clientèle internationale.

Piccoli oggetti sotto i riflettori

Le proprietà visive sono strettamente legate alla nostra percezione della qualità. Per i diversi settori industriali è importante caratterizzare le proprietà visive dei propri prodotti, come orologi, cosmetici o materiali da costruzione e controllare il processo produttivo. La misurazione dell'aspetto (ingl. appearance) – colore, lucentezza, consistenza e traslucidità – è tuttavia impegnativa.

Con l'avvento di nuovi materiali il compito diventa ancora più complesso. I materiali gonocromatici cambiano colore a seconda dell'illuminazione e/o della direzione di visualizzazione. Essi possono anche avere gradi di brillantezza molto diversi o scintillare. Tali materiali devono quindi essere misurati in diverse condizioni di visualizzazione e illuminazione, nonché con risoluzione spaziale.

Le misurazioni vengono effettuate con i cosiddetti goniospettrofotometri. Una sorgente luminosa illumina l'oggetto in una direzione specifica, mentre un apparecchio ricevente misura la luce riflessa dall'oggetto in un'altra direzione. Il misurando multidimensionale, che viene denominato funzione bidirezionale di distribuzione della riflessione (BRDF), dipende dalla direzione di osservazione, dalla direzione d'illuminazione, dalla lunghezza d'onda e dalla polarizzazione.

Nell'ambito del progetto «Appearance» sono state costruite due stazioni di misura con i nomi µBRDF e MARS, con cui è possibile misurare la riflettanza di piccoli oggetti (di dimensioni inferiori a 1 mm) con risoluzione spaziale. Questa specializzazione risponde alle particolari esigenze dell'industria svizzera, ma è a disposizione dei nostri clienti in tutto il mondo.