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# A novel approach to color matching of automotive coatings

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**Abstract**

The coatings industry requires a fast and accurate color formulating process. Today the manual/visual color matching procedures are time consuming and require high skills, in particular when metallic and pearlescent colors are involved. For that reason, a new approach to the colorimetry of paints was followed. This resulted in the development of a system employing an easy to use instrument and powerful software allowing instant formulation of almost any desired color. The system comprises a portable multi-angle spectrophotometer in combination with a personal computer and dedicated color matching software. Development of both the instrument and the software resulted from research on optics, vision science, color mixing properties and computational procedures. In the software new algorithms describing the light–paint interactions (absorption and scattering) and the procedures applied at on site color matching are imbedded. The system retrieves the optimum paint formula through fully automated multi-angle spectral measurements followed by an analysis of the spectra and subsequent data bank search. When desired, correction procedures allow adjustment of the formula through additional measurements on a spray out sample.

*Keywords:* Color matching; Automotive coatings

## 1. Introduction

Exact imitation of object colors today is a combination of both art and skill. This holds especially in situations when no visual distinction between the original and reproduced color is allowed like in the case of the car refinishing business. The art of color matching becomes even more exclusive and virtually three-dimensional when the so-called effect colors, metallics, pearlescents and their mixtures, are involved. The requirement of a perfect match at any observation and illumination angle can create considerable problems with respect to the formulation of the car refinishing top coats.

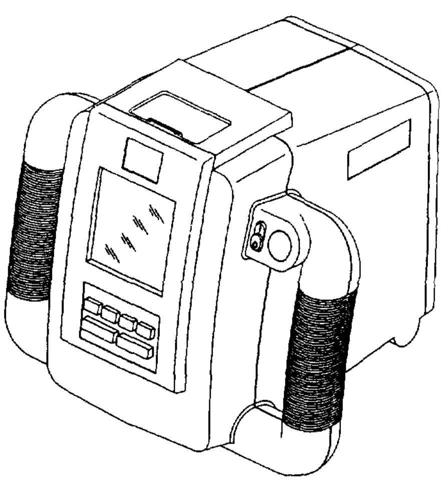

Fig. 1. The multi-angle spectrophotometer Colorchecker G-630 developed for on site reflectance measurements on effect coatings and manufactured by the Macbeth company.

Each year new flashy effect colors are being introduced by the designers in the automotive industry. The steady market share increase of the vehicles that are coated with these colors may reflect the aesthetic desires of the customers but also causes a substantial increase of eventual car refinishing efforts.

To ease this job on site (in the body shops), the paint manufacturers should provide not only the paints to the body shops but also specific colorimetric instruments and dedicated software. Interpretation of the measurements by means of optical models should allow rapid and accurate color formulation with both minimum efforts and minimum spills.

Development of such sophisticated colorimetric systems became thus an essential part of R&D policy of modern coatings producers [1,2]. In this paper the research results are described, which led to the development of a customized field system. The system includes a robust, though highly sensitive portable multi-angle, spectrophotometer in combination with software procedures and data banks on divers paint products. Using this system, efficient and accurate determination of the matching color formula can be accomplished instantly on the spot.

Design of the instrument is shown in Fig. 1.


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## 2. Background

There are two basic optical properties which determine the color of the objects: absorption and scattering of the visible radiation. The same basic properties determine the color mixing behavior of paint materials. Precise mathematical description of these interactions between the light and the various components of the paint allows the color prediction. Reversely, the modeling of the scattering, absorption and interface reflection of radiation in paint enables retrieval of its composition, i.e. the paint formula, from the spectral measurements.

Contrary to the absorption, which is chiefly a molecular process, the scattering on pigment particles has a more macroscopic character and depends thus on their shapes, orientation and size distribution. For the non-effect paints (solids), both processes, absorption and scattering, result in angle independent perception of the color (excluding the gloss effects).

This does not hold for the metallic and pearlescent coatings. Scattering in these effect coatings is strongly influenced by the content of aluminum flakes and mica platelets, resulting in the desired glittering appearance at the large viewing angles. Moreover, the platelets are often coated in order to evoke secondary absorption and interference effects at certain illumination and observation angles. This all means that color matching, whether visual or instrumental, also becomes a multi-angle procedure.

For the color measuring instrumentation, the choice of the representative illumination and observation angles is crucial for proper interpretation of the measured optical quantities. Configuration of the optical system (see also Ref. [3]) of the instrument shown in Fig. 1 is schematically displayed in Fig. 2.

An example of spectral reflectance of a car refinishing product measured at the three angles is shown in Fig. 3. Three pairs of the displayed curves represent color shades of a green metallic car coat and its imitation. In the presented example the match is good at the smaller observation angles but unsatisfactory in the flop, where the color of the original appears dark green while the imitation results in a much lighter (higher reflectance level) color shade.

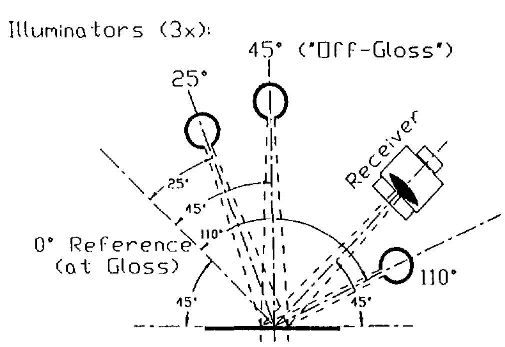



Fig. 2. Scheme of the illumination and detection geometries applied in the system.

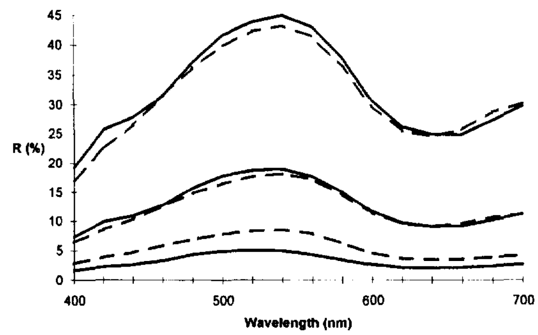



Fig. 3. Reflectance spectra of the true car color (full lines) and its imitation (dashed lines) at an oblique illumination angle (45° from the normal). The spectra were detected at a near specular reflection angle (upper two lines), at an angle perpendicular to the surface (middle two lines) and at a large observation angle, so-called 'flop' (lower two lines).

Development of instrumental computerized colorimetric systems implies solving numerous fundamental problems [1,2] such as:

(i) optimum illumination and observation angles corresponding with the visual criteria of the color match;

(ii) radiative transfer model describing the relationship between the composition of the material and its anisotropic optical behavior (color effects);

(iii) optimization procedures;

(iv) instrumental design;

(v) calibration and measuring procedures;

(vi) measurements on curved surfaces;

(vii) input, output, communication and data banks management;

(viii) functional design of the software;

(ix) optimum scenario for the whole procedure of the color formula retrieval in field.

These and other related problems have been successfully tackled resulting in the realization of the operational system. In Sections 3.1 and 3.2 more information is given on how some of these problems have been resolved.

## 3. Research

For the automated instrumental color matching in the body shops first a working scenario of the color formula retrieval had to be defined.

The scenario is schematically displayed in Fig. 4.

It includes the spectral multi-angle measurements, data transfer, color bank search procedures, communication with automatic smart scale, spray out of a sample, correction calculation if desirable and finally the paint application onto the part of the car body to be refinished.

Next to the fundamental research, each action of the scenario required solving a number of practical problems to finally enable a smooth and efficient car color repair.

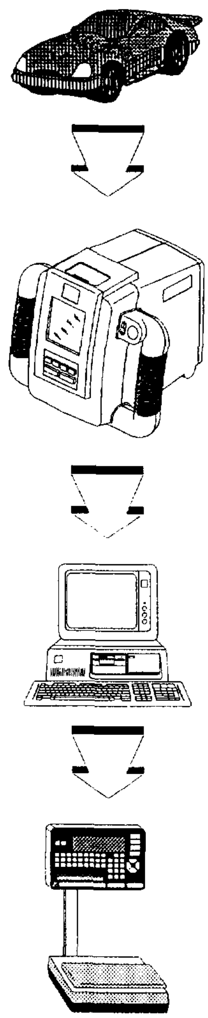


Fig. 4. Flowchart of the system for car color retrieval on site. Reflectance values measured on car bodies by means of the Colorchecker are downloaded into a PC and processed in terms of colorant concentrations. This color formula is then transferred to an automatic scale.

### 3.1. Instrumentation and measurements

Due to many reasons (aging, weather influences, previous resprayings, paint batch differences etc.) the original car color codes, supplied by the car manufacturers, do not contain sufficient information for an immediate and invisible color repair. Accurate instrumental true color determination on site is therefore an efficient approach how to substantially decrease the color matching efforts and wastes. This holds in particular for the metallic and pearlescent colors.

As stated above, a dedicated portable multi-angle reflectance spectrophotometer was developed employing modern technological components and concepts (see Fig. 1). In the design the optical accuracy and stability are attuned with robustness, low price and ease of use requirements.

Prior to the instrumental design, many practical problems were investigated. Some of them are briefly described below.

(i) Since there are hardly any really flat surfaces on the exterior of cars, a procedure for representative measurements on curved surfaces had to be developed. The problem was solved through defining a measuring area by means of several pressure sensors integrated in the instrument, which control the signal detection and prevent unwanted defocusing of the optical system.

Table 1
Measured color differences of car refinishes as caused by a temperature increase from 20 to 60 °C

| Color region | Color difference dE |
|---|---|
| Yellow | 0.12–4.25 |
| Orange | 1.13–1.63 |
| Red | 0.21–1.47 |
| Violet | 0.08 |
| Brown | 0.10–0.28 |
| Black | 0.7 |
| White | 0.15 |
| Blue | 0.22–0.48 |
| Green | 0.18–1.39 |

(ii) Statistical analysis was employed to specify the measuring procedures including multiple signal detection under several instrumental positions in order to minimize the paint application influences (in particular the orientation of the effect flakes) and measuring errors.

(iii) Compensation of the intrinsic thermal instability of the electronic components and of the paint material (thermochromy) had to be included in both the instrumental design and the measuring procedures. Some representative data on thermochromy of various pigments are presented in Table 1. Temperature range has been specified, in which the thermochromic effects of most pigments used in automotive coatings appear to be within the tolerances of car refinish acceptance. A temperature sensor and automatic out of range warning as well as re-calibration request are included in the measuring set-up and procedures.

(iv) Knowledge on the coarseness of the metallic flakes can support the matching procedure. A coarseness index and scale were defined to be visually compared with the true car color, prior to the spectral measurements.

(v) Experience learns that the first color matching attempt does not always result in an acceptable color shade. For this kind of mismatch, a specific procedure was developed allowing correction of the original formula just by addition of small amounts of available colorants. Benefits of such correction in terms of minimum material spills and efforts are obvious.

### 3.2. Data processing

Availability of extended color banks is most essential for instrumental color matching. The banks should be easily accessible and they should supply, along with the standardized colorimetric properties of each paint product, the best match formulas developed previously. Due to the high number of the existing car colors and their variants (around 80 000) the construction and furnishing of color banks of the car refinishing products required attention and computer programming skills.

There exist various measures and tolerances for selection of colors within a visually acceptable color match. For the non-effect (solid) colors the color difference parameter dE(CMC) is currently being agreed on as an optimum gauge. There are no available standards nor tolerances for the multi-angle colorimetry of the metallic and pearlescent car refinishes.

From correlation research on perceived and measured color differences under various angles a specific parameter was derived, so-called weighted average color difference (WADE), and successfully employed as a color bank search criterion. This parameter includes a linear combination of weighted color differences at specific measuring geometries. An important feature is, that based on empirically found relationships between the dE(CMC) values and specific visual color difference values at various observational conditions, the WADE parameter is a monotonous function at all angles.

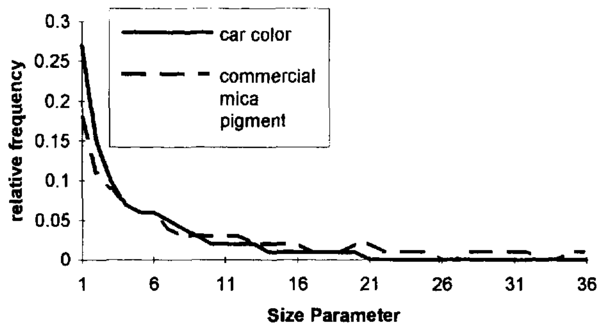
## 4. Progress

Sole spectrophotometric determinations on the effect coatings do not contain complete information on the color. The detected radiation represents an integral of the reflectance over an area of about one to ten square centimeters while the special metallic and pearlescent effects are due to the particles having a cross section of several microns. Besides, the necessary approximations in the optical modeling cannot appropriately cover the isotropic scattering on pigments and the anisotropic scattering on effect particles in the same time. Prior to the color formulation, additional information on the effect flake material is therefore very useful for an accurate match. As mentioned above, this information can be currently obtained either from additional car color data or by a specific visual assessment. Development of objective instrumental methods for the effect pigments identification appears to be highly desirable.

Along with the colorimetric data, the multi-angle measurements contain also information on the effect pigments. This information may be extracted by numerical analysis of the spectra, using modern computational tools like neural networks, genetic algorithms or fuzzy logic.

Also, further automation of the matching process is in progress employing digital analysis of the imagery collected above the coated surfaces. The algorithms developed allow identification of the spectral signatures and of the spatial 'fingerprints' of specific effect particles commonly used in the automotive coatings. Next to some standard digital image processing software, specific pattern recognition and neural network tools can be employed for this task.

An example of the identification by means of so-called size and color parameters of a specific pearlescent pigment in a car coat is displayed in Fig. 5. Standard digital image processing routines were applied in combination with specific newly developed algorithms.



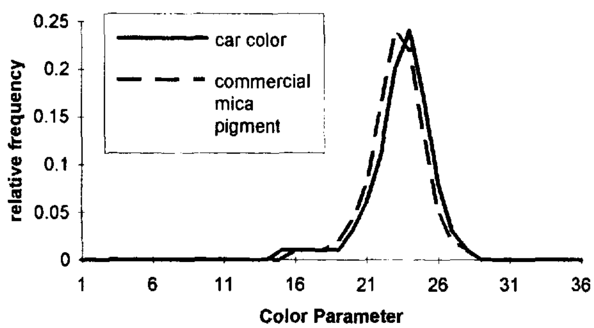




Fig. 5. Frequency distributions of the pigment size and color parameters as revealed in a dark greenish pearlescent car coating (full lines). Both parameters appear to correspond well with the data of a commercially available blue–green mica pigment (dashed lines).

After professionalization of the equipment and procedures involved, this will lead to further acceleration and improvement of the color matching process.

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