Appendix

An Angularly and Spatially Resolved Reflectometer for a Perceptually Adequate Characterization of Gloss

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Motivation for the Chosen Position of the Gloss Maximum Position
A large dynamic range for the facet angle measurement was desirable for the measurement system. At the same time, the focal depth had to be taken into consideration. A small sample holder radius would yield a large dynamic range with a limited need for a large focal depth, but the angular resolution would be poor. A fair compromise seemed to be to use a moderate radius and let the optical of the camera approximately intersect the axis of curvature of the sample holder and further to let the focal plane coincide with the gloss maximum point $G$ at the sample holder. This yields an optimal resolution at $G$ and also a good utilization of the focal depth around the focal plane, since the measurements are taken on both sides of the point $G$ and both the near- and far-zone of the focal depth are used in the measurement. At the same time, it is possible to have a large dynamic range of the surface inclination even though it is in only one angular direction. Figure 8 shows that the dynamic range of the sample holder angles is not symmetrical around the gloss maximum position $G$. In theory, we could measure facets that have an inclination $2 \times \alpha$ larger on one side (the side towards the camera) than on the opposite side, assuming that both positions are illuminated and can be observed by the camera. With this asymmetrical construction, it was possible to obtain an indication of the dynamic range of angles necessary, during the initial stages of development of the measurement system. As shown in Figure 8, assuming that the optical axis of the CCD, i.e., the normal to the center of the CCD, intersects the axis of curvature of the sample holder and adopting set-up specifications given in the section “Angularly and Spatially Resolved Reflectometry”, it can be seen that:

$$L_1' = \left( \frac{L_{\text{IMAGED}}}{2} - L_2 \right)$$  \hspace{1cm} (A1)

where $L_1'$ is the distance from the CCD pixel row 0 to $G$ (note the slight difference in the setup conditions here in the Appendix compared to in the main text, hence $L_1' \neq L_1$, but $L_1' \approx L_1$). Further is

$$i_{\text{GLOSS}} = L_1' \frac{i_{\text{IMAGED_TOT}}}{L_{\text{IMAGED}}}$$  \hspace{1cm} (A2)

where $i_{\text{GLOSS}}$ is the pixel row number in the CCD where the theoretical gloss maximum would be recorded for an optically smooth surface ($i_{\text{GLOSS}} \neq i_{\text{Gloss}}$, similar to the above), and $i_{\text{IMAGED_TOT}}$ is the total number of rows in the CCD [512 pixels]. Using Eq. (3) which defines the distance $L_1$, from $G$ to the line parallel to the optical axis of the CCD coinciding with the center axis of the sample holder, and under given specifications for the setup:

$$i_{\text{GLOSS}} = \left( \frac{L_{\text{IMAGED}}}{2} - r \sin \alpha \right) \frac{i_{\text{IMAGED_TOT}}}{L_{\text{IMAGED}}}$$

$$= \left( \frac{10}{2} - 8 \sin \left( \frac{20 \times 180}{180} \right) \right) \frac{512}{10} \approx 115.91$$  \hspace{1cm} (A3)

The nearest integer value is then $i_{\text{GLOSS}} \approx 116$.

At the beginning of each measurement session, there is an angular tuning phase where the system fine-tunes the position of the whole sample holder system by translation so that $i_{\text{GLOSS}} \approx 116$ ($i_{\text{GLOSS}}$). This tuning is done by calculating the mean reflectance in two narrow (about 10–20 pixels) bands on each side of $i_{\text{GLOSS}}$, calculated for a mean of multiple different positions at the sample surface. As long as one side has a higher mean gray scale value, the $x$-$y$ table on which the sample holder is mounted, is moved to compensate for this skewness. The step length for the $x$-$y$ table is iteratively halved down to the smallest possible step length of 1.0 $\mu$m, i.e. considerably less than the side length of a facet. This identity $i_{\text{GLOSS}} = 116$ could hence be considered as a trigonometric “anchor” for the further calculations made in the development of the RVM.

Comments on the GAS Evaluation Algorithm
The performance of the GAS-index algorithm depends on the parameters $a$, $b$, $c$, $d$ and $e$, see Fig. 7, defining the weighting function. In this work the parameters have been chosen by reasoning alone to yield a balanced output of positively and negatively rated facets for a wide range of different printed test samples. The assumption had been that the power of the system lies in the characteristic features of the algorithm and does not heavily depend on whether or not the parameters are well optimized. It would however be possible and desirable to tune these parameters, preferably on the basis of a percep-
tual evaluation of a large set of samples. In relation to the results in the Master’s Thesis on which this work is partly based, the weighting function parameters here differ as a consequence of approximations made in the present work for the calculations of the output from the function $W$, after re-measuring the samples. This leads to overall higher GAS-index values, in the present work, for the same samples. The principle shape of the weighting function is however the same, and the relative ratings of the samples are unchanged.

The focus of attention is on characterization of geometry-dependent inhomogeneity in gloss for two principal different dimensions, (a) the “variation of gloss in the spatial coordinates”, i.e., how the gloss differs between different locations on the sample, and (b) the “variation of gloss in the angular coordinates”, i.e., the how the gloss differs at different sample inclinations. The characterization of perceptual homogeneity of gloss is not however based on commonly used statistical measures of variation. No consideration has been given to the Modulation Transfer Function (MTF) of the human visual system, i.e., the relative sensitivity as a function of spatial frequency. The peak sensitivity and the frequencies at which it occurs depends on the type of visual stimulus and on the visual environment, but it is normally of the order of 5 cycles/degree. This should be incorporated by an approach similar to that of MacGregor et al., which may improve the performance of the measurement system.

Approximation of the Weighting Function

The weighting function should preferably operate on the tilt of the facets. An approximation has been made in the present implementation. The weighting function used is a linear function of the pixel distance from the pixel row (in the CCD camera) in the direction of the PA. The inclination index $i$ in Fig. 7 can thus be changed to row index $i$. The function is defined to equal +1 for $|i| \leq 2$, i.e., a narrow zone two pixels wide in both directions around the line corresponding to the direction of PA. In the transition regions, $2<|i| \leq 14$ pixel lines, the output decreases linearly from 1 to –1 and outside this range of 29 pixel lines the output is –1. This is an approximation, since ideally the rating should be based on the facet tilt not on the pixel row distance. This approximation introduces only a small error however, near the pixel line corresponding to the direction of PA. The weighting function $W(i)$ varies for only 29 pixel rows in the corresponding zone. Using Eq. (1-3) and the relation $i_{\text{GAMIRD}} = i + i_{\text{GLOSS}}$, the error can be estimated. The error is maximal for $|i| = 14$, for $i = -14$, $\beta(i) = 2.098$ degrees and for $i = 14$, $\beta(i) = -2.071$ degrees, where these are here approximated to have the same absolute value. That is, the error is bound to be less than 1.4 percent for all angle values.

Study on the Setting of the F-Stop

By increasing the F-stop value (decreasing the solid angle of accepted light) of the camera optics the focal depth can be increased. At the same time, a large F-stop value puts greater demands on the quality and accuracy of the lens system and too high a setting of the F-stop with inadequate lenses would result in an unsharp image. This smoothing of the input would lead to a more forgiving GAS-index evaluation, as the glitter effect would be less pronounced. Hence by systematically varying the F-stop from the lowest to the highest possible setting and evaluating the GAS-index value for the same sample at each setting, an indication for a reasonable F-stop setting will be obtained. The possible F-stop values for the optics used are 2.8, 4.0, 5.6, 8.0, 11, 16, 22, and 32. This was done for a LWC sample with very swollen fibers and poor gloss quality. The sample is illustrated to the far right in Fig. 4. The results are given in Fig. 15. The GAS-index has a minimum for an F-stop value of 11, i.e., the system is most sensitive (less forgiving) for this F-stop setting. An F-stop value of 11 was therefore chosen for present study.

Study on the Setting of the Illumination

The illumination was set independently for each sample in order to use the 8-bit resolution of the CCD-camera in an effective manner. This means, however, that the data for different samples cannot be combined and no mean gloss level information could be derived.

An “illumination adjustment session” is performed before each measurement. Three different images are taken by rotating the sample holder to different positions. If only 3 ± 1 pixels are saturated (have a value of 255), for a given illumination adjustment image, this adjustment is defined as “OK”. If three consecutive illumination adjustments are “OK”, the whole illumination adjustment session is defined as well tuned and the measurements can start. The “three pass OK” criterion is introduced to reduce the risk of short-term fluctuations in the illumination level immediately after illumination adjustment. Long-term variations in the illumination level, from a stable start condition were studied and the variations were negligible.

To study the sensitivity of the illumination setting for the GAS-index evaluation, the illumination level was deliberately ill tuned and the GAS-index was evaluated and compared to an evaluation for a normal well-tuned session, using the same sample “s26”. Three measurement sessions with the illumination tuned to different levels were performed. In the first session (a) no pixel in the “illumination adjustment image” was saturated, and only one pixel was in the range [245, 254]. In the second session, (b) “normal” illumination settings were used, i.e., 3 ± 1 pixels are saturated. The results from the second session were those reported for sample “s26” (the first of the three measurements in Table II) in the “Results” section in the present work. In the third session (c) 15 pixels were saturated. The GAS-index values for these three measurement sessions were: 56.37, 56.57 and 56.39 respectively, in spite of the, in this context, large variation in illumination level. Hence, the noise introduced when the illumination is set either too low or too high only effects the results marginally.

![Figure A1. The F-stop dependence of the GAS-evaluation, measured on a surface having a pronounced surface structure.](Image 315x630 to 554x758)