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Recent Progress in the Development of INCITS W1.1, Appearance-Based Image Quality Standards for Printers

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ABSTRACT

In September 2000, INCITS W1 (the U.S. representative of ISO/IEC JTC1/SC28, the standardization committee for office equipment) was chartered to develop an appearance-based image quality standard.[1],[2] The resulting W1.1 project is based on a proposal[4] that perceived image quality can be described by a small set of broad-based attributes. There are currently five *ad hoc* teams, each working towards the development of standards for evaluation of perceptual image quality of color printers for one or more of these image quality attributes. This paper summarizes the work in progress

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of the teams addressing the attributes of Macro-Uniformity, Color Rendition, Text and Line Quality and Micro-Uniformity.

Keywords: INCITS, W1.1, print quality, streaks, banding, mottle, text quality, line quality, color rendition, color fidelity

INTRODUCTION

Image quality deals with the effectiveness of the printed page in representing information as an image perceived by human observers. Printer image quality is not an intrinsic property of the materials characteristics or the characteristics of the marking process defined by engineering specifications, but rather a consequence of how we perceive the image printed on a page. A description of image quality in terms of material characteristics or engineering specifications runs the risk of being visually irrelevant, as the visual system, and hence perceived image quality, can be insensitive to many material or engineering changes. The visual significance of a measured difference in an image quality attribute between different print samples can only be quantified through the correlation between those measurements and the corresponding change in the human perception of that attribute between those same samples. Determination of the correlation between a measure of a visual attribute and the perception of that attribute provides the fundamental calibration of that measure on a scale of visual significance (e.g. units of Just Noticeable Difference or JNDs). Through this procedure, a measure can be calibrated to become an appearance-based metric. Appearance-based metrics of different attributes, through their calibration in the same manner to a common scale of visual significance (e.g. JNDs), enable direct comparison of these attributes on this fundamental scale of visual significance. Appearance-based metrics of image quality enable truly meaningful, objective comparison of printing system characteristics.

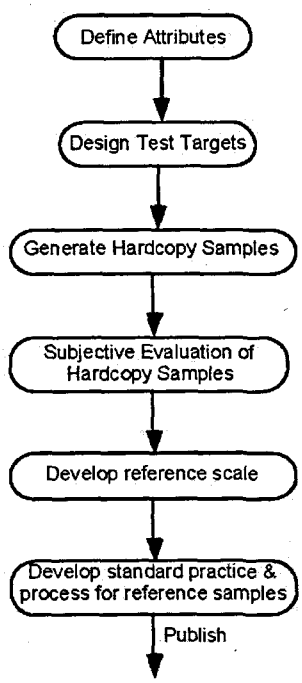

Figure 1. Psychometric evaluation development prrocedure

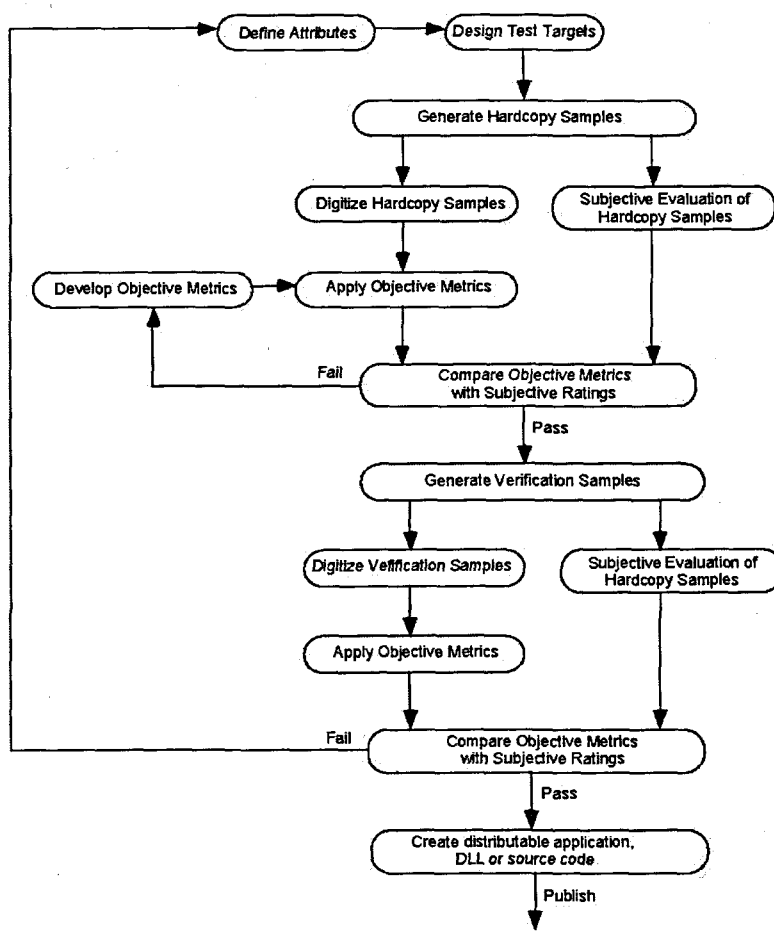

Figure 2. Instrument based metric development procedure

The W1.1 task group, reporting to the ANSI/INCITS W1 standards committee, was chartered to develop a set of appearance-based image quality standards for the evaluation of printed pages. This effort has been sub-divided into *ad hoc* teams responsible for; gloss and gloss-uniformity; macro-uniformity; micro-uniformity; colour rendition; text and line quality; sharpness or effective resolution; and adjacency.

Part of the image quality standards being developed by the INCITS W1.1 teams is a specification of the common procedure used by all of the *ad hoc* teams in developing calibrated, appearance-based evaluation methods for evaluating the image quality attributes of office printers. This common procedure consists of five steps when developing a psychometric evaluation method (Fig. 1) and of ten steps, which include the first four steps of the psychometric evaluation method, when developing a calibrated instrument-based metric that serves as a surrogate for the psychometric evaluation method (Fig. 2). By means of these development processes these standards provide a complete set of appearance-based evaluation methods for print image quality attributes with results evaluated on a common perceptual scale calibrated in terms of Just Noticeable Differences, or JNDs.

The progress being made toward establishing visually meaningful scales of macro-uniformity, colour rendition, text and line quality, and micro-uniformity are reviewed in the next four sections of this paper.

1. INCITS W1.1 MACRO-UNIFORMITY

1.1 INTRODUCTION

The INCITS W1.1 activity recognizes that printed image quality can be well described by a small set of attributes, including gloss uniformity, macro-uniformity, micro-uniformity, text and line quality, color rendition and several other attributes.[1],[2],[3],[4] The attribute of macro-uniformity is being addressed by an *ad hoc* team with the authors of the present paper as members. Macro-uniformity defects, such as streaks, bands and mottle, continue to draw much attention, as suggested by numerous recent papers that relate to assessment of such defects.[5],[6],[7],[8] The progress up to this point can be outlined as follows:

- An operational definition of the macro-uniformity attribute.
- Test patterns for assessment of macro-uniformity.
- Test patterns for characterization and calibration of scanning devices for potential instrumental measurements of macro-uniformity.
- A mathematical definition of images for a visual macro-uniformity ruler.
- A first round of tests of the feasibility of using such a ruler for assessment of macro-uniformity.

This paper will briefly review this progress, and give references to previous papers where more details can be found.

1.2 STATUS

1.2.1 Macro-uniformity attribute definition

The details and rationale for definition of the macro-uniformity attribute have been reported earlier.[9] Examples of specific print defects, which can be expected to contribute to macro-uniformity problems, include:

- Banding (1-dimensional, periodic lightness and/or chromatic variations)
- Streaks (1-dimensional, isolated lightness and/or chromatic variations).
- Mottle (2-dimensional, random lightness and/or chromatic variations).
- Gradients (could be a special case of banding where the spatial period is larger than the image size).
- Moiré patterns (1- or 2- dimensional regular patterns).

The viewing conditions are not yet precisely defined, except that the viewing distance will be approximately 40 cm, and that the samples must be evaluated in such a manner that only diffusely (non-specularly) scattered light is taken into account. The actual definition deliberately avoids reference to specific types of defects, known from various printing

technologies. The subjective evaluation must yield a single rating representative of the overall uniformity, which in most practical cases means a combination of the effect of diverse types of defects.

1.2.2 Test patterns

Several test patterns have been defined, corresponding to different base colors, all sharing the same layout as shown in fig. 1. The central uniform area is large enough to allow a mask to be placed such that only a sub-region of 160 mm by 160 mm is visible to the observer. The macro-uniformity evaluation procedure will assign a rating to a single test sample, while the more complex question of how to evaluate a printing system for macro-uniformity across the entire

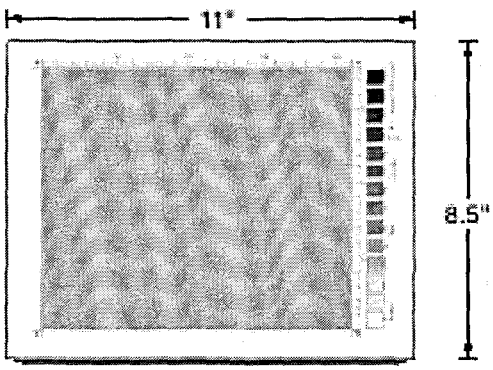

Figure 1. The macro-uniformity test pattern, reduced to approximately 20% of actual size.

color gamut, is currently not being addressed.[9]

The ultimate goal for this standards activity is to enable the development of objective measurements, most likely based on capturing a digital image of the test sample with suitable commercial flatbed scanners. A major challenge in this regard lies in, that commercial scanners are not designed to be measurements instruments. Issues related to both spatial sampling and color conversion to colorimetric quantities were discussed previously,[9] and a test pattern has been developed to serve for scanner color characterization.[10],[11] The subject of qualification of scanners for these metrology applications has become the focus of a separate standards activity, described elsewhere in this volume[15].

1.2.3 Macro-uniformity ruler

It is not clear whether methods currently exist that would readily be acceptable as objective, instrumented measurement methods for a perception-based standard, and therefore the *ad hoc* team has decided, as a first step, to develop a method based on subjective evaluations using a visual quality ruler. The quality ruler method, as described in ISO 20462-3,[12] is advantaged over many other psychophysical methods, in that quality levels that span a large range can be evaluated with relatively few resources. The *ad hoc* team will strive to develop a quality ruler that is suitable for macro-uniformity and adheres to the guidelines of ISO 20462-3 to the extent possible. Two significant steps were taken towards creation of such a ruler:

- It was decided to consider initially only the most stressful document: the nominally uniform "cover page." The pros and cons of this choice were discussed earlier[10], with the main concern being how to ensure that ratings on such a scale are indicative of perceived quality of real-world customer documents.
- To ensure monotonicity of the ruler, and to minimize bias for any specific defect types, it was decided to create ruler samples by imposing increasing levels of non-uniformity through a synthetic defect pattern, which consisted of a multitude of normally occurring defect types. The mathematical details of these ruler images were explained in detail earlier.[10],[13]

Fig. 3 illustrates a ruler sample. Only the central 160 mm by 160 mm region would be visible to the observer, while the remainder of the test pattern is useful for quality assurance in reproduction of the samples. Across the ruler, the spatial pattern of the central region varies only in contrast, and remains otherwise fixed.

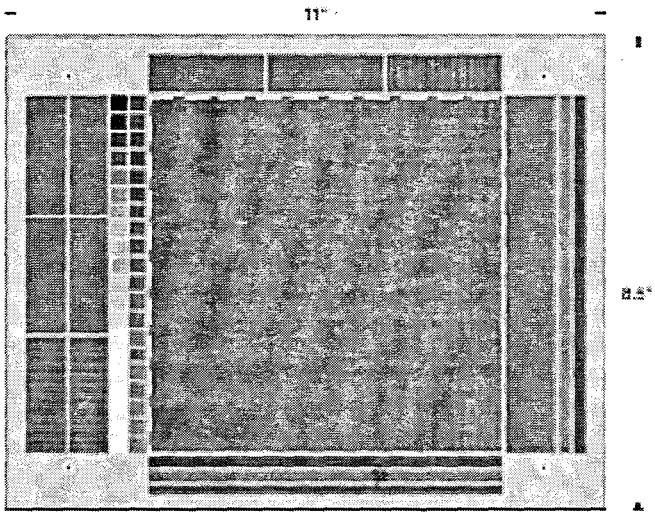

Figure 3. The test pattern used for printing of the simulated images for the ruler. Only the large central region, within the dashed white rectangle, is visible to the observer. The other elements of the test pattern are intended for control and validation of the process used to print the ruler samples.

1.2.4 Pilot survey

A pilot survey was conducted to get a sense of how the method performs on criteria such as reproducibility and precision. The ruler samples were produced with seven different overall amplitudes, with the best sample appearing nearly perfect. The samples were printed on an image-setter that ensured nearly imperceptible defects from the printing process. Several copies of the macro-uniformity ruler were produced and distributed to several different sites, along with instructions for the survey. The key direction of the survey was "*You must evaluate the test sample by matching its overall appearance of being uniform to the ruler in front of you.*" The complete survey instructions can be found elsewhere.[14] Five different and carefully selected samples were evaluated with the rulers at four different sites and a total of 88 observers. The survey was designed to probe both reproducibility from site to site, as well as precision. On both accounts the results were encouraging for the proposed methodology.[10]

1.3 CONCLUSIONS

The macro-uniformity attribute has been defined, test patterns have been developed, methods for creation of a visual quality ruler have been implemented, and a pilot survey has been completed with promising results. This paper has reviewed past progress and provided references to more details on this work. At this point further tests with the current draft ruler will be conducted using simulated test samples of typical macro-uniformity defects. This will provide further information on whether the evaluation precision is sufficient to be useful in practical situations. A number of questions identified earlier[10] will also be addressed, before proceeding to implement a final quality ruler.

2. INCITS W1.1 COLOR RENDITION

2.1 INTRODUCTION

In order to create a standard for evaluation of the color rendition of hard copy output generated from digital input, the Color Rendition *ad hoc* team is considering what it means for the rendered color to "look right," and how to measure the ability of any given printer to properly render color.

Three important parameters or sub-attributes have been identified as being necessary to describe what it means for color to be well rendered:

(1) Color quantization, defined as the ability to merge colors where needed,
(2) Color scale, defined as the ability to distinguish color where needed. This attribute is a superset of tone scale involving changes in any combination of the colorimetric parameters lightness, chroma and hue,
(3) Color fidelity, defined as a balance between a pleasing overall color appearance and colorimetric accuracy, when a reference exists;

A measurement method for evaluation of the color quantization sub-attribute and experimental results from photographic, electrophotographic and inkjet printing experiments were reported earlier[16],[17]. The results of a pilot survey to develop an evaluation methodology for the color fidelity sub-attribute were reported at the 2006 IQSP conference[3].

2.2 STATUS and PLAN

A revised study, including significant changes to the pilot survey was deemed necessary to address several issues in this pilot survey:

- Insufficient information about the tone scale exhibited by the prints in the study was available. Detailed tone scale steps will be printed with all images in revised study.
- The set of prints (printers x images) included in the pilot survey were insufficient to provide good coverage over the quality range of the color fidelity sub-attribute. In the revised study, deliberate manipulation of the digital source files using image manipulation software such as Adobe Photoshop® will be employed to provide better coverage.
- Some important color areas were inadequately represented in the images selected for the pilot survey. A broader set of images sampling "memory colors" and having stronger representation particularly in the cyan and purple regions will be used in the revised study.

The total number of different images created for this revised study, each of the selected images with all of the defined manipulations applied, will be large. In order to improve the efficiency of the psychometric scaling operation required to provide preference data for analysis, we plan to follow the Image Quality Ruler scaling procedure as outlined in ISO 20462. This procedure is expected to allow the large number of prints involved in the experiment to be evaluated sufficiently quickly to avoid imposing excessive time commitment and hardship on the the multiple observers needed to obtain good analysis statistics. However, in order to apply the Image Quality Ruler scaling procedure, two additional steps are required to create the individual Quality Rulers for the selected images. The Image Quality Ruler procedure outlined in ISO 20462 provides a straightforward and time efficient capability to either (A) evaluate the quality of an arbitrary image for the attribute present in the ISO 20462 reference prints, or (B) evaluate the quality of a set of prints representing a quality range due to some different attribute given that the reference Quality Ruler employs the same image as that used in the prints to be evaluated. The two additional steps required to create Quality Rulers for each of the selected images in the revised study are:

(1) Create sharpness variations in each of the selected images to be used in the revised study that span the wide range in image quality spanned by the ISO 20462 Reference Quality Ruler. Each of the selected images in the revised study will be filtered by the filter set used to create the ISO 20462 Quality Ruler to create bitmaps for printing with a digital silver halide printer similar to that employed for producing the ISO 20462 prints. This produces a set of images that differ from the ISO 20462 Reference Quality Scale in image content but are degraded in exactly the same attribute (sharpness) that is used for the Reference Quality Scale.

(2) The printed samples of each of the selected images, degraded in the same attribute as the ISO 20462 Reference Quality Ruler will then be scaled against the Reference Quality Ruler to create the secondary Quality Rulers, again varying in sharpness, for each of the individual images selected for use in the revised study.

This will enable establishment of quality rulers for each of the images of this new image set in accordance to the procedures defined in ISO 20462

We plan to err on the side of more images and more manipulations than may be required to provide a meaningful analysis of the color fidelity attribute. This should allow us to correct for any residual factors without having to revise the entire experiment. With this in mind, we will print the full gamut of selected images and defined manipulations, again with the high quality digital silver halide printer similar to that employed for producing the ISO 20462 prints. Both the reference prints and the evaluation prints for the revised study will be printed using the same high quality process. Comparison of the sets of printed, manipulated images produced for this experiment can then be directly compared to the Quality Ruler for a particular image to establish a quality rating for each of the manipulations of an image. Initial psychometric scaling experiments with this full gamut of prints may enable a meaningful subset of images and manipulations to be selected before the psychometric scaling experiments involve a large number of observers.

Great difficulty has been encountered in obtaining good quality images of all the required content for this study with full rights of release for use by the ISO within the budgetary constraints of this development effort. We are currently proceeding with the study using many images for which we have more limited rights of use, with the intent of identifying or creating images for eventual use by an ISO standard.

2.3 CONCLUSIONS

A method for quantifying the perceived image quality in the color rendition of a printer has been defined as comprising three basic sub-attributes: color quantization, color scale, and color fidelity. A measurement method for evaluation of the color quantization sub-attribute and experimental results from photographic, electrophotographic and inkjet printing experiments has been reported[17]. Initial experiments to develop an evaluation methodology for the color fidelity sub-attribute reported earlier[18] have led to the definition of a more comprehensive, revised study that is currently being started. Rather than produce the desired range of color rendition quality with a range of printers whose capabilities proved difficult to quantify, we have defined a set of controllable image processing methods that are easily parameterized and applied to the selected image set to provide the desired range of color rendition quality. Additional tone scale steps have been introduced for processing and printing with each image in order to allow easy quantification of the rendition tone scale characteristics. To assist in the image scaling experiments for this study, a set of blur filters designed to produce a sharpness range similar to the range employed in ISO 20462 were applied to each member of this new image set to create Quality Rulers for each of the selected images.

3. INCITS W1.1 TEXT AND LINE QUALITY

3.1 INTRODUCTION

In September 2000, INCITS W1 (the U.S. representative of ISO/IEC JTC1/SC28, the standardization committee for office equipment) was chartered to develop an appearance-based image quality standard.[1],[2] The resulting W1.1 project is based on a proposal[4] that perceived image quality can be described by a small set of broad-based attributes. There are currently five *ad hoc* teams, each working on one or more of these image quality attributes. This part summarizes the work of the Text and Line Quality *ad hoc* team, and is an update from the previous paper[18] presented at Electronic Imaging 2006.

3.2 SCOPE

The INCITS W1.1 image quality standards are applicable to gray-level and full-color printing systems. They are intended to be both appearance-based and printing technology-independent. "Appearance-based" means that the evaluation is done by, or simulates, normal visual inspection without magnification, and any physical measurements need to be scaled to match human perception. "Printing technology-independent" means that the evaluation is applicable

to the output of any of the major printing technologies, as diverse as, for example, electrophotography, thermal inkjet, and silver-halide. These standards address the performance of the entire printing system, not just the print engine.

For INCITS W1.1 Text and Line Quality, only positive text/lines on white background are considered. The quality of overlays on a colored background, and of negative text/lines, is considered to be a combined function of Text or Line Quality and the Adjacency attribute.

3.3 STATUS

Aspects of a draft digital test pattern for Text Quality evaluation were proposed in our last report.[18] The following aspects have been covered since then:

3.3.1 Test pattern

A 2-page draft test pattern was constructed in PDF format, including embedded fonts. This test pattern contains text in a range of sizes in serif and san-serif fonts, as well as "analytical fonts" (graphical shapes designed for instrumental measurement).

3.3.2 Print samples

The test pattern was printed at three different sites (HP-Spain, Oce, and Xerox) on a variety of printers. These printers covered a range of marking technologies, including electrophotography, and thermal and solid inkjet, using a variety of print modes and a range of media types, including coated, plain and specialty papers.

3.3.3 Print samples evaluation

The print samples described in 3.2 were distributed to all team members for evaluation. The purpose of this evaluation was to identify test pattern elements that are useful in distinguishing between the text quality of the various print samples, not (at this point) to evaluate the printers themselves.

Team members agreed that the print samples covered an adequate range of text quality, from very good to quite poor. One of the samples (printed on an imagesetter) was deemed to be of sufficient quality to serve as a reference. Issues were found with the composition of a few of the test elements.

The next stage will be the weeding out of test pattern elements that are found to not add much value, with a goal of producing a single (A4/letter) page test chart if possible. It is intended to do this by a psychophysical experiment in which observers will be asked to rank the print samples for Text Quality, and to identify the test pattern elements used in their evaluation.

4. INCITS W1.1 MICRO-UNIFORMITY

4.1 INTRODUCTION

Micro-uniformity has been loosely defined as characterizing any non-uniformity that is visible in "busy" images that contain only small regions of nominally uniform color. By a small region we mean a region of less than 25mm on a side. Non-uniformities within this region, to qualify as micro-uniformity, would have a nominal extent or wavelength of less than 6mm[19].

4.2 STATUS

The micro-uniformity ad hoc team has identified a number of sub-attributes that contribute to the perception of micro-uniformity. The visual definitions of these sub-attributes are:

(1) Streaks – one-dimensional random line-like structure;
(2) Bands – one-dimensional (uniformly) periodic line-like structures;
(3) Voids – pinhole-like defects;
(4) Textures – Moiré, small-scale mottle, half-tone structure and patterns with correlated phase; and
(5) Graininess – two-dimensional random or quasi-random fluctuations in lightness, hue or chroma.

JPEG image examples illustrating these sub-attributes have been made available on the W1.1 web page: http://www.incits.org/tc_home/w11/incits_w11.htm The definitions of the micro-uniformity attributes and the viewing conditions under which they are to be evaluated have been coordinated with the macro-uniformity ad hoc team to ensure continuous coverage in spatial frequency. The test targets developed for the evaluation of macro-uniformity were deemed appropriate for use as printing targets to obtain micro-uniformity samples. Samples of these test targets printed at reflection levels of L* = 40, 60, or 80 and cut to an area 25mm square, would be mounted on a 100mm square substrate for viewing in the evaluation process.

An initial set of neutral hardcopy test samples from inkjet, electrophotographic, digital silver halide, and thermal dye/wax transfer printers have been generated. For each printer utilized, both a "nominal" and a "highest quality" setup were employed in order to obtain samples representative of "nominal" use and "highest quality" use for each technology[20].

Flatbed scanners available several years ago were evaluated as problematic for use in the evaluation of micro-uniformity due to difficulties in obtaining repeatability, accuracy, and uniformity of scan files. Additional work in calibration and compensation of flatbed scanners was deemed necessary before they could be employed as measurement devices in the evaluation of micro-uniformity.

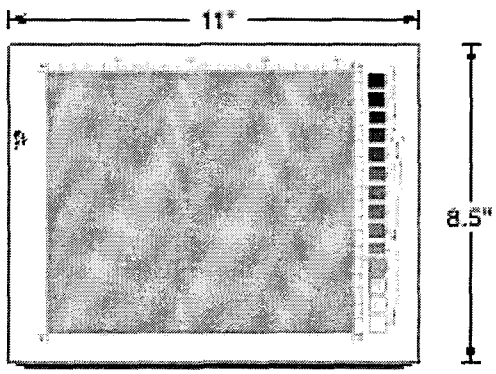

Figure 1. The test pattern used to obtain micro-uniformity samples, at approximately 20% of actual size.

4.3 PLANS

The ad hoc micro-uniformity team has been recently re-started with an updated membership and is working towards the solution of several technical challenges. First among these challenges is evaluation of the Image Quality Ruler scaling procedure as a practical means of evaluating perceptual micro-uniformity attributes. The work required to address this challenge includes:

(1) Identification of methods for controllable, analytic creation of micro-uniformity artifacts. This capability would be employed to process images to produce a set of bitmaps for evaluation.
(2) Printing the images with controlled levels of artifacts on a variety of printers employing a range of technologies.
(3) Creating Quality Rulers from these printed images using the procedures outlined in ISO 20462.
(4) Investigating the effect of printing technology on the perception of micro-uniformity.
(5) Evaluating the correlation between Quality Ruler results of prints using the available printing technologies.
(6) Enhancing the controlled artifact creation methods to avoid technology-specific interactions.
(7) Clarify the differentiation between micro-uniformity and macro-uniformity.
(8) Incorporate lightness and color effects into the Quality Ruler evaluation.
(9) Evaluating the correlation between Quality Ruler results and end-user experience.

Additional work to calibrate and compensate for limitations of reflection scanners when used as analytic measurement devices will be necessary before an instrumental surrogate for the psychometric scaling methods embodied in the ISO 20462 Quality Ruler procedure can be considered[7].

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