IMAGE QUALITY QUANTIFICATION IN CAMERA PHONE APPLICATIONS

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ABSTRACT

The International Imaging Industry Association (I3A) launched the Camera Phone Image Quality (CPIQ) Initiative in June 2006. The goal of this initiative was to develop an image quality testing and performance rating system that could enable manufacturers and carriers to make comparisons between capture devices, and to communicate a substantiated product quality rating to consumers. The participating companies include wireless network operators, wireless device vendors, camera module manufacturers, camera component manufacturers, and image services providers. This paper will review the image quality issues addressed in the I3A CPIQ effort, the work plan, and the current status of the CPIQ initiative.

Index Terms— image quality, camera phone, I3A, CPIQ, photography

1. CHALLENGES WITH CAMERA PHONES

A camera phone is a mobile phone equipped with an image sensing device and associated post-processing electronics. Most camera phones have one sensor head, although a small percentage of them have two sensors, with the second being used for special purposes such as video conferencing. Today eighty percent of mobile phones on the market have image acquisition capability, and this number is projected to increase over time. When camera phones were first introduced to the market, the sensor resolution was low (VGA format, i.e. a 640x480 pixel array). For example, in 2004 seventy nine percent of the camera phones had VGA format sensors. Since the early stages of adoption, the improvement in sensor technology has been dramatic. Today the most popular camera phones have a 2.0 MP camera, and camera phones with 3.0 MP or higher pixel count have been introduced in the consumer market. In addition to the improvement in pixel count, the functionality of the camera phones is also becoming more sophisticated, and they now include features similar to digital still cameras (auto white balance, auto exposure, and auto zoom). In principle, camera phones have all the capabilities required to replace the digital still cameras (DSCs), and these devices can be used extensively to record meaningful moments in life.

To the surprise of many, this replacement has not happened at a mass scale. Contrary to initial projections, consumers are not sharing a large volume of pictures between wireless devices, and they are not uploading all captured images to internet sites for storage. Furthermore, very few camera phone images are actually being printed. The usage is up, but the pace has been gradual and certainly not consistent with the initial expectations of the wireless carriers and photo service providers. In fact, ninety five percent of images captured using camera phones today stay in the camera phones.

One of the difficult issues with camera phones is that of image quality. With new camera phones appearing with resolutions of 2.0 MP, 3.0 MP, even 5.0 MP, consumers assume these devices can produce images equal to that of digital still cameras. In the realm of DSCs, a 2.0 MP camera would produce good images on a 4x6 print, and a higher pixel count is frequently linked to better image quality on larger print sizes. However, for camera phone products, this linkage seems to be broken, with some higher pixel count sensors showing reduced image quality relative to lower resolution products.

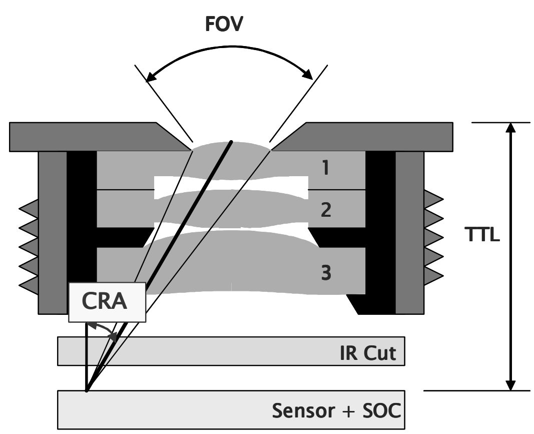

Figure 1. Schematic view of a camera module on camera phones. CRA = chief ray angle. TTL = total track length. SOC = system-on-chip. IR cut = IR cut filter. FOV = field of view. Numbers 1,2,3 are elements of the optical lens system.

The differences between DSCs and camera phones are many, including size, cost and usage patterns. Figure 1 shows a schematic view of a typical camera module in camera phones. This camera module needs to squeeze into a multi-purpose, portable device that is mainly used in making phone calls. As a result, a camera module is much smaller in size compared to a DSC. For example, a camera module size can be 10 x 10 x 6 mm, whereas a pocket size digital still camera can be 96 x 60 x 25 mm. Because the size of a camera module is small, the image sensor is small, the total track length (TTL) of the camera module is short, and the number of digital signal processing (DSP) chips that can be used in the camera module is limited. All three factors can have significant impact on image quality. For example, a camera phone CMOS sensor may have a pixel size of 1.75 μm while the CMOS sensor on a D-SLR camera may have a pixel size of 7.2 μm. A smaller pixel size in general means less sensitivity to light, and higher noise level. A short total track length dictates that the focal length of a camera module lens is small (~6 mm). As a result, the chief ray angle for camera phones can be as high as 27 degrees while in a DSC it is typically less than 12 degrees. Numerous problems can arise from the high chief ray angles, most notable being lens shading and color crosstalk. The limitation on the number of DSP chips will reduce the processing power of the image pipeline, and hence establishes an upper limit on image quality enhancement that can be achieved.

The second primary difference between a camera phone and a DSC is that of cost. The wireless service vendors today offer free mobile phones to obtain multi-year service commitments from consumers. From the perspective of the vendor, it does not make much sense to put an expensive camera module in a give-away phone, and therefore, the camera modules on camera phones must be extremely low in cost. This low cost strategy affects the quality of components such as the selection of optical lenses, with obvious impacts on image quality.

The third difference between the camera phone and a DSC is in their pattern of usage. Photography using a DSC typically occurs in a planned fashion, to capture events such as birthdays or weddings. On the contrary, a camera phone usually stays with the consumer most of the time, making it possible to take spontaneous pictures. Those pictures are frequently taken in low light conditions such as inside a pub, and most likely people are the main subjects in the pictures. A camera phone with small pixels may perform comparably to a DSC in bright light conditions, but may not do so under low light conditions. With the distribution of captured images skewed towards indoor and low light conditions, the perception can be that camera phones produce inferior image quality compared to a DSC. Furthermore, consumers generally use only one hand to capture images using camera phones, resulting in significant motion blur artifacts.

2. THE I3A CPIQ INIATIVE

Because of these significant issues, the need to improve image quality for camera phones has been recognized across the industry. What is the best approach to improve image quality for camera phones? Can one company achieve this goal alone through proprietary work, and hence gain a competitive advantage in the industry? Is a concerted effort from multiple companies needed to achieve this goal? The answer to these questions can be found in the very nature of this camera phone industry.

The camera phone eco-system is a hierarchical structure. At the bottom are the semiconductor companies that manufacture image sensor core chips and digital signal processing chips. The lens companies make lenses, and the camera module companies combine these module lenses with imaging sensors into packaged camera modules. The handset manufacturers then integrate camera modules into their camera phones. The wireless carriers are the ultimate vendor for the camera phone handsets, providing wireless services and creating/maintaining a relationship with the end users. There are also photofinishing services and online photo storing and sharing services that serve the camera phone end users peripherally. Because image quality is a combined effort from all layers of this camera phone eco-system, it is important to share a common set of image quality specifications between the players at all levels. Therefore, there is an incentive for all participants in the camera phone industry to work together to improve image quality.

In June 2006, the International Imaging Industry Association (I3A) launched the Camera Phone Image Quality (CPIQ) initiative. The CPIQ initiative is a multi-phase project that identifies key camera phone attributes that affect image quality, and proposes objective and subjective test methods to measure these attributes – ultimately resulting in a consumer-oriented rating system that will allow the public to choose the best camera phone given their particular needs. According to the plan, Phase 1 will try to understand the fundamental attributes that contribute to camera phone image quality as well as identify existing standards and other useful information relating to these attributes. Phase 2 will further define objective and subjective test methods for measuring camera phone image quality attributes, and provide specific tools and validated test methods to facilitate standard-based communication and comparison among carriers, handset manufacturers and component vendors, regarding camera phone image quality. From these test results, Phase 3 will develop and validate a model consumer-oriented rating system for camera phones. Additional phases might be undertaken in the future to address the changing nature of the customer experience using camera phones to capture and make use of images in a variety of applications.

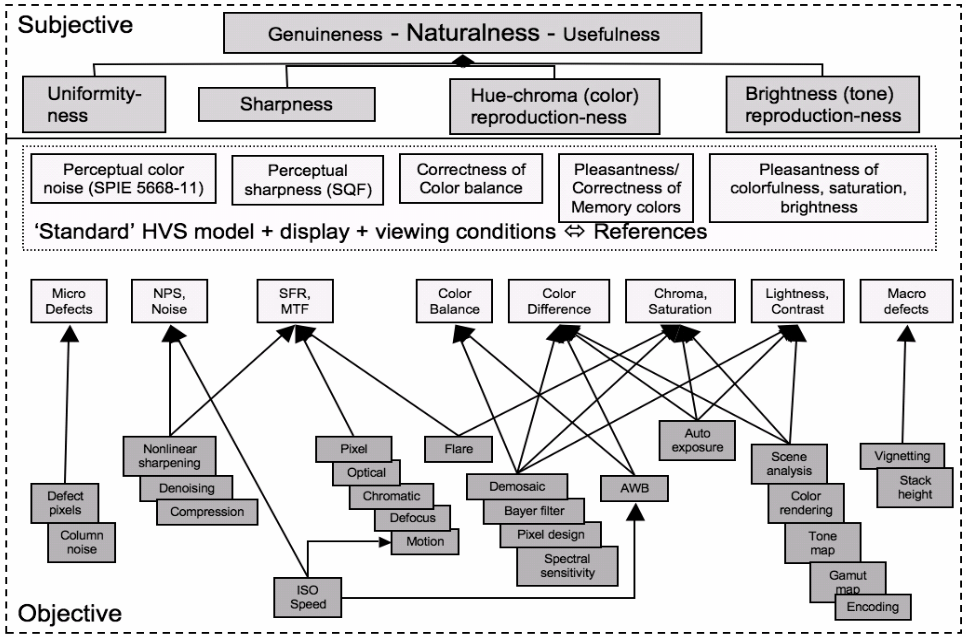

Figure 2. Hierarchy of image measurements.

The CPIQ Phase 1 effort covered the period from June 2006 to May 2007. Sixteen companies around the world participated in the CPIQ Phase 1 effort. These were: Advanced Micro Devices (AMD), DxO Labs, Eastman Kodak Company, Flextronics, Foveon, HP, Micron Technology, Motorola, Nokia, Nethra Imaging, NVDIA, Palm, Sensata Technologies, Sprint, Sony Ericsson Mobile Communications, and Texas Instruments. During the period, the collaboration among companies was achieved by four quarterly face-to-face meetings, and numerous bi-weekly teleconferences.

At the beginning of the Phase 1 effort different options for evaluating image quality were discussed. As mentioned in the camera phone eco-system description, different companies participate at different levels of the camera phone eco-system. For the participating companies it is very important to understand the pass/fail criterion of their own customers, and this pass/fail criterion can exist at different stages in the imaging path. For example, the sensor companies may receive technical specifications from their customers on the number of pixel defects allowed after defect correction. The camera module companies may get specifications from their customers on tolerances for brightness falloff in the final images. While it is very important to consider serving the interests of individual companies, it should always be remembered that the end users are the ultimate judges of the camera phone image quality.

What does image quality mean for the end users? Fundamentally for consumers, cameras are used to preserve memorable moments in life. Desired are images without artifacts such as color noise, blurred edges, banding, etc. The preference is for the sky to be blue, the grass to be green, and people look healthy on the photos. Figure 2 was developed by CPIQ to demonstrate the hierarchy of image measurements [1], from objective measures at the bottom to subjective evaluation at the top, and various layers of image quality measurements in between. An important decision the CPIQ initiative group made in Phase 1 was to measure image quality using the rendered images, i.e., the images that the end users would see. All other engineering measurements and manufacturing tolerances which reside in the intermediate stages will be derived later from the measurements of the rendered images.

Another major activity completed in CPIQ Phase 1 was a survey of the existing solutions in the measurement of image quality. There have been numerous ISO standards developed for electronic still-picture cameras [2]. ISO 9358 defines a test method for measuring veiling glare of image forming systems. ISO 12232 defines a test method for exposure and ISO speed. ISO 12233 defines a test method for resolution measurements. ISO 14524 defines a test method for measuring opto-electronic conversion functions (OECFs). ISO 15739 defines a test method for noise measurements. These industrial standards have helped the imaging industry in controlling factors related to image quality by providing robust test methods in laboratory and manufacturing environments.

One participant of the CPIQ Phase 1 Investigation Group, Nokia, sponsored a study at Helsinki University of Technology (HUT) in Finland to perform measurements using the following measurements recommended by CPIQ

Phase 1 [3]: resolution, speed, auto exposure, uniformity, color uniformity, camera flare, and auto white balance. Seven camera phones were tested in the study, including models ranging from VGA, 2.0 MP, 3.0 MP, up to 5.0 MP formats. A 7.0 MP DSC was also included in the test. For most tests different lighting conditions were used, and the variation was either in intensity or in color temperature. The study showed that some tests were difficult to perform in the camera phone context. For example, the ISO speed could not be calculated if there was no EXIF data on the captured images to record exposure time and f-number. The study reported that going through all tests was a lengthy process. On average it took 8.9 hours to perform all tests on one camera.

It was clear from the discussion around the ISO standards and the HUT study that the ISO standards in digital photography established a good starting point in developing objective measurements for image quality for the camera phone industry. However, the implementation process of those standards in manufacturing environment needs to be improved. More importantly, the existing ISO standards do not attempt to provide a link between objective measurements and subjective evaluation of image quality, and hence are insufficient for the scope of work CPIQ proposed.

The CPIQ Phase 2 effort started in September 2007. The goal of Phase 2 was to develop objective and subjective test methods for measuring camera phone image quality attributes. A list of objective metrics important to the participating companies was generated, including metrics for color uniformity, sharpness, noise, texture detail, chromatic aberration and lens distortion, and color and tone rendition.

At the time of the paper submission the group has been working on an objective metric for color uniformity that correlates with subjective evaluation. This metric becomes important to the camera phone industry because the unique design in camera phones makes this artifact clearly visible to the viewers. Color non-uniformity can occur due to factors in several levels. At the sensor level, there can be manufacturing variations in micro-lens shift and alignment tolerances in CFA and micro-lens masks. At the module level, the factors can be lens falloff and chromatic aberration, IR-cut filter variations and vignetting, module lens offset and tilt, die placement and bonding to packaging, crosstalk, and use of auto focus/zoom lenses. In the image pipeline, lens shading correction algorithms and calibration, color saturation control, and tonal correction will also affect the perceived color non-uniformity on the rendered images. The use cases for this color uniformity metric will be 4x6 inkjet prints and viewing on a PC monitor. The test images will come from both simulations and real imagery captured by camera phones. Both objective and subjective evaluation methods will be explored, and the deliverables of this work will be a set of test targets, test procedures, and algorithms to obtain objectives metrics for color uniformity.

3. WHAT LIES IN THE FUTURE?

Many new features will be implemented in the camera phones in the near future. One such feature will be the extended depth-of-field (EDOF), a sensor/software system solution that enables a camera module equipped with fixed-focus lens optics to deliver sharp images from the foreground through the background. Face recognition technology has been implemented in digital still cameras, and this can facilitate the settings in white balance, exposure level, and auto focusing - this technology will eventually appear in camera phones as well. Furthermore, image stabilization technologies available in more expensive digital still cameras will find their way into camera phones sooner or later.

New camera features call for new tests. Currently, the majority of the test charts are 2-dimentional charts. A test of the EDOF technology would call for 3-dimensional test scenes. A test of face detection-based auto exposure algorithm would need the test scenes to be image-like and include faces. A test of the image stabilization technology will require subjecting the camera to motion similar to real capture conditions. It is hoped that the CPIQ effort can be extended beyond today’s technology and used to develop test methods for tomorrow’s technology.

Many of the materials used in this paper are from the I3A document repository by permission from I3A. The Camera Phone Image Quality (CPIQ) Initiative is a technical project of the International Imaging Industry Association (I3A). For more information on CPIQ and I3A, please visit http://www.i3a.org.

4. REFERENCES

[1] CPIQ Initiative Group, “Camera Phone Image quality – Phase 1 – Fundamentals and review of considered test methods,” I3A CPIQ Phase 1 document repository, May 2007.

[2] ISO 9358, “Optics and optical instruments – Veiling glare of image forming systems – Definitions and methods of measurement”, 1994. ISO 12232, “Photography – Digital still cameras – Determination of exposure index, ISO speed ratings, standard output sensitivity and recommended exposure index”, 2006. ISO 12233, “Photography - Electronic still picture cameras - Resolution and spatial frequency response measurements”, 2000. ISO 14524, “Photography - Electronic still picture cameras- Methods for measuring opto-electronic conversion functions (OECFs)”, 1999. ISO 15739: “Photography - Electronic still picture imaging - Noise measurements”, 2003.

[3] P. Valve, “HUT CPIQ Phase 1 feedback v0.1”, I3A CPIQ Phase 1 document repository, September 2007.