Mobile Imaging Sensor Assessment – a Customer's Point of View

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Abstract

This paper considers the imager selection process and criteria for mobile imaging. The main challenges arise from having good camera functionality in a module with strict size targets. The imager selection is a continuous process from future technology evaluation to final product benchmarking.

1. Introduction

The portion of the mobile phones having a camera has been increasing rapidly, and the growing mobile imaging market is driving many of the imager suppliers.

The primary advantage of a camera phone over a traditional digital still camera is that the end user virtually always carries it and it is ready for use. This puts a big challenge to the size and reliability of the device. Furthermore, increasingly complicated functions are included in the cameras, and the resolution of the imagers is rising. Because of the strict size requirements, a higher resolution leads to smaller pixels, e.g., [Oda05].

The cameras used in the mobile phones are not a single consistent group of devices, but they range from small fixed focus devices to complicated auto-focus or even zoom devices. The sensor implementation technology also ranges in various types of CCD and CMOS type devices, and there are a large number of suppliers.

Selecting the most suitable imager for a given product is one of the keys to successful cameras. The challenging mobile phone environment and the diversity of options makes the imager selection a demanding task, and it is considered in this paper.

The next section considers the imager tracking and selection process. Section 3 clarifies the selection criteria and challenges in mobile imaging, and Section 4 concludes the paper.

2. Tracking and selection process

Due to the tight product development cycle, a preliminary selection of the imager may have to be made before there are samples available. A key solution to this problem is open and continuous communication and mutual understanding with the suppliers. The imager performance and roadmap should be openly communicated.

The first step of the selection process is tracking the new technologies that could appear in products in a couple of years.

The next step is the roadmap exploration, which happens using an imager roadmap questionnaire. The supplier is asked to fill a form, which describes the imager roadmap and their expected parameters. The form includes technology, image quality, and system level parameters. The main parameters are shown in Table 1 (last page of this paper). The preliminary candidates for the new products are selected using roadmap data and the earlier results and experiences with the supplier. The results of the survey also provide the understanding on what is going to happen in the market.

For the available chips and camera modules, a sequence of test images is requested from the supplier. The guideline for taking the test images is summarized in Fig. 1. The test images are stored to an internal database, and they are analyzed visually and using analysis tools. The results show how, e.g. the noise and color performance change in different lightning conditions. For visual analysis, thumbnails images are generated by fist applying the auto-contrast (the histogram is stretched from 0 to max) and then generating the resized image by subsampling the image. This reduces the relative brightness differences in the images and enables observing the noise of the original image in the small thumbnail.

Test images of GretagMacbeth color chart are taken in 1, 5, 10, 30, 60, 100, 300, and 1000-lux lightning conditions. 3200 K or halogen light source is used. The sensor operates at 15 fps frame rate. If this is not possible, the maximum frame rate is used but the maximum exposure time is still limited to 1/15 s. f/2.8 lens is used. Both raw and color processed images are taken. No improvements in computer are allowed. However, if the final camera processor cannot be used, the color processing can be done in a computer environment, but the processing must be similar to that of the camera processor.

Fig. 1. Guideline for taking test images.

The process continues with a detailed evaluation of the most suitable imagers, when the physical chips become available. Here, the supplier is asked to provide a full characterization report of the imager. The report must include, e.g., the measured performance parameters, photon transfer curves, dark current distribution, and color filter responses. The photon transfer curves must showing both temporal and spatial noise components and they are to be provided with minimum and maximum gain. The SMIA characterization is also requested for SMIA sensors [Nok04c].

The samples are also requested for internal evaluation when they are available. Here, the data supplier has provided is verified and some internal test, such as a dynamic range test demonstrated in Fig. 2, are run to the imager. The actual integration to the product can also start at this phase.

As the final step of the process, the actual products are benchmarked and compared to competitors' products – both camera phones and digital still cameras. This final stage includes a test using a group of people to evaluate test images. This way, a parameter describing the subjective image quality is formulated. The final products test use all the features and capabilities the products have – they do not just concentrate on the imager performance, e.g., if a product has a flash it is used in the test. The results give feedback to the decisions made in the design phase.

3. Selection criteria

The mobile cameras can be roughly divided into two categories: mainstream and high-end. The

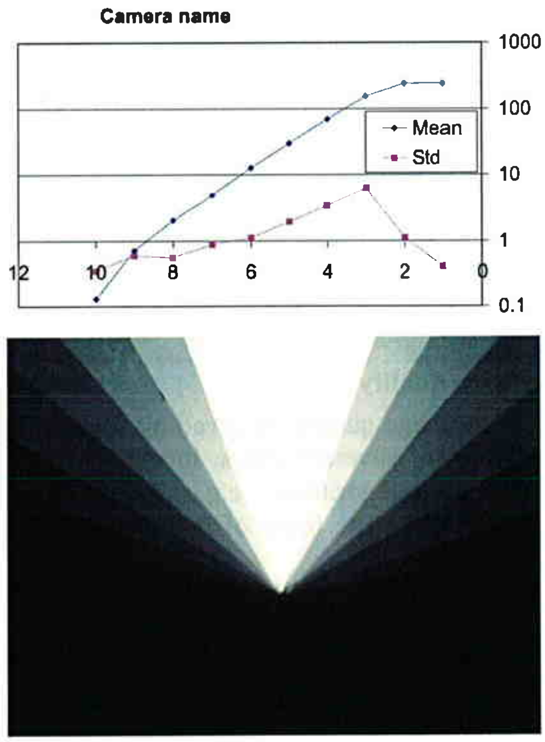

Fig. 2. Example of the dynamic range test.

basic challenges and criteria are the same in both cases, but the importance of each parameter is different.

For imaging oriented high-end product, the image quality is the first priority, whereas the production capacity and price may be more important for high-volume mainstream products. Naturally, the target is always to have both good image quality and competitive price.

3.1 Resolution and video performance

The still image resolution and video performance – resolution and frame rate – are the typical imager-related parameters specified for cameras in marketing brochures.

The mobile cameras are facing a race in the number of pixels in the sensors. To be able to meet the strict size targets, smaller and smaller pixels are used, which is the source of most imager related challenges currently. Small pixels also set heavy requirements to the optics, and diffraction sets the ultimate limit for the optics resolution.

The video resolution is also becoming larger as the devices used to watch video improve and the capacity of the storage media increases. On the other hand, the typical video frame rates used currently are 15 and 30 fps, but even 60 fps can be used to diminish the rolling shutter distortion of a CMOS sensor.

To meet the high resolution and frame rate requirement, binning or digital scaler, e.g., as in SMIA profile 2, may need to be implemented in the sensor. If scaling is supported, windowing or cropping the image should also be included to enable high-quality digital zoom.

3.2 Image quality

The final image quality observed by the end user is the sum of several factors: imager and optics performance, algorithms, e.g., [Nok04d], and display quality. The focus of this paper is in the imager selection.

When assessing the image quality, the problems in noise level and color reproduction are usually the most visible to the end user. The noise level in low light conditions is a special problem is mobile imaging due to lack of powerful flashguns (which would be too large) and due to small pixels. The noise level in bright areas is also becoming a more challenging problem due to the reduced full well capacity of small pixels.

Several parameters of the questionnaire (Table 1) focus on the low light performance: readout noise, sensitivity, quantum efficiency and dark signal non-uniformity. On the other hand, the full well capacity and PRNU (photo-response non-uniformity) affect the noise level in bright areas of an image.

The issues in color performance in mobile imaging often arise from optimizing some other parameter, such as the noise level, at the expense of the color performance. The color performance is evaluated using signal non-linearity, color filter responses, and naturally the test images.

The lack of dynamic range is especially visible in outdoor photography. Dynamic range is also a challenge related to small pixels. It is difficult to keep ratio between the full well capacity and noise level when the pixel size becomes smaller.

Vignetting is a big challenge in mobile imaging. The small optics height leads to large chief ray angle and vignetting of the sensor. The problem becomes more visible when moving optics are used. In this case, the chief ray angle is not constant and the optimizing the microlens shift becomes more difficult. The pixel stack height and maximum sensor acceptance angle are the parameters that are used to measure vignetting for given optics.

The pixel crosstalk is yet another parameter that becomes more important as the pixel size becomes smaller. Pixel crosstalk may cause image blur special artifact patterns. Crosstalk is enquired in the sensor questionnaire. More detailed information, including the distribution between electrical, optical and color filter crosstalk, must be included in the full sensor characterization report.

Finally, special technology limitations, such as such as smear or rolling shutter distortion, are included in the image quality evaluation.

There are no strict requirements for the values of each parameter. Due to the subjective nature of the image quality, specifying limits for each parameter is impossible.

2.3 System level

A mobile phone is a difficult environment regarding the EMC. Therefore, a serial bus, such as CCP2 [Nok04b], is used whenever possible in all product categories. Another advantage of the serial bus is that is saves IO pins from the camera module.

Image processing is done outside the sensor chip in both high-end and mainstream products. Therefore, the sensor needs to have a raw output. If the imager has a scaler, as discussed in Section 2.1, it has to be a raw image scaler. Having the imager and camera processor as separate chips enables selecting the best options for both parts.

2.3 Schedule, production capacity, and price

When considering which imagers should be candidates for a given product, the schedule is the parameter that is considered first. A good visibility to the supplier imager roadmap also helps product planning and scheduling.

The production volume of a mainstream product is usually much higher than a high-end product. Due to the large production volumes of the mainstream products, at least two sources for each imager are required. The true enabler of this is the SMIA standard [Nok04a], and only fully compatible SMIA devices are considered for mainstream products.

Because of the different priorities in the high-end products, the SMIA compatibility is not required. However, even though the selection is more flexible regarding the functionality, the no compromises can be mad in the image quality of the high-end products.

Mobile market is very price sensitive, especially in the mainstream class. However, also the high-end sensors need to have competitive price.

4. Conclusions

Sensor selection process and criteria for mobile imaging have been considered in this paper. Most challenges arise from the requirement of small camera size while still having good camera functionality. Furthermore, a high production capacity and competitive price are required, especially in the mainstream products. The imager selection is a continuous, several step process including future technology evaluation, roadmap exploration, initial performance study, full characterization report, internal evaluation, product integration, and final product benchmarking.

References

[Nok04a] Nokia and ST, *SMIA 1.0 Introduction and overview,* 2004.

[Nok04b] Nokia and ST, *SMIA 1.0 Part 2: CCP2 Specification,* 2004.

[Nok04c] Nokia and ST, *SMIA 1.0 Part 5: Camera Characterization Specification,* 2004.

[Nok04d] Nokia, Camera Imaging Chain, 2004, http://www.nokia.com/nokia/0,8764,54238,00.html.

[Oda05] Masahiro Oda, Takayuki Kaida, Shinichiro Izawa, Takahiko Ogo, Kazutaka Itsumi, Yoshihiro Okada, Kazuhiro Sasada, "A 1/4.5in 3.1M Pixel FT-CCD with 1.56μm Pixel Size for Mobile Applications", in *Digest International Solid-State Circuits Conference,* San Francisco, CA, USA, February 2005, pp. 346 – 347.

Table 1. Part of the sensor parameter questionnaire.

Parameter	***Comment***
Sensor technology	CMOS/4T, CMOS/3T, IT-CCD, FT-CCD, ...
Dimensions	Optical format, e.g., 1/2"
	Pixel array [mm x mm]
	Chip [mm x mm]
	Packaged [mm x mm]
Pixel size	[um x um]
Resolution	Visible pixels [X x Y]
Process design rule	[um]
Pixel stack height	From the bottom of the microlens to the top of silicon [um]
Number of transistors per pixel	[#]
Color filter type	E.g., RGB bayer
Fill factor	Geometrical [%], effective [%]
Full well capacity	Full range, linear range, ADC range [e]
Read-out noise	Analog, full res @ 15 fps.l
Quantum efficiency	450 nm / 550 nm / 650 nm [%]
Responsitivity	@ 550 nm [e / (lux * s)]
Dark current	Per pixel @ 60 C [e]
Dark current doubling temperature	Temperature rise for doubling dark current [C]
PNRU	[%]
DSNU	[%]
SNR max	Including temporal and spatial noise component [dB]
Pixel electrical crosstalk	@550 nm adjacent pixels [%], @550 nm diagonal pixels [%]
Conversion gain	[uV/e]
Maximum ray acceptance angle	@ center and @ 100% of image height, 50 % signal attenuation or define criteria.
Non-linearity	Max. deviation of the responsitivity at the ADC range [%]
Accuracy of parameters	Measured / simulated / estimated
SMIA	Yes / no, if yes indicate also the profile and suggested module package
Power supplies	[V]
Power consumption	Sensor and ADC, 30 fps VGA [mW]
ADC resolution	[bits]
Maximum frame rate at full resolution	[fps]
Maximum output data rate	[Mbits/s]
Scan mode	Progressive / interlaced
Shutter	Rolling / global