Elaborazioni di Immagini per Dispositivi Mobile

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Advanced System Technology
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Agenda

- Introduction
  - Mobile camera Devices
    - Pre-processing: Auto Focus, Auto Exposure
    - Color interpolation
    - Color interpolation
    - Noise management
    - Noise estimation
    - Croma management
    - Codecs still/video
    - Codecs still/video
    - Applications
    - Red eye
INTRODUCTION

Who I am

- 1998: University degree in Electronic Engineering
- 1999: Joined ST
- ST Mission: “To offer strategic independence to our partners worldwide, as a profitable and viable broad range semiconductor supplier”
- AST Mission: “To provide the advanced system technology able to establish ST as the leading company in the system on a chip market”
- Imaging Team: founded 1999, currently 13 employs + 2 collaborators
Who You are

Wide range of applications aimed to cover all the steps of a image reconstruction pipeline, from the sensor to the final encoded output

- Defect pixels removal / Noise Reduction
- Anti Vignetting
- Auto Focus
- Geometric Distortion Correction
- Depth of Field Extension
- Auto White Balancing
- Colour Interpolation and false colour removal
- Automatic Contrast Enhancement
- Expected Colour Rendition
- Digital Image Stabilisation (Video and Still)
- HDR & Dynamic Range Extension
- Adaptive Zooming
- Tone Mapping
- Panoramic view
- Fixed length visual lossless Bayer and colour compression
- JPEG rate control
- DCT artefact removal
Miniature Camera Required know-how

Optics

Mechanics

DSP/Algorithms

Electronics

Vision

We want our content available whenever... ...and wherever we are.

With the Highest QUALITY
This translates to:

- QUALITY

- USABILITY:
  - Enhanced User Interaction
  - Sharing
  - Archiving

STV0986 + VB6850 3MP

Eye is magic...
Eye is magic…

MOBILE CAMERA DEVICES: OVERVIEW
Camera Phones now account for 2/3 of the WW Imaging Market*

- Market now dominated by camera phones
- Camcorder segment declining
- Automotive segment becoming perceptible
- Other new markets yet to emerge

Source: STMicr.

* excluding CCD sensors

WW Camera Market

Worldwide Camera Sales: 1999 - 2009

Source: The Camera Imaging Market
CMOS Image Sensor: A disruptive technology

- **Sustaining Technologies**: "Technologies improving the performances of established products".
- **Disruptive Technologies**: "Technologies that underperform established products in mainstream market. But they have other features [...] cheaper, simpler, smaller, and, frequently, more convenient to use". 

Source: C.M. Christensen Innovators Dilemma HBS Press

The challenge for embedded computing architecture

- **Algorithmic/Application Complexity**
- **Processor Performance (Moore’s Law)**
- **Battery Capacity**

Source: Advanced System Technology 11 March 2008
STMicroelectronics Imaging Products

1. CMOS Sensors

2. ISP

3. Micro-modules

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**VGA**
- 50 mm²
- 14 mm²
- 8 mm²
- 4 mm²

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**ADVANCED SYSTEM TECHNOLOGY**

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**VGA Module: smaller and smaller**

VGA module: size evolution

- VGA SmOP I: 0.95 cc
- VGA SmOP 1.5: 0.53 cc
- VGA SmOP II-N: 0.5 cc
- Monochip: 0.22 cc

Sensor + YD + caps

**System: The Yellow Duck**

- Image sensor
- Imaging array
- Colour filter array
- Illumination
- Lens
- Scene
- Input processor
- Colour engine
- Recovery engine
- Anti-vignette, spatial distortion
- Encoding
Processor: Algorithm Pipeline

Pre-Processing:
- AF
- AWB
- AEC
- Noise Red.
- Exp. Time
- Dig. Stab
- Bayer

Post-Processing:
- Interpolation
- Colour Boost
- Anti Aliasing
- RGB

High End Image Enhancement:
- Gamma
- Matrix
- Stab.
- Colour
- Boost
- Panorama
- Img. Fusion
- Red Eye

Processing:
- Memory
- Display
- JPEG
Processor: High Level Performances

- Canon
  - Digic III
  - Vivid Photo
  - Photo Optimizer Pro
  - iSAPS

- SONY
  - WEGA
  - Digital Reality Creation
  - RGBE CCD

Quality

Computational Power

Power Consumption

Camera-Phone Architectures

- **Single Chip Phone**: Legacy Baseband or Super Basebands
  - Loudspeaker
  - Camera
  - Display
  - Base band (Modem)
  - Microphone
  - Keyboard

- **2 Chip Phone**: Baseband + BackendIC
  - Loudspeaker
  - Camera
  - Display
  - BackendIC - Multi-Media Co Processor
  - Base band (Modem)
  - Microphone
  - Keyboard

- **2 Chip Phone (High End)**: Baseband + APE
  - Loudspeaker
  - Camera
  - Display
  - Application Processor Engine
  - Base band (Modem)
  - Microphone
  - Keyboard
Camera System Partitioning in Mobile Phones

YUV SOC

Bayer Patterned Sensor

RAW

Image reconstruction

YUV, RGB, JPEG

ITU CCIR

Application Engine

Baseband

Display Chip

OR

Bayer Patterned Sensor

RAW Bayer data

CCP 2.0

Image reconstruction

Application Engine

Baseband

Display Chip

High-quality DSC-class image processing

YUV, RGB, JPEG, MPEG

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Increasing Functionalities & System Complexity

LED Driver

Lo Res Camera

Chip Enable 1

Clock

Imaging Processor

Camera IF 1

GPIO

Hi Res Camera

Chip Enable 2

Clock

Camera IF 2

GPIO

Focus Driver

Zoom Driver

Flash Driver

Shutter Driver

I2C Master

GPIO

GPIO

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Multi sourcing
- The standard supports the volume growth of cameras in mobile phones by allowing components to be commoditised.

Serial interface
- The standard includes a high speed serial interface for high frame rate, low pin count and low EMC emissions.

Efficient / Versatile ISP architecture
- The standard can support an efficient architecture where ISP is integrated in the host device.
- Versatile as the same device can be used with integrated or discrete ISP.

SMIA is a Complete Camera Module Spec

- Standard Frame/Field Format
- Standard Register Map Functions
  - Set-up
  - Control
  - Sensor Capabilities
- SMIA SW architecture
- Logical device driver

- Electrical Serial Interface, CCP2
  - Max bandwidth 650Mbps
- Output Image Format
  - Raw Bayer Data

- Reference architecture
- Example Camera Device Driver

Functionality
- Serial interface
- Software
- Mechanics
- Characterisation
- Reliability

- SMIA
- Sizes (SMIA65, SMIA85, SMIA95)
- Socket variants (SMD, through hole, flex)
- Optional EMC shielded
- Characterisation Methods
  - Functional performance
  - Test methods
- Qualification test requirements
System Controller
Provides system level hardware interface between all functional blocks

Image Processing
Provides improved system level performance via hardware accelerated image processing
Optional MPEG/JPEG Encoder
Encodes digital sampled and streaming images into MPEG/JPEG compliant format

Microcontroller
Orchestrates proper and timely system interactions between hardware and software
Processor: Architecture

Memory Controller
Provides system level interface signals for accessing memory devices and resources

Storage Controller
Provides access signals to nonvolatile secondary storage devices and resources
NTSC/PAL/SECAM CODEC
Transforms digital RGB values into viewable video signals via standard TV/CRT displays

LCD Display Controller & Driver
Enables control and display of digital captured and streaming images
Processor: Architecture

Digital Transport MACs
USB 2.0, IEEE-1394, Ethernet

SENSOR MODULE
Each "pixel" on a digital camera sensor contains a light sensitive photo diode which measures the brightness of light. Because photodiodes are monochrome devices, they are unable to tell the difference between different wavelengths of light. Therefore, a "mosaic" pattern of colour filters, a colour filter array (CFA), is positioned on top of the sensor to filter out the red, green, and blue components of light falling onto it. The GRGB Bayer Pattern shown in this diagram is the most common CFA used since 1976.
Instead of the traditional RGB color filter array this CFA is made up of Red, Green, Blue and Emerald (like Cyan) color filters. Sony claims that this expands the gamut of color which the sensor can capture and greatly improves color response.

Foveon X3 image sensors have three layers of pixels. The layers of pixels are embedded in silicon to take advantage of the fact that red, green, and blue light penetrate silicon to different depths – forming the first and only image sensor that captures full color at every point in the captured image.
CFA: 3-CCD Technology

For each pixel all colour components are acquired.
For best image quality and ease of use, separation prisms should have a few simple characteristics:
• All output images should be oriented in the same direction as the input image
• All channels must have the same optical path length
• The prism transmission should handle all polarizations with good uniformity
• All coatings should be protected from the environment
• Ample space should be available for mounting of filters and sensors

CFA: ClearVid CMOS sensors

A standard Bayer sensor features two green sensors for every red and blue sensor. Sony ClearVid CMOS sensors have six green sensors for every red and blue sensor. Sony are claiming that a two megapixel ClearVid sensor will yield a sensor resolution equivalent to a four megapixel camera, roughly a 1.4x resolution advantage over a standard two megapixel image sensor.
Sensor: CCD vs CMOS

Charge-Coupled Device:
- the charge is actually transported across the chip and read at one corner of the array
- use of a special manufacturing process to create the ability to transport charge across the chip without distortion.
- Higher Fill Factor

Complimentary Metal-Oxide Semiconductor:
- several transistors at each pixel amplify and move the charge using more traditional wires
- is more flexible because each pixel can be read individually
- use of the same traditional manufacturing processes to make most microprocessors.
- Easy integration.
- Lower Fill Factor

Sensor: Microlens filter

To compensate for lower fill factor (typically 30-50%), most CMOS sensors use microlenses, individual lenses deposited on the surface of each pixel to focus light on the photosensitive area. Microlenses can boost effective fill factor to approximately 70%, improving sensitivity (but not charge capacity) considerably.
Sensor: Microlens filter

Ideal Charging
All the photons intersecting at any angle a filter element in the CFA are colour filtered and accumulated in the photodetector under the filter element.

Sensor: Microlens filter

Optical Crosstalk
Optical Crosstalk results when a photon intersects at an angle with a filter element in the CFA and enters the adjacent pixel's photodetector (photodiode) and not the photodetector under the filter element. This can contaminate the adjacent pixel's charge packet.
**Sensor: Microlens filter**

Electrical Crosstalk
In electrical crosstalk, photons passing through the red filter travel further into the silicon before generating electrons. This leads to a non-uniform response to the different colors, a loss of charge into the substrate and electrons wandering into the wrong pixel well.

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**CMOS Sensors – Microlens Vignetting ➔ Anti-vignette microlens (radial shift)**

- Move microlens wrt pixel ➔ NO Vignetting

US6840855, Jeff
US7049168, Keith
The Need For Microlens Shifting

Chromatic Aberration

Chromatic aberration of a single lens causes different wavelengths of light to have differing focal lengths. As a consequence a given point in the scene is represented in different pixels in the sensor.
Signal to noise ratio

- SNR is the primary figure of merit for image quality
  - SNR max: maximum image quality
    - related to saturation level and PRNU at saturation
  - Minimum illumination: image quality at very low light level
    - Noise: Charge transfer, Dark current, Temporal noise, Fixed Pattern Noise, Quantization...
    - Sensitivity: number of electrons vs light.

![SNR vs. signal Temporal + FPN](image)

Effect of lens/ulens vignetting on Image

- Relative Illumination
  - Lens
    - typically only 50-60% illumination in image corners
  - Pixel
    - CRA angular response of pixel
    - extra RI reduction

- Colour
  - IR Filter
    - Reflective interference filter
  - Pixel
    - Crosstalk – colour matrix
    - Delta Gr/Gb
    - Hue, colour ratio

![Relative illumination equation](image)
Q&A