COACH-6 Product Data Book

SECTION I

Applications and Features

COACH-6 “Camera On A Chip” Digital Still Camera Processor

Proprietary Notice

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About the COACH-6 Data Book

The COACH-6 Data Book Section I - *Applications and Features* is the first of two parts of the COACH-6 Product Data Book.

The information contained in these documents refer to the COACH-6 Digital Still Camera (DSC) Processor, and provides the reader with an understanding of the hardware architecture, interfaces, and various hardware aspects related to the chip. It is the hope of the authors that this will allow a system designer to develop a digital still camera driven by the COACH-6 processor, and take full advantage of its broad functionality and cutting-edge performance delivered.

The Data Book, Sections I and II should be considered as the main documentation supplied with the processor. These documents, along with the Coach-6 Application Notes, are designed to cover specific hardware aspects that the system designer is likely to encounter.

Note: The term "COACH-6" and "chip" are used interchangeably throughout this document.

COACH-6 Configurations

The COACH-6 is designed to provide a solution for a broad range of camera devices from entry-level to high-end, while delivering a cost-effective and highly integrated solution.

COACH-6 comes in three flavors:

- COACH 6e (ZR36440) – Entry line, supporting up to 3.3M pixel sensors, 10-bit images
- COACH 6m (ZR36441) – Entry line, supporting up to 16M pixel sensors, 10-bit images
- COACH 6p (ZR36442) – Performance line, supporting up to 16 M pixels, 12-bit images
- COACH 6 MCM (ZR36445) – Multi-Chip-Module package with COACH 6p and 128Mbit embedded SDRAM

All the 6e, 6m, 6p and MCM versions, software and design tools compatible.
The COACH 6e and 6m are pin to pin compatible devices.

Terminology

Throughout the document, many terms will commonly appear that may not be known immediately by the reader. Below is a list of these terms:

1. **COACH** – The "Camera On A Chip" device, including its hardware and firmware.
2. **SW. Component** – A single, purpose-dedicated software components library. Each software component provides a well-defined external interface. Access to the component can be performed through this interface only, prohibiting the internal data of the component from being exposed to outside environments.
3. **SW. Application** – A program that runs on the COACH-6 is called a software application. Only one application can run at a time, and each application has its own architecture and design.
4. **COACHWARE** – Also known as the COACH firmware is provided by Zoran as libraries. It runs on the COACH embedded CPU processor and contains a SW Components as well as part of the SW Application.
5. **HCE** – *Host COACH Embedded* – embedded host functionality in the COACH. This occurs on the customer's SW layer. Applications interface the COACHWARE via dedicated API commands.
6. **COACHWARE API** – An API layer through which the host, or HCE, communicates with COACHWARE.

Introduction

The COACH-6 is a highly integrated microprocessor solution for Digital Still Camera (DSC) and entry level Digital Video Camcorder (DVC) devices. It combines a number of functions that are required in the implementation of these devices and will lower both the cost of manufacturing and allow manufacturers and OEMs alike to accelerate their time to market:

- Image data acquisition from either CCD or CMOS imagers
- Image display (LCD)
- Image processing and image storing
- Control of general purpose I/O functions
- Data communication, internally and externally
- Control of user functions
- On-screen Display
- Camera system management

This ground-breaking microprocessor also provides a large number of interface supports that allows manufacturers to increase the devices the camera may connect with:

- Communication with PCs
- Communication with flash-cards
- Serial communication ports for controlling other devices in the camera

The design is based on an MIPS microprocessor that controls the entire chip. A number of hardware resources, controlled by MIPS, perform digital camera functions such as image DSP processing, JPEG coding/decoding, DMA access to SDRAM, and video encoding. All these computationally intensive functions are implemented in hardware which can be programmed according to user specifications, thus allowing MIPS to be free for other user-defined functions.

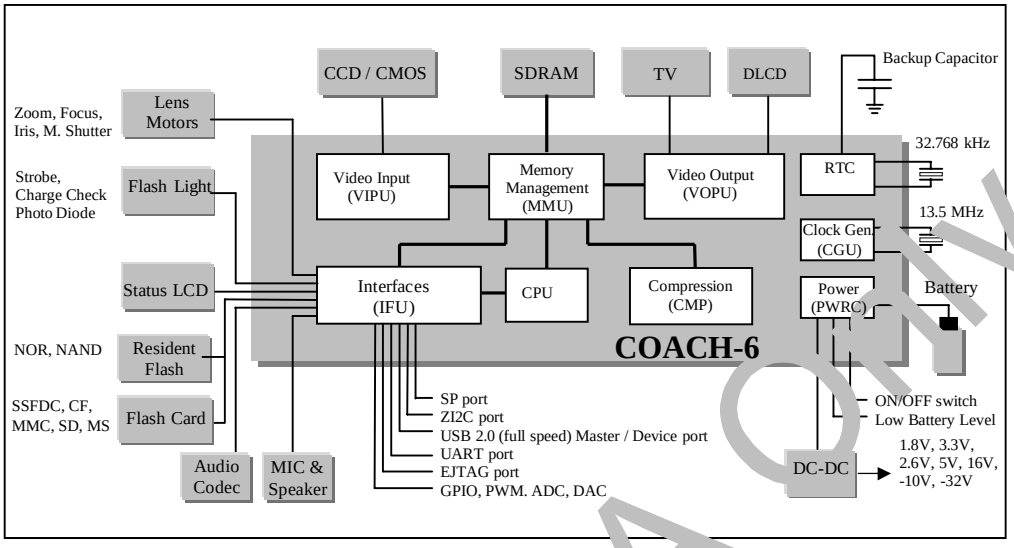

Figure 1: Block diagram of a typical COACH-6 based Digital Camera

Note: MCM package contains 128 Mb SDRAM embedded

Applications

Below is a short list of typical applications enabled by the COACH-6 processor:

- A stand-alone, fully-functional digital still camera (DSC) with or without real-time motion capture and web/intranet camera capabilities.
- A DSC plus MP3-enabled audio playback and audio recording combination applications.
- A Digital Video Camera (DVC) device featuring MJPEG movie recording, up to 16x virtual-stepless digital zooming capabilities, and direct streaming to the storage media with high bandwidth for TV-like movie quality.
- Other image/audio capture portable devices where high image quality is desired.

The figure bellow illustrates the typical COACH-based camera solution:

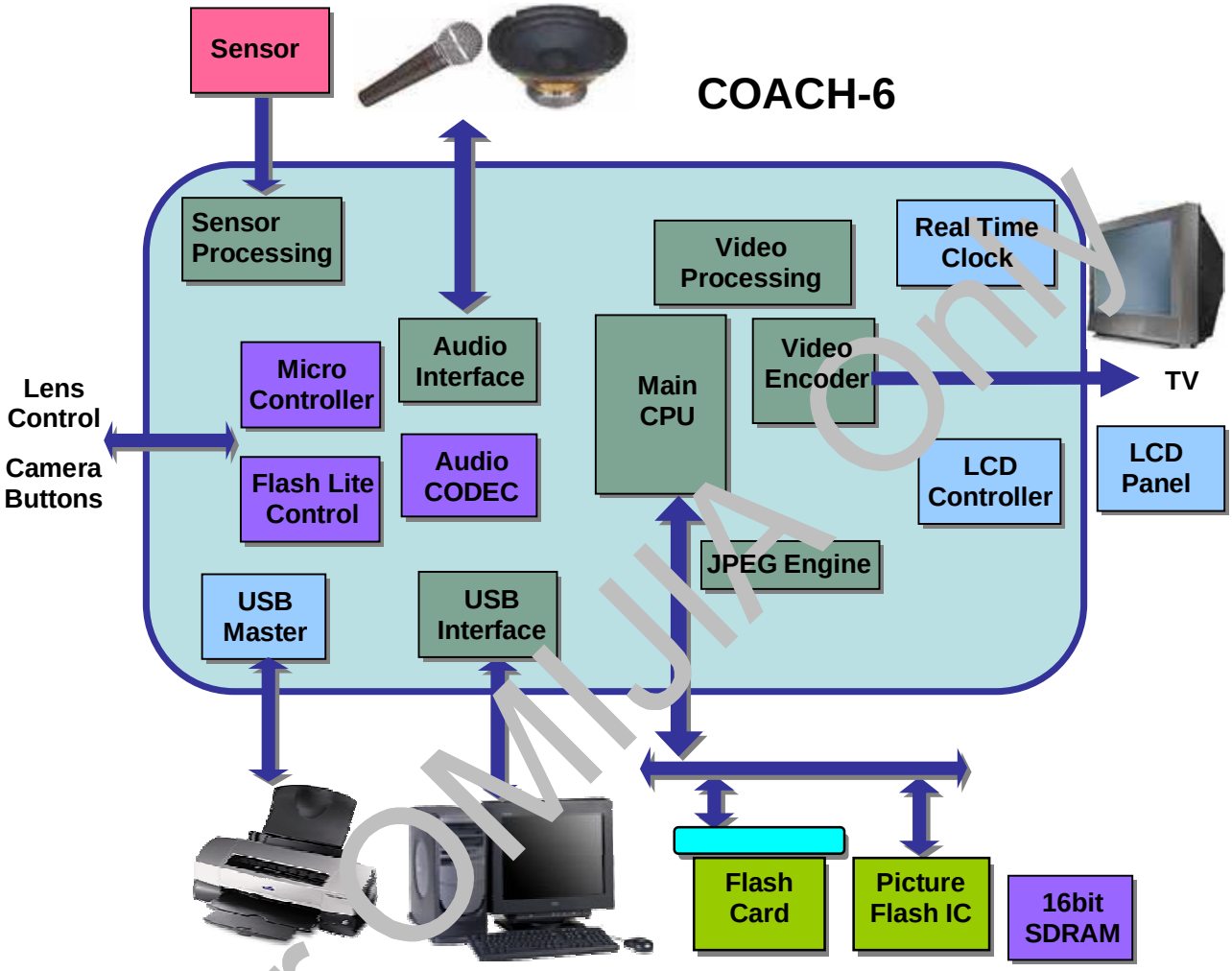

Figure 2: COACH-based Camera solution

Features List

The extensive list of features of the COACH-6 microprocessor provide manufacturers with the ability to increase the functionality of their devices in a very competitive market while lowering costs and, more importantly, not increase the power consumption or size of the device. The COACH-6 rises above the competition with more system cost-efficiency, higher integration, increased interface support, and better overall performance.

Additional features of the COACH-6 superior microprocessor for DSCs and DVCs are:

- 32-bit CPU engine provides programming for camera differentiation.
- Support for image capture of resolutions up to 16M pixel*
- AVI clip support
  - Capture of CIF size 30 frames/sec and VGA 30 frames/sec directly to the card. The size of the clip limited only by card size.
  - Playback including advanced control function.
- Direct glue-less interface to industry standard CCD sensor arrays from Sony, Sharp, and Matsushita (progressive and interlaced), and CMOS sensors including multi field sensor support.
- Supports external TG and 12-bits CCD analog front end (CDS-AFE)
- On-chip advanced 12 bits* CCD signal processing unit that performs:
  - Three-colors Anti Lens Shading filter (patent pending)
  - White Balance Correction
  - Programmable Gamma LUT
  - Bayer Grid Color Filter Array (CFA) reconstruction (cumulative 11x11 filter)
- CCD noise suppression:
  - CFA grid noise reduction
  - Black noise compensation
  - Color aliasing suppression
  - Black frame subtraction
- Programmable Edge Enhancement
- Color matching and Color space conversion
- Chroma correction
- Luminance correction block for histogram manipulations, which can be used for:
  - Contrast Stretching
  - Dynamic Range Compression
    Histogram Equalizations
  - Other Histogram functions
- Automatic Focusing (AF)
- Automatic White Balance (AWB)
- Automatic Exposure (AE)
- Smooth, high quality 16x to 1/16x scaler. Allows zero-overhead smooth up to 16x digital zoom in:
  - Preview
  - Capture
  - Clip Capture

* The numbers provided are relevant for COACH 6p chip.

  - PC Video
- Image mirroring support mechanism
- On-chip support for flash light control, including red-eye reduction.
- Direct interface to resident flash memory (NAND or NOR type) and/or removable memory cards (CompactFlash (CF), SmartMedia (SSFDC), Secure Digital (SD), Multimedia Card (MMC), Memory Stick, XD and SDRAM storage.
- Support single 16-bit data width SDRAM of 64Mbit, 128Mbit or 256Mbit.
- Micro controller functionality integration
- On-chip 6-input* successive approximation 8-bits ADC with 100k samples/sec.
- Embedded Real time clock (RTC)
- Over 40* GPIO and special DAC (PWM) pins. Some GPIO signals are multiplexed with unused pins.
- On-chip general pattern generator for motor control support with 16 PWM outputs.
- Advanced power management. On-chip control for power ON/OFF sequence and low battery indication.
- 32-color on-screen display (OSD) with 4 transparency levels.
- True color graphics mode (64,000 colors), with hardware graphics accelerators
- ZI2C port
- Serial Communication Port for RS-232
- On-chip EJTAG port for debugging probe
- On-chip 2.0 Full Speed USB master/device interface, including USB line drivers.
- Integrated 8KHz, 12-bits speech-codec including internal input and output amplifier and glue-less interface to microphone and speaker.
- Interface to low cost audio-codec, including audio clock generation.
- Direct output to NTSC/PAL TV monitor (CVBS format) with no need for off-chip encoder or video DAC.
- “Glue-less” digital video output, including on-chip programmable controller to interface
  Casio, Epson and Unipac DLCD TFT LCD panel support
- URT and GiantPlus STN panels.
- Quantization Noise reduction filter for 6-bit DLCD and STN.
  - Embedded host control (HCE) software architecture allows the creation of DSC applications with minimal effort.
  - Traditional COACH software API set. Backward compatibility with previous generations.
  - Open firmware architecture allows easy customer modification to base software modules.

- Advanced bit rate control guarantees the size of the JPEG compressed pictures at maximum visual quality.
- Thumbnail preview mode allows viewing of miniature versions of the stored pictures on an LCD and/or a TV monitor.
- DCF image and audio file format, with FlashPix™-ready compliance. Full performance, easily customizable DCF library.
- Fully customizable EXIF library
- Fully customizable DPOF support.
- On-chip font-based OSD engine for displaying user-interface messages on the LCD/TV. Support for host controlled cursor for advanced GUI.
- Support for the retrieval of pictures from a PC for later presentation, at a remote location, on a regular TV monitor.
- Audio support
  - Optional audio annotation of pictures
  - Playback and recording of sound in AVI clips
  - Sound effects, including shutter effects.
  - Dictaphone feature
- Video Capture mode, for capturing CIF resolution real time video (MJPEG compressed) to a PC, without a capture card or any other additional hardware.
- Image Editing
- Image playback including up to 16x playback zoom, accelerated playback and rotation feature

- 3.3V I/O power supply
- 1.8V Core power supply
- 1.6V-3.6V battery supply
- 272-pin 17x17 (COACH 6p) , 217-pin 15x15 (COACH 6e and 6m) LBGA and 276-pin 19x19 LBGA Multi-Chip-Module (COACH 6 MCM) packages.

Features	COACH-6 MCM	COACH-6p	COACH-6m	COACH-6e
CMOS & CCD sensors	Up to 4 MP	Up to 16 MP		Up to 3 MP
Input & processing color depth	12 bit			10 bit
Digital Zoom	Up to 16x, 1/256 step			
Analog TV (NTSC/PAL)	Yes			
LCD output	EPSON / CASIO / GiantPlus / AUO (Unipac) / Sony / URT			
Graphic-based OSD function	Yes			
Motors control	Yes			
Mutli-functional GPIO (see *Note 1)*	138 in total + 9 as GP outputs only		121 in total + 9 as GP outputs only	
Enhanced CPU & microcontroller functions	Yes			
Performance (boot to click time, click to click time, click to view time)	Same across all the COACH-6 platforms			
AVI clips capability	30fps, VGA MJPEG			
EJTAG debug interface	Yes			
Program space	Not limited (up to 4 GByte program/data space)			
Embedded Audio D/A and A/D	Yes, 12bit speech audio D/A and A/D and embedded amplifiers			
External audio codec interface	Yes			No
Integrated ADC	8-bit, 6 channels			8-bit, 4 channels
Integrated PWM	8 channels			6 channels
Embedded USB2.0 full speed	Yes			
Fast UART	Yes, over 1Mbit			
RTC and PowerC core	Yes			
Flash Strobe Control	Yes			
Storage media	NAND/NOR Flash, SMC, MMC, SD, CFA, MS, xD			
SDRAM	128Mbit	External, up to 256Mbit		
Package (*Note 2)*	19x19 mm	17x17 mm		15x15 mm (pin to pin)
Lead free	Yes			No

Note 1: The number reflects the total amount of gpio, including those that are multiplexed with other functions. An exact amount of general purpose I/O pins is determined per particular system configuration.

Note 2: both COACH-6m and COACH-6e are mutually pin-to-pin compatible.

Overview

The COACH-6 encapsulates most of the DSC electronics in a single chip. It accepts raw image data from common, widely adopted progressive-scan or interlaced CCD or CMOS image sensors, with resolutions of up to 16 M pixels are supported.

The chip processes this data in order to display and/or capture the picture while compressing it, immediately as it is received. The CCD advanced image processing contains black noise removal, white balance, de-mosaicing, gamma and color correction, edge enhancement, contrast enhancement and other image-quality oriented features.

Storage of either compressed or uncompressed images is handled by the chip, writing them into flash memory. An on-chip USB engine is designed to transfer the pictures to a PC or printer (utilizing the USB mastering ability of the COACH-6).

A complete flash memory controller resides on the processor chip. Both, resident flash memory chip and removable flash memory cards are supported, as well as a combination of them. CompactFlash (CF), SmartMedia (SSFDC), MultiMediaCard (MMC) and Secure Digital (SD), XD and Sony Memory Stick cards are among the supported memory cards.

The COACH-6 provides a complete file management that readies the image files for rendering by MS Windows OS (covering all current consumer Windows platforms such as Win 98, 2000, CE and XP). Therefore, no additional drivers are needed for reading card content into a PC and rendering the images.

A single 16-bit SDRAM 64Mbit, 128Mbit or 256Mbit device is necessary to handle image processing operations. Higher image resolutions imply larger SDRAM devices (up to 256 Mbit (TBD)).

While in **View** mode, the COACH-6 displays the incoming video on a local LCD panel and optionally on a TV monitor connected to the camera. The embedded DLCD controller provides a direct physical interface to common DLCD panels offering a DLCD controller-less (external chip), that is cost-effective, yet offers high performance – greatly simplifying the system design.

Typical image processing functionality such as Auto White Balance and Auto Exposure is performed in **View** mode.

In the process of **Capturing an Image**, the COACH-6 goes though several consecutive modes of operation:

- First, bit-rate control is applied to assure the compression to the desired image size. Zoran's Advanced BRC algorithm assures precise control over the remaining memory space on the storage device.
- Then, the compression takes place, with attention paid to the software-set pre-defined compress ratio. The compressed image is stored in off-chip SDRAM and is transferred further to the final storage media, e.g. flash memory directly governed by the chip, USB host. The file format is DCF-compatible with

common JPEG-enabled viewers such as Netscape or Microsoft Internet Explorers, or other widely known programs.

The capturing of a picture sequence using a single shutter button release is made possible due to the **Capture Sequence** mode in which a number of images are sequentially captured in a near real time rate. The number of images captured sequentially per Capture Sequence session is only limited by the storage media capacity. In the case that the storage device is unable to cope with continuous data streaming of multiple images, the only limitation imposed on the quantity of pictures taken in a single Capture Sequence session is by the SDRAM size.

COACH-6 allows titling information to be saved in the dedicated segment of the compressed image file. An audio title can be attached to the picture or the image can be erased or protected.

Images stored on the flash memory can be played back on the LCD/TV. Additionally, multi-image preview is supported in which a group of stored images are restored on the LCD/TV and exhibited as miniature versions of the original images (thumbnails). This option gives the user a general idea of what media items are on the storage device in an immediate and intuitive way.

The chip handles real-time motion video capture (CIF 30 fps or VGA 30 fps) with the ability to transfer the compressed video data stream to the USB host, e.g. PC. Real time compressed video capture is complemented by a mode of non-compressed QSIF-size video streamed to a USB host. This feature can be useful in teleconferencing applications.

The COACH-6 boasts an AVI recording and storage ability with a performance level similar to that achieved in motion video (CIF 30 fps or VGA 30 fps) while the recorded AVI duration is only limited by the available memory on the removable media.

Audio synchronization to the video streaming and recording is achieved automatically assuring no audio-video time-lag issues. This feature is especially important for DVC operation, during which real-time virtual step-less digital zooming is possible.

The ”brain” of the COACH-6 chip is a programmable CPU core that assists the hardware in computations, governs the operation of all other units of the chip, and manages the interfaces to the flash memory, remote printer and other optional remote devices. The program of the CPU can be stored in the same flash IC utilized for image storing purposes (NAND-type flash device), or alternatively, an on-board ROM/NOR-type flash can be used for program storage purposes. Both devices can be directly interfaced to the COACH processor. A single NAND option contributes to reduced system cost and power consumption. During boot-

up, the COACH-6 downloads the mandatory real-time portions of the program into the on-chip program RAM from which the program is executed. The rest of the program, in the case of large program applications, is loaded and executed from the system's SDRAM.

Taking the advantage of the horsepower of its CPU, supported by DPS processing versatility, the chip can apply a number of special effects on the stored images while they are viewed, e.g., for pre-print editing. Among those are bi-dimensional spatial filtering, linear and non-linear point operations and superposition of two images.

A font-based OSD is implemented and supported by a feature-rich graphic library providing a powerful, interactive user-interface through the LCD/TV including cursors, menus, and so forth. For temporary storage of the image, OSD information and similar external SDRAM is used.

In addition to storing, displaying and processing the images by the COACH-6 processor, it is possible to retrieve the pictures from a storage location on a PC, media downloaded from the Internet, and so forth, for presentation on a LCD or TV monitor.

In tethered applications, based on USB protocol, the COACH-6 powered system can be controlled by the host (PC, for instance). Furthermore, the chip allows the downloading of the program via a USB channel, which in turn enables the camera manufacturers to provide their end user customers with instant firmware upgrades through the Internet.

Advanced power management, SmartPower™, ensures that in every mode of operation power is provided only to those units that actively consume power, while all others are suspended and no clock is supplied to them. For further power efficiency, the chip can be programmed to suspend one or more units either permanently or temporarily during specific modes of operation. For example, the video output units can be permanently suspended in the cameras not featured by local LCD, or the units can be activated during LCD-required modes (e.g. View, Playback, and so forth).

Integration of the high performance CPU core opens new horizons in camera performance by allowing all of the processing, including HCE functionality, to be fully performed by the core, eliminating the need for an external micro-controller. Virtually any camera-related processing can be performed by the embedded CPU. However, an external micro-controller can be added to a system, if desired.

Feature enhancements between COACH-5 and COACH-6

The COACH-6 predecessor, the COACH-5, has been adopted by many DSC manufacturers worldwide to power their cameras, earning a considerable share of the DSC consumer market. The COACH-6 processor offers additional high-level features, propelling the DSC camera performance to a new level.

Here is the list of new and performance-updated features introduced by COACH-6:

- **Black level Evaluation and Correction**
  Any type of image sensors, especially CMOS-types, introduce a certain degree of black level noise which may somewhat affect image quality. The noise level varies among various sensors, and to assure the final quality of the image, the camera processor must be able to compensate for it. The COACH-6 does just that, reading Optical Black pixels to estimate the average black level noise at particular shooting conditions, and then an appropriate compensation is performed. This feature is especially important for CMOS sensors, which are known to produce a somewhat greater Black Level noise levels than CCD-types.
- **Black Frame Subtraction**
  This feature is to overcome the fixed pattern noise that is usually exaggerated in long exposures taken in low-light ambient conditions. The Black Level Subtraction mechanism substantially improves the fixed noise performance level allowing higher quality images to be acquired in less then perfect lighting conditions.
- **Lens Shading Compensation (patent-pending)**
  Lens shading is a phenomenon caused by a non-uniform lighting propagation through the lens exhibiting certain degradation towards the lens' corners. The effect is especially pronounced in low and mid-end optics.

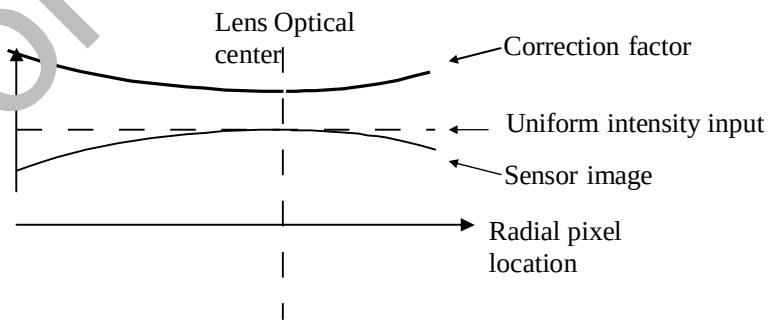

Figure 3: Lens Shading Compensation

COACH-6 boasts a special algorithm that compensates for such a situation through calibration based on a particular lens-type, giving a final image with uniform lighting spread across the frame. The COACH-6 features an innovative 3-color (R-G-B) lens shading compensation algorithm with no performance penalty.

- **White Balance Correction**
  To cope with various ambient lighting conditions which may potentially affect the image color appearance under non-natural lighting. The artificial lighting usually found in-doors may cause significant color shifts which may ruin an otherwise good image. A robust White Balance Correction mechanism on the COACH-6 allows the device to cope with such situations and provide consistent, natural looking images under virtually any lighting conditions.
- **12-bit Gamma conversion**
  The purpose of this feature is to compensate for the non-linearity of display devices, e.g. LCDs. The standard calls for digital cameras should be gamma-corrected for NTSC or PAL monitors.
- **CFA Grid Noise reduction**
  Reduces significantly the color filter array noise. This feature is especially useful for eliminating CCD grid noise effects.
- **Color Interpolation**
  Sophisticated innovative color interpolation algorithms assure better color reproduction, and minimum noise and false colors. The unit is programmable to match camera optics and image quality requirements.
- **Color Space Conversion** (RGB -> YUV) and **Color Matching** (RGB -> RGB)
  Converts the sensor's recovered RGB to the display YUV 4:2:2 format as well as the sensor's RGB to display YUV 4:4:4.
- **Edge Enhancement**
  This feature focuses on the need to create an illusion of crisper image through sharpening the edges. The degree of sharpening is highly adjustable to match particular image quality requirements. Sharper, better-looking images can be yielded with reduced noise levels thanks to the special non-linear gain function especially developed to enhance the mechanism performance.
- **Color Anti-Aliasing Filter**
  Reduces the false colors artifacts around the edges (color-fringing).
- **Luminance Correction**
  Applied to the Y-component allowing a number of histogram manipulations to suit particular luminance-related image appearance requirements such as:
  - Contrast stretching
  - Dynamic range compression
  - Histogram Equalization
  - Other functions

- **Chrominance Corrections**
  Allows rotation transformation of U, V space in order to enable precise adjustments of colors. Supports Sepia transformation.
- **Image Scalers**
  The COACH-6 boasts a powerful, high-quality programmable hardware scaler that is able to produce multiple ratios. The scaling can be performed in the input stage while the image comes from the sensor on its way to the DRAM image buffer, or can be used to scale the image stored already in DRAM. The scaling range is 1/16 – x16, in 1/256 steps. The mechanism allows smooth zero-overhead digital zooming up to x16.
- **Smooth Digital Zoom**
  Performed without blanking out the screen, in extremely small steps allowing the implementation of optical-like digital zooming. Digital zoom is also supported during video capture and AVI capture. No time overhead exists for image scaling.
- **Image Flip**
  Powerful mechanism for input image flipping (mirroring) manipulation. Works in both horizontal and vertical directions "on the fly" – no performance penalty while data is processed by image processing engine.
- **OSD and Graphics support**
  There is support for the hardware On-Screen-Display (OSD) function, which provides a configurable 5-bit palette (32 selectable colors).
  4 different blending levels are supported (1/4, 1/2, 3/4 and transparent OSD)
  Two HW Highlight Rectangles are available while the COACHWare (software libraries provided with COACH-6) provides the RichOSD library to achieve a more flexible and rich GUI. A number of graphics accelerators significantly improve the graphics mode performance.
- **CPU subsystem**
  The COACH-6 features are integrated with a MIPS M4KE CPU running at 108 MHz. The power of the CPU core and high integration level eliminate completely the need to external uCon:
  - **Instruction and Data caching**
    The program is executed from DRAM through a high performance cache mechanism. The 32-bit address space eliminates any program and data size restrictions.
  - **System Boot options**
    The boot options available are from UART, USB, SD, MMC, CF, NOR, NAND and SSFDC. This allows instant resident memory-stored software updates from any remote source as well as removable media, by the end-user.
  - **DSP Extension**
    The CPU features a multiple-accumulated accelerator and specific DMA channels offering high performance execution of image processing algorithms.

- **System Integration**
  - **RTC**
    A 46-bit Real Time Clock with under 1uA power consumption that still runs even through COACH-6 is powered off. The RTC operates even in low-battery conditions down to 1.5V. An external capacitor can preserve the RTC settings even when the battery power has been lost.
  - **Power Control**
    The COACH-6 built-in power management unit, directly supplied from the battery, significantly simplifies the power-up and power-down sequence, and battery level monitoring while achieving high efficiency power management throughout camera operation. The added robustness of the unit reduces significantly the system manufacturing costs.
  - **Lens Module Control**
    Zoom lenses usually found in mid- and high-end digital cameras are featured by several motors incorporated into the lens module for aperture, focus and zoom controls. COACH-6 features for integrated Lens Module Control unit that directly interfaces and governs a variety of step motors usually utilized for the purposes mentioned, eliminating the extensive lens motors control circuitry found in many digital cameras.
  - **Audio Interface**
    COACH-6 embeds a 12-bit audio codec that is optimized for speech recoding and playback (voice codec). An external linear codec interface is also offered for high-quality audio performance. Speaker and microphone amplifiers are integrated simplifying greatly the external circuitry design.
  - **Direct DLCD and STN interface**
    COACH-6 directly interfaces to digital LCDs from Casio, Epson and Unipac. A number of STN displays can be interfaced in a similar fashion (from GiantPlus and URT). Special algorithms are implemented to improve LCD image appearance quality. Among those are Error Diffusion algorithms that eliminate quantization distortions in the areas of gradual tone changes due to reduced data width of certain DLCDs, while the programmable gamma correction optimizes the hue to that of specific panels.
  - **USB 2.0 Full Speed Master/Device port**
    There is an integrated USB 2.0 Full Speed Master/device core as well as on-chip USB line drivers.
  - **Fast UART communication port** (Serial Port for RS-232)
    Based on an industry standard PC16550 UART device with fully compatible with software drivers. Supports asynchronous communications with a remote device from 9600 bps up to 1.5Mbps.

Interfaces overview

Major DSC system network:

- **CCD/CMOS sensor port**
  Direct interface to either CMOS image sensor of CCD chipset. Provides 12-bit width image data and timing controls as well as flashlight triggering signals.
- **SDRAM port**
  Standard SDRAM interface governed by the built-in SDRAM controller, or fixed 128Mb capacity SDRAM embedded in MCM package
- **Video output port** (DLCD & TV)
  An 8-bit width output bus providing DLCD data as well as all the necessary DLCD and STN timing signals. Provides the ability to support narrower data interface DLCD devices (such as certain 6-bit Epson models), effectively compensating for the quantization artifacts inherent into data depth downgrading.
- **Lens motors control port**
  Direct lens motors interface to govern aperture, focusing and zooming step motors in optical units.
- **Flash Light interface**
  An ability to fully control Flashlight operation including Red-eye reduction feature.
- **Resident Flash memory port**
  "Glue-less" interface to standard Flash memory devices of either NOR or NAND technology. Resident flash memory device is utilized as a main camera-driving program storage.
- **Flash Card storage port**
  Direct support of various kinds of removable media for image/AVI/audio mass storage. No need for external logic in order to connect to CF, MMC SSFDC (SmartMedia), SD and Memory Stick.
- **External Audio Codec port**
  Besides the built-in voice codec, an additional audio port is available for external linear codec interfacing for high-quality audio operation.
- **Microphone & Speaker port**
  Built-in microphone and speaker amplifiers simplifies the system design and reduces the system cost significantly.
- **Service ports**
  - **SP port**
    Serial Protocol port – an output-only port typically utilized by CCD chipset configuration.
  - **ZI2C port**
    Zoran I2C protocol interface port – supports standard I2C protocol as a Master device.
  - **USB 2.0 Master/Device port**

Standard USB 2.0 Full Speed port capable of either Master or Device operation. The line drivers are built-in into the chip.

- **UART port**
  Standard UART full duplex asynchronous communication port providing speeds in the range of 9600 bps to 1.5 Mbps. Acts also as a built-in CPU debugging facility.
- **GPIO port**
  General Purpose I/O port offering up to 21 I/O pins (besides numerous functional/GPIO convertible pins) for application flexibility.
- **PWM port**
  Pulse Width Modulation/Low Frequency DAC port – for any analog-based voltage controlled applications (e.g. reference voltages, controllable photo-detector reference voltage for flash exposure control, flashlight PWM and so forth).
- **GPADC**
  A 7-input general purpose ADC for any application requiring the reading of analog values into the COACH-6. The feature is especially suited for extensive keyboard implementation, freeing additional GPIOs to be available for other uses.

COACH-6 system operation overview and COACHWare™

Camera Host function

The term "host" refers to the functionality of the HCE layer or "traditional" host (uC or PC), which reads the camera, input buttons and controls the camera operation by sending commands to the COACH processor.

With COACH-6, there is no need for an external host. The host functionality is implemented on the COACH itself as a software layer (HCE) that is running on the COACH CPU. In most COACH-6 based cameras there is no need for an external uC (in conjunction to COACH) at all.

Host Commands Language

The host process (denoted HCE) communicates with the COACHWARE using a set of API commands. The communication between the host-process and firmware is accomplished by sending API commands and in some cases, acquiring the responses to those commands.

HCE – Host Embedded Process

The HCE – Host Control Embedded is a process running on the COACH CPU implementing the control code. The HCE process is awakened by the firmware kernel as a result of various events (e.g. button press, interrupt, and so froth). The HCE process then commands the firmware and reads data through the Commands Language.

More on the Host Control Embedded is detailed in the specific SW Application Notes.

"Hosts" Other Than HCE

In the same way that the HCE controls the firmware (and hence the camera), a remote host can control the firmware through either the USB or the UART port. The USB uses the same API Commands Set as the HCE. It is possible, for example, to develop host code on the PC, emulate its work through the USB channel, and then run the same code on the COACH itself. This framework is called a PC-HCE environment. Please refer to the specific SW Application note for more information about PC-HCE.

COACH Program Storage Location

Through a PC tool provided with the development kit, a database which contains the executable program, the OSD font maps and the configuration parameters are generated. This database is loaded to the COACH while booting.

The database must reside in a memory location that is accessible to COACH during boot time. The options are:

- ROM / NOR parallel flash resident device
- NAND flash resident device (is shared also for an optional image storage memory bank)

Naturally, the COACH program takes only a small portion of the resident memory that can be used to store pictures, in conjunction to the program. This booting sequence is explained in detail in the *Functional Description* chapter of this document, and in an appropriate SW Application Note.

Note: COACH-6 allows booting from removable memory card which is useful for debugging as well instant reprogramming purposes. For more information regarding this option please refer to an appropriate SW Application Note.

Functional Description

The COACH operation is described in terms of operational modes. Each mode is associated with a set of executable tasks. Some of the modes are “continuous” modes, i.e., the COACH remains in these modes until the host orders a transition out to another mode. Other modes are “one-time” modes - in which the COACH executes the tasks associated with them and transits out, normally to the idle mode.

In order to initiate a new mode the host sends the **SetMode**(new_mode) API. The usage of the different modes depends on the specific application in which the COACH is used. The internal management of the operation modes is performed entirely by the COACH. The current mode is reported to the host via a message to HCE.

Figure 4 illustrates the basic Event-driven flow application:

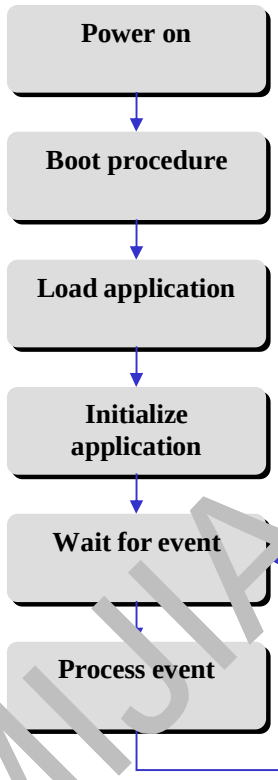

Figure 4: Event-driven flow application

Event types:

Hardware Events:

- User Press a Key
- Battery
- Card Detection
- Camera Mode Change

Software Events:

- GUI
- Operation-Controlled Events

A simplified mode transition diagram is depicted in Figure 5. Note that this diagram does not include all of the COACH modes and transactions, and the diagram is for explanation purposes only. For example, the transition from Capture to Store is a self-initiated transition, while the transition from View to Capture is instructed by the host.

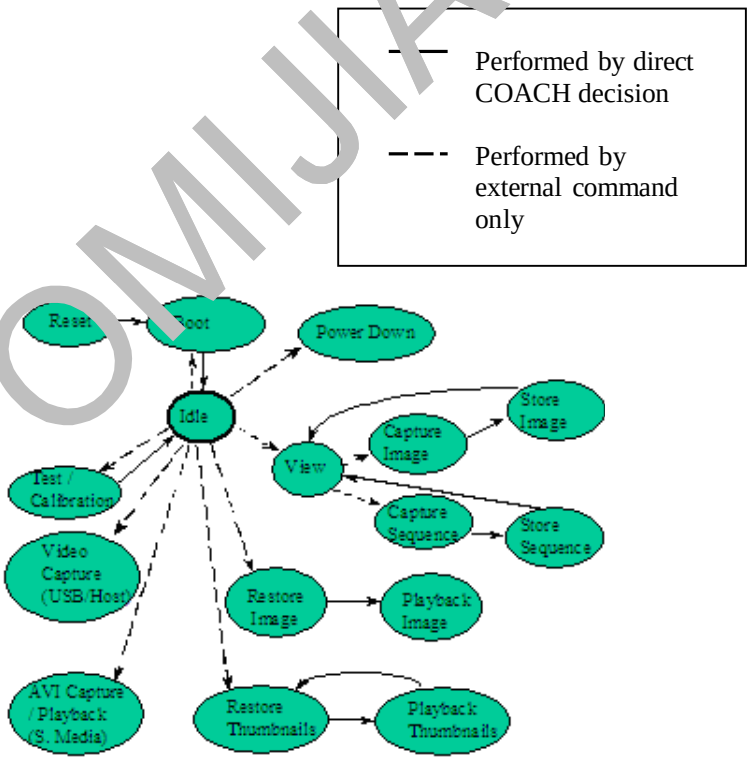

Figure 5: Simplified Mode Diagram[1]

The modes can be sorted into three main groups:

Reset Mode
This mode is effective when the power supply is **ON** and the ***RESET#*** input signal is asserted. During that time the chip does not consume power. Upon ***RESET# input*** de-assertion the COACH latches the values of several configuration pins. These pins are later used for other purposes.

Boot Mode
This mode is initiated automatically after the completion of the reset procedure, as described above. In the Boot mode the COACH loads the executable program.

Idle Mode
In this mode the image processing functions of the COACH are suspended. The contents of all registers and on-chip memories are preserved. The units that are suspended consume minimal current (practically zero).

The display is by default disabled. If the host enables it, the background color is displayed over the entire active display window, and sometimes on OSD.

In this mode, the host is allowed to send various commands to the COACH. The first entry in this mode is ideal for the host to configure the chip per the characteristics of the system, to initialize the OSD font map, etc.

The example of Idle mode LCD window is shown in Figure 6:

Figure 6: White Balance feature screen

File transferring between the COACH and the host is permitted in Idle mode, if the pictures are stored on a flash memory device (either a resident chip/chip array, or a removable card), that is directly accessible to the COACH. The COACH can send or receive image files and/or audio files, and/or send the thumbnails only, through either of the following communication ports: UART/IrDA interface or USB interface.

View Mode

In this mode the COACH runs the sensor’s processing and, if the video display is enabled, displays video in the selected format.

Since different sensor settings may be applied for preview and for image capturing, the COACH reconfigures the CCD TG or CMOS configuration and the internal CCD (when applied) interface logic when transiting to View mode. This setting may be automatically performed by the COACH or by the host using a dedicated API.

If enabled, the CCD AWB, AE and AF algorithms are executed in the View mode. Upon conversion of the optimal exposure and white balance values the COACH notifies the host, an HCE message giving permission to capture an image. The View mode can be initiated with or without the display option. The latter can be used to save power.

In addition, the host can switch the display option on and off while the COACH is in the View mode, using a dedicated API. Scaling and cropping of the displayed image may be required in order to adopt the image to the display characteristics. The scaling values are automatically calculated by the COACH, but can be changed by the host when necessary.

OSD information is displayed in the View mode. The COACH remains in the View mode as long as another mode is not initiated.

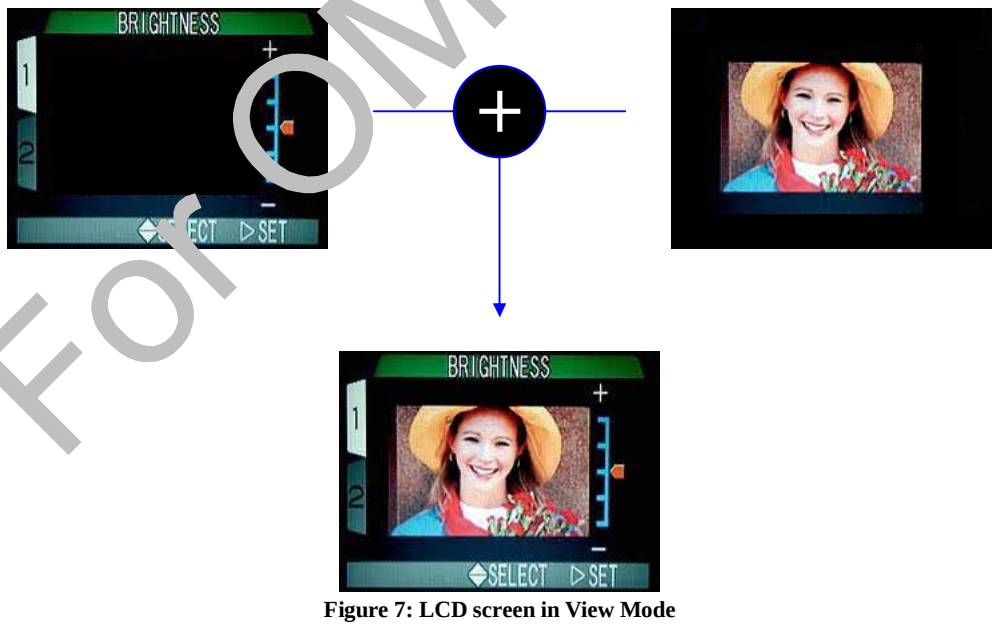

Figure 7: LCD screen in View Mode

Capture Image Mode

This mode is initiated by the host, which transfers the COACH from the View mode, with an optional programmable delay. In the Capture Image mode the COACH captures one image frame into DRAM, runs statistical passes on it, and compresses it back to DRAM. The compression ratio is programmable and can also be applied by the host through a dedicated API. The COACH reconfigures the sensor when transferring to Capture mode.

When the compression is completed the COACH registers the total code volume of the image and indicates to the host that capturing is done. It then transfers to Store mode.

Delaying the Store for User Confirmation

The actual store can be delayed while the COACH displays the captured image from the DRAM for a programmable number of seconds. During this delay, before the actual storage begins, the host can confirm the store or indicate that the image is not wanted. In this case, the COACH does not store the image and transfers back to View.

During the Capture Image mode the image can be shown on the display. If the display option is enabled, the COACH displays the background color only, possibly with OSD.

JPEG or TIFF

The Capture mode can be dynamically configured by the host to capture the image as JPEG compressed or TIFF. In the case of a TIFF image capture, the COACH does not generate a JPEG code. In Store mode a TIFF file is generated and the image is stored on the flash memory.

Red-Eye Reduction Flash Firing

The COACH supports red-eye and pre-flash firing before the main flash. The red-eye or pre-flash features are activated in View mode before the transition to capture.

The COACH supports red-eye flash by activating the Flash Trigger following a programmable delay after a frame start event, for a programmable duration. The camera host, in accordance with the programmable parameters through the COACH, must command the start of the red-eye flash firing, and to command the stop after the required number of flash firing.

Main Flash Firing

If flash firing is required (either forced or requested by the AE algorithm), the “main” flash triggering takes place after the delay - or after the red-eye reduction pre-flash if there was no delay, or after the configuration of the TG, if red-eye pre-flash was not required.

The flash triggering mechanism looks for the next frame (or first field) readout, waits for a pre-defined delay time, and outputs a pulse on **FLSHTRIG** for a pre-defined duration time.
Only after completing the preparations described above is the COACH ready to capture a frame.

Capture AWB
In Capture mode the COACH can run a "capture AWB" algorithm. This AWB operates on the RAW image while in DRAM. It is an "open loop" AWB running with one-iteration in RGB. This AWB is more accurate than the "closed loop" AWB that runs in preview.

If the Capture AWB is disabled then the Preview AWB affects the capture image, which also results in a good and accurate image.

Capture Sequence Mode
This mode is initiated from the View mode, possibly with a programmable delay. In this mode the COACH captures and compresses a sequence of frames to DRAM, in half the real-time frame rate (i.e., every other frame is captured). The COACH may be configured by the host to wait for a pre-defined delay, between two consecutive captured sequence frames.

The number of images in the sequence (N) is provided through a dedicated API. If the command is not issued the default number is that of the COACH executable program. The compression ratio is set either through a dedicated API, or by the COACH itself.

Note: Images are stored in the DRAM are already compressed, so actual code is piled in DRAM.

Store Image Mode
This mode is auto-initiated by the COACH following the Capture Image mode. In this mode the COACH transfers the compressed image from DRAM to the flash memory, or to the host through the host interface. This is indicated by the **SetMode** API. The compressed image is written as EXIF 2.2. The COACH generates the EXIF file header, including the thumbnail of the image, during this mode.

Conditional Storage
The Store mode can be configured to either:
- Immediately start the store operation.
- Play the image for a programmable time and then store the image.
- Play the image until the host confirms or deletes the stored image.

During the delayed time, when the captured image is being played, the host can confirm or delete the store operation. If the host confirms the store then the actual storing begins. If the host deletes the store then the COACH transfers to View mode without storing the image.

In the second conditional storage option, if the host does not confirm, or deletes the store during the delay time, then the COACH stores the image as if it is confirmed.

Figure 8: Conditional Store menu in View Mode

Background Store

The storage to the flash memory is performed as a background process, i.e. one can take another image immediately after the capture process is completed and before Store is completed.

Storing to Flash Memory

Prior to the capture of another image, the host should inquire about the available flash memory size, through a dedicated API, prior to sending the COACH to Capture-Store. The host should not instruct the COACH to Capture and Store an image if there is the chance that not enough space is in the flash memory.

Files are written to the flash memory so that they comply with a file system and are ready to be transferred to a floppy or a hard disk on a PC.

Restore Image Mode

In this mode the COACH processor:

1. Transfers a single picture to DRAM and its corresponding audio title (audio message file) if it exists, from the flash memory or host interface, depending on the availability of a flash memory device.
2. Passes the EXIF “file header” and, depending on certain parameters of the header, configures the Compression Module and the Video Processing Module, such that they are adjusted and ready for playing back the compressed image.

3. Decompresses the image and stores the decompressed image in DRAM, ready for display.

Restoring from Flash Memory
Upon initiating Restore mode the COACH starts reading the image file, that is currently pointed to by the flash file pointer, to the code buffer in DRAM. The mounted flash memory can either be a flash memory card or resident flash device.

First, the COACH reads the file header and passes it, for the purpose of checking its compliance. The COACH ensures the compressed file is compliant and legal by checking the following:

- The uncompressed image is not too large to fit in memory.
- There are no more than 2 quantization tables.
- The Huffman table is compliant.
- The number of color components is 3.
- YCbCr sub-sampling is 4:2:2, i.e. H1=2, H2=1, H3=1, V1=1, V2=1, V3=1.

When opening the image, the COACH searches for the existence of an audio message file (XYZ.wav) that corresponds to the compressed image file indicated by a dedicated tag of the EXIF file. The correspondence between the image file and its audio file is according to the DCF File System. If an audio file exists, it is read after the image file is decompressed, and stored in the audio buffer in DRAM.

After successful restoration, COACH generates *Mode Completed* event, and moves to Idle mode (in the Host Control option) or to Playback Image mode (in the Self Control option).

Restoring and Displaying Policy
One of the stored images is always pointed to as the current image by the current image pointer. The current image pointer is managed by the COACH according to a set of rules, however, it can also be dictated by the host using the **SetCurrentImage**( ) command.

The COACH restores the thumbnail of the current image, several images preceding, and succeeding the current image. The current image (thumbnail) is centered, with several images preceding it and several images succeeding it, such that the total of NxM images will be displayed. The COACH indicates the host which images are restored, the order of the display and the current image.

Playback Image Mode
In this mode the COACH displays the decompressed image, and possibly, OSD messages, in an interlaced fashion out to the selected video output channel. A number of special APIs are allowed during the Playback Image mode. These commands support erasing/locking of the compressed image file,

recording/playback/erasing/storing an audio message file, and a few pre-print image processing operations.

The COACH remains in the Playback Image mode as long as another mode is not initiated.

Accelerated Playback
To allow instantaneous playback and browsing of images, the COACH can (optional) playback the thumbnail of the image (centered or up-scaled), followed by the playback of the full size image.

While a thumbnail is played the user can skip to next / previous image or stop the playback operation.

Audio Capturing and Playing
During playback mode the COACH is capable of recording and playing audio messages that are associated with the currently displayed image. Such operation is instructed through a set of audio-related commands. Evidently, using these commands makes sense only in a system where the audio port of the COACH is connected to an audio ADC-DAC. The detailed description of these commands is provided in the *Host to COACH Commands* document.

Restore Thumbnails Mode
This mode is initiated through the **SetMode** (RESTORE_THUMBNAILS) API. It may be initiated from the Idle mode or from Playback Thumbnails mode.

In this mode the COACH generates miniature versions of NxM sequential pictures from the flash memory and places them in DRAM, ready for display.
The host can configure the number of thumbnails (N and M), display location and frame width.

Figure 9: Thumbnail Mode on LCD display

The information required for the thumbnail restoration must be provided prior to initiating this mode, i.e. while in Idle mode. It is performed through the **ConfigThumbnail**( ) command (refer to the *Host to COACH Commands* document).

The thumbnails are read from the APP marker of the corresponding compressed image EXIF files in the flash memory, and arranged in DRAM so that they are ready to be displayed. If any one or more of the compressed images to be displayed as thumbnails does not have a thumbnail, the COACH fills the respective area in frame buffer with Y=U=V=128. This will result in grayish white rectangles at the locations of these thumbnails.

If the actual thumbnail is smaller than the size configured by the **ConfigThumbnail**( ) command, the COACH up-scales the thumbnail the configured size. If the actual size is larger than the required, the COACH "crops" the excess and displays only the upper-left portion that fits into the required size.

Playback Thumbnails Mode

This mode is initiated by the host from the Idle mode or automatically by the COACH from the Restore Thumbnails mode. In this mode the COACH plays the thumbnails that have been restored in the Restore Thumbnails mode.

The COACH remains in this mode until the host initiates a new mode or until the current image is not displayed. In the latter case the COACH initiates a self-mode transition (only if working in self control) to Restore Thumbnails.

Thumbnails Highlighting and Browsing

The COACH highlights the frame of the current image displayed thumbnail. For thumbnail browsing the COACH supports **ThumbnailShiftUp** and **ThumbnailShiftDown** commands. These commands are allowed only in the Playback Thumbnails mode, and only if the COACH is the master of the storage media.

In response to the appropriate APIs the current image is increased/ decreased respectively, and the following updating sequence is followed:

- If the new current image is displayed then the COACH highlights it and stops highlighting the previous current image.
- If the new current image is not displayed, the COACH stops highlighting and transits to Restore Thumbnails mode.

Thumbnails Numbering

The COACH creates thumbnails numbering automatically. The host can inquire the numbers of the current displayed thumbnails using the appropriate command, which returns the first thumbnail's number - that is the upper left thumbnail image number - and the last displayed thumbnail - that is the bottom right one.

Video Capture Mode
In this mode the COACH transmits real-time compressed video through the USB interface to a PC.

The host (PC) has to actively withdraw the compressed video, as a compressed images stream, from the COACH. Using the appropriate API, the host initiates the COACH to transfer a stream of compressed images in defined time base.

The file format of the compressed images is MJPEG, and with some other tags, degenerated in order to reduce the overhead of the CPU. The COACH does not display in this mode, irregardless of the display option set by the appropriate API.

Power Down Mode
In this mode all units of the COACH are not functioning, except for the SDRAM controller, which guarantees a minimal refresh rate that will keep the SDRAM contents intact. The configuration control registers and the status registers preserve their values. The program and data memories of the CPU preserve their contents. The CPU is in a power down mode.

Prior to going into this state the CPU software shall use the GPIO signals to put other devices in power down state. However, the latter is specific software that tightly depends on the application. Any external access to the IRQ# pin of the COACH will stop the power down and place the IDLE mode.

Calibration Mode
This mode is dedicated for automatic or semi-automatic tuning (calibration) of certain image sensor processing related parameters during production and development of COACH-based systems.

The parameters that can be tuned via the Calibration mode are:
1. VMEM – for optics correction adjustments – implies CCD sensor's fine mode, downscaled/cropped stream to TV
2. RAW data acquisition – fine or draft mode for sensor and optical quality adjustments
3. Mean Value of Black Noise - The mean value of the "black noise". In normal operation this value is subtracted from every incoming pixel
4. MS (Mechanical Shutter) calibration
5. R, B Gains (ScaleR, ScaleB) – for AWB calibration and CTC table creation.
6. PDC – Defective Pixel Detection and Correction
7. External AGC - Support for setting the gain of the external AGC according to the Lens Shading correction – aimed to obtain lens shading compensation response
8. Fixed Focus and AF calibration mode

Several transitions to calibration mode can be applied in order to adjust parameters to different conditions. Note that the COACH performs all of the calculations required for MBN, ADC gain and R, B Gains every session of the Calibration mode. Therefore, following one session of this mode the host can acquire the values required for MBN, ADC and R, B gains adjustment.

The Calibration mode is described in details in the Application Note document.

COACH*Express* tools

The COACH CPU runs a COACHWare program that controls the hardware and performs various algorithms. In most cases the system will be based on an HCE host. These Hosts handle the user interface and other system related functions.

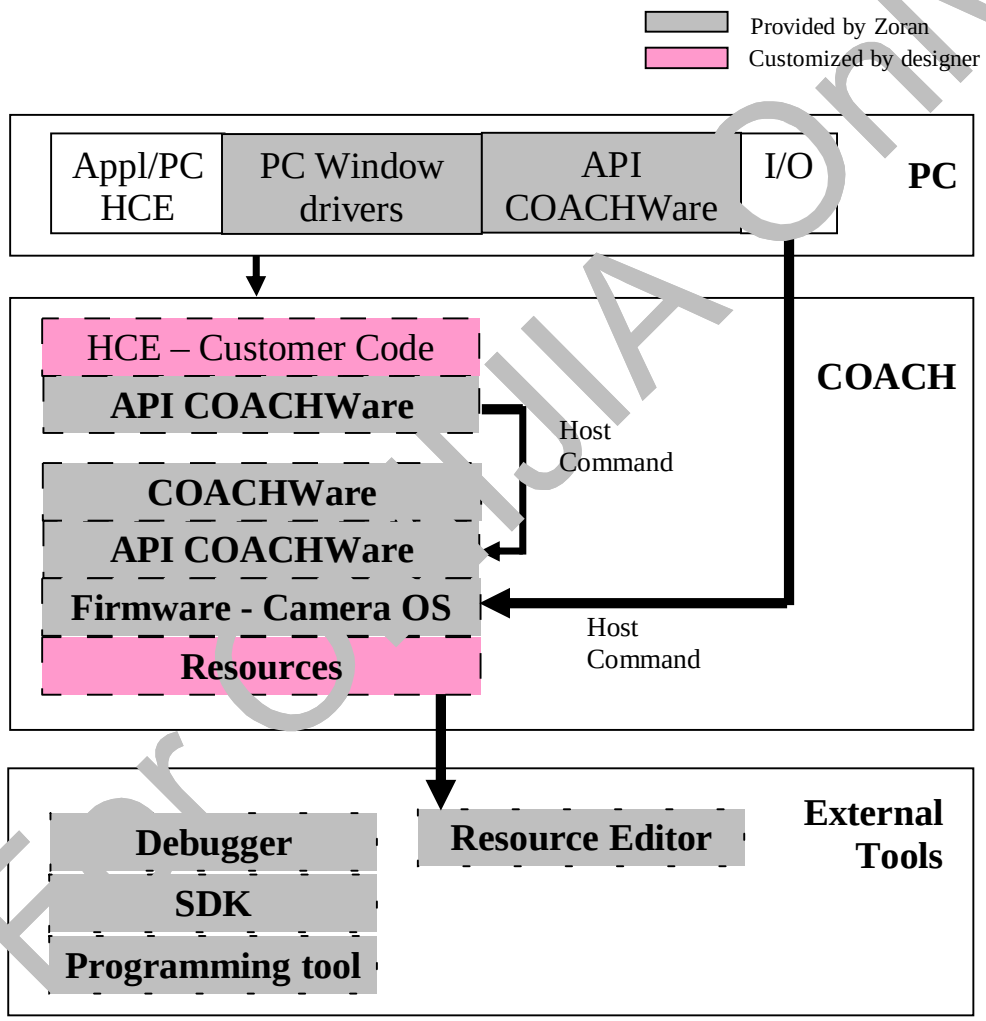

Figure 10: Main Software Modules and Tools

The host functionality can range from simple FW code that interfaces a few operation buttons into the COACH Host Interface, up to a sophisticated HCE

program that serves as a rich user interface process, controlling all buttons, other discrete circuitry in the camera, user menus, and all LCD messages.

To facilitate the camera development process, Zoran provides the system designer with a complete set ready-to-use customization tools.

The Camera Programmer (ProgTool)

The Camera Programmer is a PC utility that enables the COACH system designer to comfortably change and override HCE, COACHWare and resources. The Camera Programmer generates the database and loads it to the COACH according to the boot destination parameters.

The Resource Editor and Converter (FontMaker)

The utility enables the COACH system designer to create a COACH-compatible font map with as little as a mouse click.

COACH SDK

Provides necessary development framework such as debugger, C compiler, linker and assembly compiler.

PC-HCE

Provides convenient framework for HCE code development and debugging using MS VS (MS Visual Studio) standard tools.

THE COACHWare API

The COACHWARE API is a C language high-level API implementation for the camera host that reduces compound function calls required by each application into the basic COACH Host Commands. The COACHWARE wraps the COACH hardware and protocols into a compact, programmer-friendly software layer.

Using the COACHWARE API, the system designer can control all aspects of COACH behavior, without having to learn and be skilled with the low-level details of the COACH architecture. Using this API reduces the schedule and scope of work associated with designing a COACH-based camera, but still allows for unlimited differentiation between one COACH-based system to another.

The COACHWARE API flexibility allows the system designer to include only those COACHWARE functions that are required for his/her specific camera, while

not linking the undesired functions to the resulted application. The COACHWARE API includes a "default" menu system that enables the application software to control user interface menus using high-level function calls.

Cam-On development kit

The Cam-On is a complete camera system using the COACH reference design kit and contains the following:

- Camera main board and a CCD/CMOS daughter card
- PC drivers
- Cam-On operating manual
- Hardware description document
- Electrical schematics
- BOM

The Cam-On development kit is a superset of a typical digital camera based on the COACH digital camera processor. The kit provided by Zoran can be served not only for evaluation of the COACH chip and algorithms, but also as a basis for a new camera development, according to the required specifications.

The platform comprises a variety of removable media (storage card) interfaces, memories as well as image sensor connectors to suit virtually any particular configuration chosen by the customer for his digital camera product, thanks to the sophistication and high flexibility of COACH-6 interfacing ports. The added benefit of the Cam-on development kit availability is the ability of the DSC development team to work simultaneously on hardware and software so that the software debugging can be fully handled while running it on the development platform and then transporting the working software to the camera hardware once it is ready.

Software drivers

The list of software drivers supplied is a follows:

- **Video Stream WDM MiniDriver**
  A Zoran Kernel WDM Driver that has standard DirectX video capture interface and enabled all standard DirectX applications to the Camera utilized as a video stream source. The driver has passed Microsoft Windows XP WHQL tests as a "Digital Camera Device" and "Video Stream Device".
- **Video Stream VFW Driver**
  Microsoft Wrapper that wraps the WDM Video streaming MiniDriver enabling all standard VFW applications to use the Camera as a video stream source.

- **Twain Driver**
  Zoran User Mode Driver that enables standard Twain applications to obtain live video stream from the camera and capture images.
- **Video Stream WIA Component**
  Microsoft wrapper that wraps the MiniDriver and enables Twain/WIA applications to obtain live video stream from the camera. Appears in the Computer's Explorer window as a "Scanner and Camera" device.
- **Camera's Memory Explorer WIA Driver**
  Zoran User Mode driver that enables standard Twain/WIA applications to explore the Camera's memory, send pictures requested to a PC, take or delete pictures. The driver appears in the Computer's Explorer as a "Scanner and Camera" device and enables the user to browse the camera storage as an external disk.
- **Mass Storage Component**
  In Mass Storage Mode the camera identifies itself as a USM Mass Storage Class Device. It appears as a removable disk on the PC with the full ability to be browsed as part of PC's file system.

Glossary of Terms

Direct Show - Refers to Direct Show applications such as MGI Video Wave II, etc. Direct Show applications offer the same operability as VFW applications plus support for a wide set of various video modes, video editing, etc.

Twain Drive - TWAIN application such as Kodak Imaging, Adobe Photo Deluxe, Jasc Software Paint Shop Pro, etc. TWAIN applications can pre-view the live video from the camera, configure image parameters and take sequence of pictures.

Video for Windows - Video for Windows applications such as Microsoft NetMeeting, etc. Allows life video view from the camera, save video clips on a disk an AVI files, send live video over the Internet for video conferencing.

Mass Storage - USB feature providing the ability for PC OS to treat the Camera as an external hard drive. Image files on either resident or removable media (once inserted into the camera) can be browsed as well image down/uploading is available.