Milbeaut ISP for Digital Cameras

● Kentaro Endo

The Milbeaut image signal processor (ISP) enables a digital camera system to be implemented on a chip. It can process signals from a variety of image sensors, perform enhanced-quality image processing, and store 20-megapixel-plus still images and full high-definition (Full HD) video. This paper introduces the MB91696AM ISP, the sixth generation of the Milbeaut series. It features high-speed continuous shooting and Full HD video capture thanks to a newly developed high-speed signal-processing platform. It provides enhanced noise-reduction performance and optical-correction functions that have been improved with every Milbeaut generation and incorporates general-purpose image-processing macros to satisfy market demands. As a processor that provides high-performance and high-quality processing of still images to Full HD video as desired by today's camera users, the MB91696AM has come to be used in many digital cameras that require a high pixel count, high-speed processing, and multi-functionality.

1. Introduction

The appearance of mirrorless interchangeable-lens cameras and the further evolution of camera functions such as video capture have helped to expand the digital-camera market to a scale of about 150 million units. A digital camera basically consists of an image sensor and image signal processor (ISP), and there is a growing demand for digital cameras with advanced image sensors and high-speed, enhanced-image-quality, multi-functional ISPs. It would be no exaggeration to say that ISP performance is now the determining factor in digital-camera performance.

Fujitsu's MB91696AM ISP, which is introduced here, can perform noise removal and other types of enhanced-image-quality processing for image sizes in excess of 20 megapixels. Combined with a high-speed image sensor, this ISP supports high-speed continuous shooting at about 100 megapixel/s and full high-definition (Full HD) video capture at 1920 × 1080 pixels and 30 frames per second (fps).

2. Processor overview

The MB91696AM processor is the latest version of the Milbeaut[1), note1)] series of ISPs. Beginning with the M-1 series in 2000, Milbeaut represents an evolution of image processing algorithms that are now in their sixth generation with the MB91696AM.

The MB91696AM system LSI is designed for use with digital cameras. It features two ARM processors from ARM Ltd. as independent CPU cores, sensor signal processing, JPEG compression/decompression, HD-video compression/decompression, a DDR3/DDR2-compatible SDRAM controller, a video interface, a USB 2.0 interface, and a variety of card interfaces. With a significantly improved image processing algorithm and a newly developed H.264 Full HD codec engine, the MB91696AM provides a high-performance, high-image-quality digital camera system-on-a-chip that meets the needs of today's camera users, from still images to Full HD video.

A block diagram of the MB91696AM is shown in **Figure 1**, and its external appearance is shown in **Figure 2**. The main specifications are listed below.

- Processor technology: 65-nm CMOS process

note1) "Milbeaut" is a trademark of Fujitsu Semiconductor denoting its series of ISPs for digital cameras.

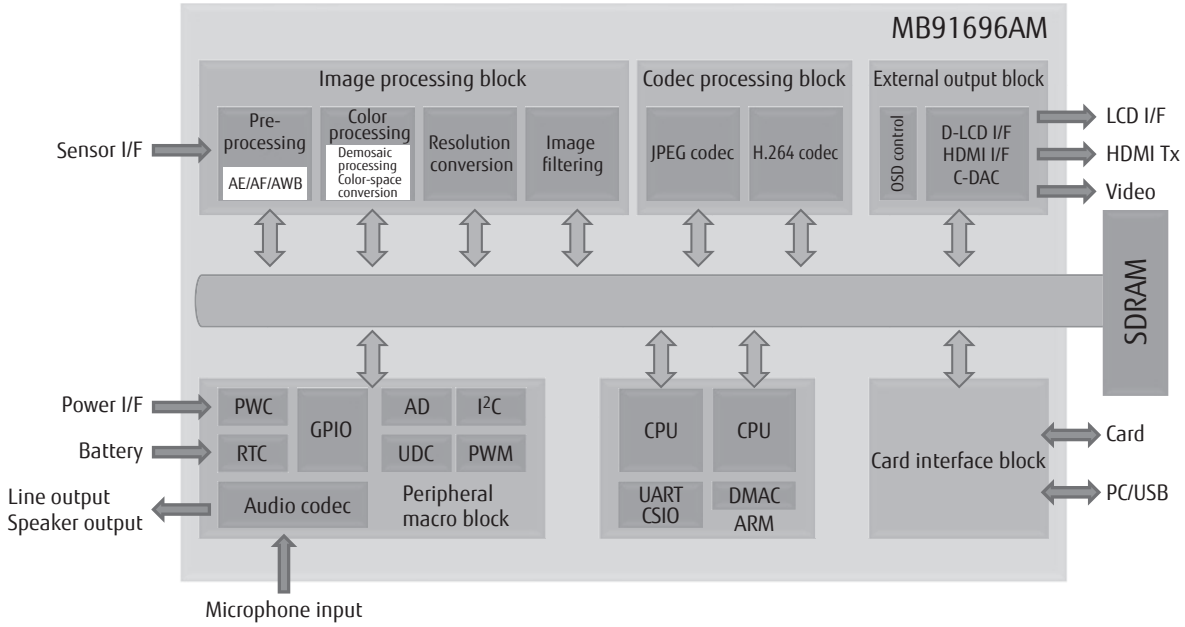


Figure 1
MB91696AM block diagram.

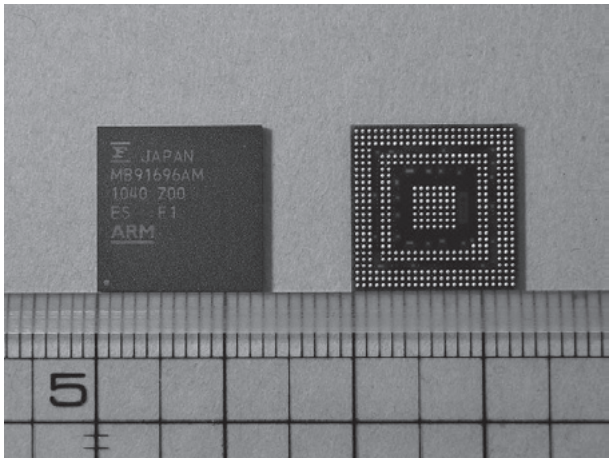


Figure 2
MB91696AM external appearance.

- CPU-core operating frequency (max.): 288 MHz
- Image processing rate (max.): 216 megapixel/s
- Video codec: H.264/MPEG-4 advanced video coding
- HDMI interface: Yes
- Package type: FBGA-385
- Package size: 13 mm square

The following sections introduce the key features of the MB91696AM ISP, namely, high-speed processing, techniques for enhancing image quality, Full HD video support, and multi-functionality.

3. High-speed processing

As the pixel count of image sensors increases, the amount of processing required for high-speed continuous shooting of still images and the capturing of Full HD video increases at an exponential rate. Achieving such processing at high speed with a high level of image quality is difficult, however, with existing technologies. To resolve this problem, we developed a new image-processing platform and thoroughly optimized image processing for the MB91696AM ISP.

3.1 Two ARM processors

We developed the base firmware for the MB91696AM by using an ARM platform, which is widely used in the development of many kinds of portable devices. This approach provides the following benefits.

1) Increases development efficiency across multiple customers
2) Simplifies customer-based customization
3) Facilitates implementation of diverse applications
4) Reduces development labor hours through the use of extensive middleware and a rich development environment

The MB91696AM incorporates two ARM processors as independently operating cores. The base firmware can treat these processors as a main CPU and a sub-CPU. It can allocate system control, operating system (OS) control, and sub-CPU control to the main CPU and some control tasks to the sub-CPU. It can also treat the latter as a dedicated CPU for executing image-processing applications. This scheme results in a number of advantages. When shooting still images, it enables multiple image applications such as face recognition, scene recognition, panorama shooting, and high dynamic range (HDR) shooting to be launched simultaneously so that parallel processing and high-speed image processing can be performed. Furthermore, this double-core approach makes it possible to capture Full HD video at 1920 × 1080 pixels and 30 fps while shooting video and running applications like face detection, face recognition, and image stabilization (camera-shaking compensation) simultaneously.

3.2 Optimized image processing

An ISP receives signals in a Bayer arrangement[note2] from the image sensor and performs various types of image processing. High-speed continuous shooting and the capturing of Full HD video, which demands high-speed processing, requires that signals input from the image sensor be processed one after the other in rapid succession. This requirement calls for pipeline processing. The MB91696AM's image-processing block is divided into smaller blocks for processing signals including a pre-processing block for processing signals in a Bayer arrangement, a color-processing block that includes demosaic processing,[note3] a resolution-conversion block, and an image-filtering block. We have optimized these processes so that they do not require time-division processing, thereby enabling them to be pipeline processed.

Circuits that were previously processed in different macro blocks within the image-processing block have been incorporated into one macro block. This means that data storage to SDRAM and reference processing that had previously been performed between two macro blocks can now be omitted.

note2) A mosaic arrangement of red (R), green (G), and blue (B) color filters

note3) Interpolation processing to obtain an RGB signal from a Bayer-arranged signal

We also made advances in converting applications to hardware, which, in addition to speeding up processing, is expected to reduce power consumption by reducing the processing load on the CPUs. This is particularly effective for face-detection processing when capturing Full HD video, which already places a heavy load on the CPUs.

3.3 High-speed continuous shooting

High-speed continuous shooting requires high throughput for a series of signal-processing tasks consisting of the input of Bayer-arranged signals from the image sensor, the processing of signals to enhance image quality, and the storage of data.

While previous ISP processors featured only parallel interfaces for the image sensor, the MB91696AM is also equipped with a differential signal serial interface to connect with new types of image sensors. The MB91696AM can input Bayer-arranged signals at a maximum rate of 216 megapixel/s when connecting to a high-speed image sensor, and it incorporates an SDRAM controller supporting DDR3/DDR2 interfaces. When combined with DDR3 SDRAM, the MB91696AM can achieve a data bandwidth about 2.5 times that of previous processors and an image-processing performance of about 100 megapixel/s. On top of that, it provides an SD-card interface supporting SDR50 mode of the UHS-I specification, enabling high-speed storage of JPEG data.

Thanks to the above features, the MB91696AM can achieve high-speed continuous shooting of about 8 fps (for 14-megapixel images), which is about 5 times faster than with previous processors.

4. Techniques for enhancing image quality

Image sensors with higher pixel counts are a current trend in digital cameras. Compact digital cameras frequently use 1/2.3-inch image sensors. These image sensors comprise over 15 million photosensitive elements in an area of 6.2 × 4.6 mm, which is about the size of a fingertip. The trends in area/pixel and total pixel count in image sensors used in compact digital cameras are shown in **Figure 3.** This data shows how pixel features have become finer year after year, reaching an area/pixel of 1.7 μm^2 in 2011 models. Greater integration, however, is increasing the amount of heat

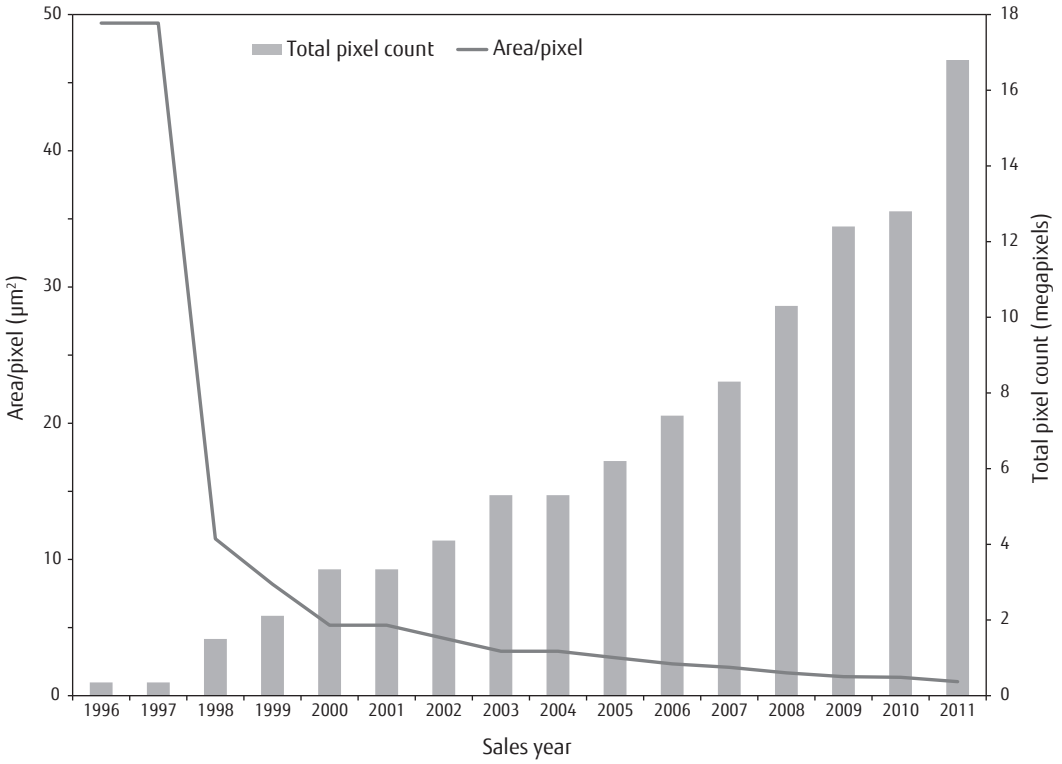


Figure 3
Change in area/pixel and total pixel count of image sensors.

generated, resulting in the generation of thermal noise and the degradation of the S/N ratio for data output from the image sensor. Compact digital cameras, moreover, make optical design difficult since they call for a compact and thin configuration while requiring low-cost optical components to keep the sales price low. There is consequently a high possibility that optical problems like distortion and shading will occur.

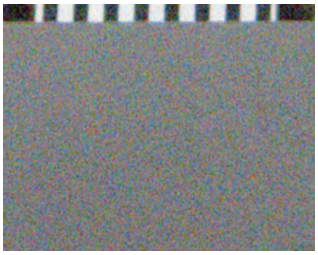
In light of the above, the demand for enhanced noise-removal performance and optical correction functions in ISPs is high. The Milbeaut series of ISPs has been improving performance and functionality with every generation. In the following sections, we describe how the MB91696AM enhances image quality.

4.1 Enhancing image quality against Bayer-arranged signals

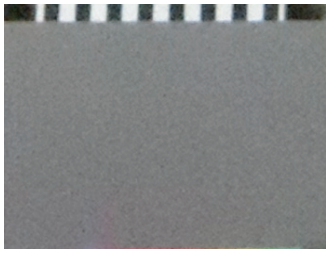
Optimal signal processing in the image-processing block differs depending on whether it is performed before or after demosaic processing. First, we present three main processes in the pre-processing block that come before demosaic processing.

The first is defect pixel correction. Defect pixels included in a Bayer-arranged signal can be corrected by using a static process that identifies noise pixels from an image frame captured under light-blocking conditions and then corrects them on the basis of pixel-defect information set in SDRAM. Defect pixels can also be corrected by using a dynamic process in real time. Contiguous defects can be corrected as well.

The second process is noise removal. Multiple noise-removal filters can be used to remove not only noise coming from the image sensor and hardware but also noise unique to Bayer-arranged signals such as color moiré, block noise, and color unevenness. A feature of the MB91696AM algorithm is that long-wavelength luminance noise can be removed while preserving the high-frequency components of the target object. In short, noise components can be efficiently removed without losing a sense of high resolution (**Figure 4**). The MB91696AM can also remove noise by detecting the optical zero level and taking the optical-zero-level portion of the input signal into account. This raises correction accuracy for dark areas of



Before correction



After correction

Figure 4
Noise-removal effect.

Before correction

After correction

Figure 5
Distortion-correction effect.

the image, where the signal level is low.

The third process is the application of correction functions with respect to sensor output and the lens itself. The MB91696AM has built-in correction functions for pixel gap, linearity, shading, distortion, and chromatic aberration of magnification; it can therefore deal with the optical problems associated with compact digital cameras mentioned above. An example of the distortion correction effect achieved with the MB91696AM is shown in **Figure 5**.

4.2 Enhancing image quality after demosaic processing

After demosaic processing, the ISP converts the RGB signal into a YC signal, separates that into a luminance (Y) signal and a chrominance (C) signal, and performs noise removal for each signal. For example, processing of the luminance signal may focus on the signal level (brightness). In bright areas of the image, the level of the luminance signal is high and the noise level is relatively high as well. Adaptive processing that achieves both high noise-removal performance and a sense of high resolution can therefore be performed. At the same time, applying a low pass filter (LPF) only to the chrominance signal makes it possible to remove false colors or conspicuous color noise in low-saturation areas while maintaining contours.

In addition, the MB91696AM adds contour enhancement/correction components to an image after it has been subjected to noise-removal processing. In the past, components targeted for correction were extracted through the use of a high pass filter (HPF); for the MB91696AM, we have developed an algorithm that reduces disturbance in the correction components with respect to contour pixels. This approach achieves images with sharp edges.

5. Full HD video support

5.1 Codec engine for digital cameras

The first single-lens reflex camera equipped with a function for capturing Full HD video went on sale in 2008. It was then predicted that compact digital

cameras would one day be equipped with such a function, and, as it turned out, the MB91696AM was the first ISP in the Milbeaut series to support Full HD video capture at 1920 × 1080 pixels and 30 fps. Needless to say, capturing Full HD video requires the processing and storing of a huge amount of data compared to still images. With this in mind, we developed an H.264 Full HD codec engine specialized for digital cameras that is based on Fujitsu Laboratories Limited's proprietary H.264 codec algorithm, which is widely used in many audio-visual devices. This engine features low power consumption due to the use of an architecture that substantially reduces the amount of image data that needs to be transferred. By using this engine, which efficiently compresses and encodes video data through dedicated hardware, the MB91696AM achieves clear, Full HD video capture with little noise. This function can operate simultaneously with a variety of applications such as face detection, camera-shaking compensation, noise removal, motion detection, and wide dynamic range (WDR) correction.

5.2 Noise removal

The MB91696AM ISP provides the dedicated hardware described above with a time-axis filter and removes noise during H.264 video compression. Specifically, it compares information between consecutive frames along the time axis and performs adaptive alpha blending, which has the effect of reducing temporally fluctuating random noise. Moreover, since the bit rate that had been consumed by random noise can now be assigned to the video signal itself, this process also has the effect of improving compression efficiency.

The color-noise-removal process performed in still-image processing was expanded so that it can also be used in video capture. With the approach previously used, performance of this processing by a single hardware macro, there was no margin in the processing band, and the processing speed was insufficient for capturing Full HD video. In response to these problems, we added a faster version of this process that removes color noise generated during video capture. With this new approach, color noise in low-frequency bands, which is normally very difficult to remove, is removed. This approach is quite effective when shooting video in a high-sensitivity shooting environment such as an indoor location. The MB91696AM ISP thus has a great advantage over processors not equipped with this color-noise-removal process for video capture.

6. Multi-functionality

Recent years have seen an ongoing drop in the price of compact digital cameras despite gains in performance and functionality. As a result, camera makers find it necessary to place camera products with new functions on the market in relatively short product cycles while keeping costs down. In addition to software-based functions that can be easily updated, the MB91696AM comes equipped with general-purpose image-processing macros that can be executed through hardware processing that excels in terms of processing time and power consumption. This scheme provides for a flexible response to ongoing demands for multi-functionality. We here introduce a few of the many applications provided by the MB91696AM.

1) Face detection

Face detection is now considered to be an essential function of digital cameras. The MB91696AM not only can detect faces but can also distinguish between adults and children and detect smiles and blinking. It provides, moreover, a face-enhancement function that automatically corrects for facial blemishes such as fine wrinkles, age spots, and dull skin. These processes are achieved by dedicated hardware in the MB91696AM.

2) Automatic scene recognition

The MB91696AM recognizes scenes by comparing an input image with scene data stored in a database. It can then control exposure, focus, flash, and other parameters as needed for the recognized scene. It can recognize, for example, portrait, landscape, and macro scenes as well as shooting conditions such as twilight, night, backlight, and low-light.

3) HDR correction

HDR correction expands the dynamic range by combining multiple images taken with different shutter speeds. For example, shooting with a shutter speed appropriate for highlights can capture tones in a highlighted area, and shooting with a shutter speed appropriate for shadows can capture tones in a shadow area. Images shot with these different shutter speeds can be combined using image filter processing in the MB91696AM so that highlight areas do not become saturated and shadow areas become more visible, thereby expanding the dynamic range.

7. Conclusion

In this paper, we introduced Fujitsu's MB91696AM ISP, which was developed for digital cameras. The need is growing for higher processing performance to keep up with the trend toward higher pixel counts, faster processing speeds, and multi-functionality in digital cameras, as discussed in this paper. This trend toward higher performance also has the effect of increasing power consumption, so developing measures for reducing power has become an urgent matter. While not directly touched upon in this paper, we are also expending efforts on developing technologies for reducing power consumption. At the same time, the deployment of a high-speed communications infrastructure is expected to drive expectations for network support and other advanced functions that go beyond the conventional framework of digital cameras.

Looking forward, we will strive to determine market needs as accurately as possible and continue to develop and market the high-performance, high-picture-quality Milbeaut series of ISPs featuring ever evolving image-processing algorithms.

References

1) Fujitsu: Milbeaut Imaging Processors. *http://www.fujitsu.com/global/services/microelectronics/product/assp/milbeaut/*

Kentaro Endo
Fujitsu Semiconductor Ltd.
Mr. Endo is engaged in the development of image processing algorithms.