Milbeaut Image Signal Processing LSI Chip for Mobile Phones

● Satoru Komatsu ● Mitsumaro Kimura ● Akira Okawa ● Hideaki Miyashita

The camera function of mobile phones has progressed in the last few years, as typified by the rapid spread of high pixel count, high resolution, and full high-definition video recording and playback features in smartphones. Although it is possible to implement camera functions such as rapid imaging and browsing from personal computers and mobile terminals into the application processor in a mobile phone, many customers prefer dedicated image signal processors (ISPs) as they offer image quality and performance comparable to those of compact high-end digital cameras. This paper describes the development and performance of the Milbeaut Mobile image processing LSI chip developed by Fujitsu for mobile phones.

1. Introduction

The market for smart mobile phones continues to expand due to their diverse applications and functions. The camera function in particular has been evolving steadily since it was introduced to mobile phones in 2000 and is now a major mobile phone function, providing high-pixel count and high resolution as well as full high-definition video recording and playback.

Milbeaut Mobile is a series of image signal processors (ISPs) for use by the camera function in mobile phones. It was developed by Fujitsu and has been on the market since 2003. Here, we present an overview of the Milbeaut Mobile series and describe the system architecture, features, functions, and processing performance of the MBG046, the latest Milbeaut Mobile processor.

2. Evolution in Milbeaut Mobile functionality

The camera function is achieved by using a specialized lens and image sensor that must be small and thin for mounting on mobile phones. These constraints initially prevented image quality from being as good as that of digital cameras. An ISP must therefore be able to raise the quality of images captured by a lens and image sensor under such severe constraints to a level satisfactory to users.

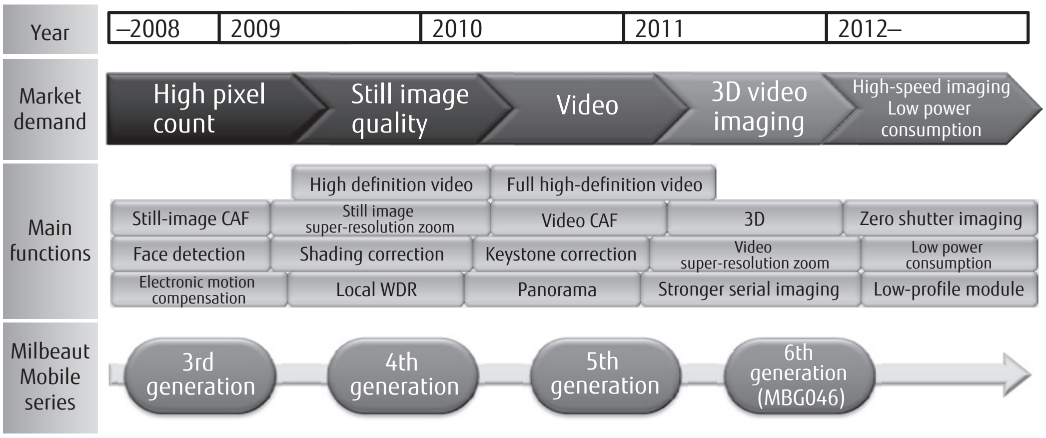
By 2008, the 3rd generation Milbeaut Mobile ISP incorporated such digital camera functions as still-image continuous automatic focus (CAF), face detection, and electronic motion compensation (**Figure 1**). The latest generation ISP (the MBG046) incorporates nearly all camera functions. It also features full high-definition (1920 × 1080 pixels) video, video CAF, and 3D video imaging as demanded by the market.

The recent achievement of a further reduction in imaging device pixel size, a higher pixel count, and faster imaging has caused problems with image quality and has increased ISP power consumption.

3. ISP architecture

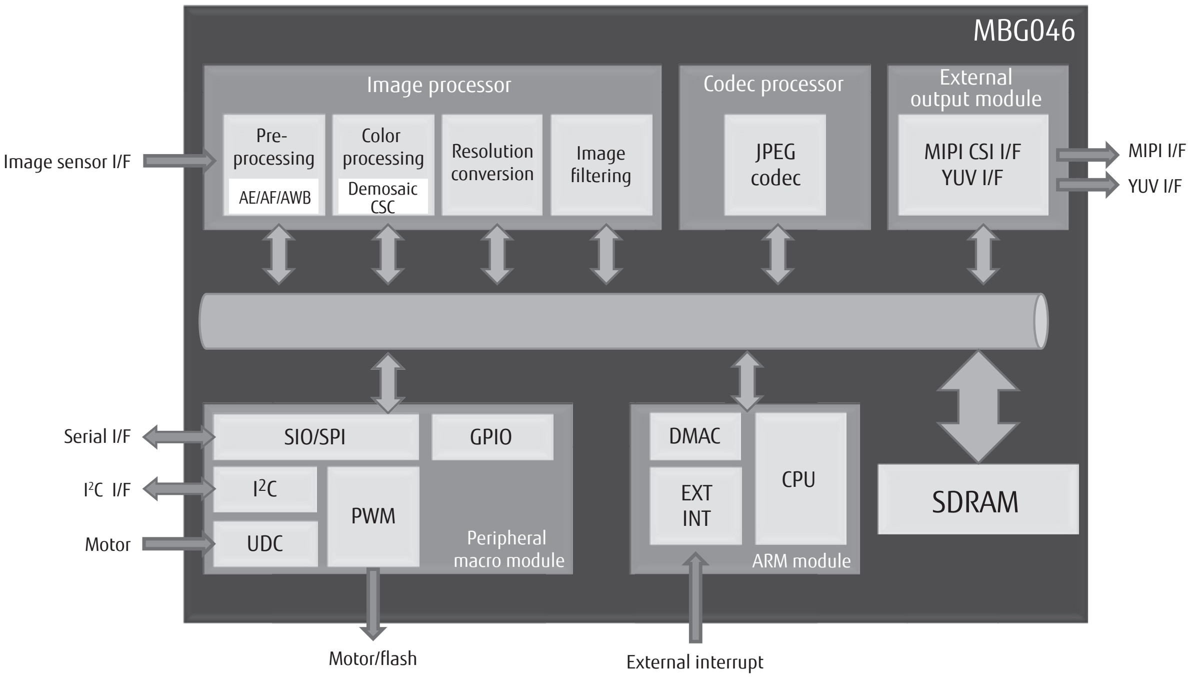
The image processor module is the main functional component of the Milbeaut Mobile ISP (**Figure 2**). It sequentially processes the image data received in the Bayer array signal from the image sensor, including noise removal and other corrective functions, to produce a beautiful image and conversion into a format for display on the screen of a mobile terminal or personal computer.

The module can also access hardware image filters and the CPU to perform additional processing (rotation and distortion correction, software image processing,



WDR: Wide dynamic range

Figure 1
Evolution in Milbeaut Mobile ISP functionality.



AE: Automatic exposure
AF: Automatic focus
ARM: High-speed processing using a platform made by ARM Ltd.
AWB: Automatic white balance
CSC: Color-space conversion
CSI: Camera serial interface
DMAC: Direct memory access controller
EXT: External
GPIO: General-purpose input/output
I^2C: Inter-integrated circuit
INT: Internal
MIPI: Mobile industry processor interface
PWM: Pulse width modulation
SIO: Serial input/output
SPI: Serial peripheral interface
UDC: USB device controller
YUV: Signal format consisting of luminance and color difference

Figure 2
MBG046 block diagram.

etc.) on image data that is stored in SDRAM (memory device for image data). That enables flexible advanced image processing such as face detection, high dynamic range (HDR) composite processing, still-image motion compensation, object tracking, panoramic image generation, and scene detection.

4. MBG046 ISP functions

The latest generation Milbeaut Mobile processor is the MBG046. Its basic operation involves real-time conversion and correction of the Bayer array signal from the sensor for output to the application processor (not shown in Figure 2), which is connected to an external output module. The ISP is thus optimized for mobile camera systems and enables the application processor to display the received image data on the screen and store the data in the storage device without modification.

1) High-speed image processing

As described in Section 3, the image processor performs the basic image processing functions. It can process 8-MB images at up to 27 frames per second (fps) and high-definition images at more than 60 fps.

The preprocessor, which is part of the image processor, accepts the Bayer array signal from the image sensor and performs sequential conversion and correction processing. It also collects statistical data on the image data. The statistical data is used in software computation to obtain an appropriate white balance and exposure time. The calculated results are used to reset the hardware to enable basic camera operation. Thus, nearly all of the basic image processing functions are implemented in hardware, resulting in high-speed processing and low power consumption.

2) Strong noise reduction

Because Milbeaut Mobile targets cameras built into mobile phones, it is most often used with lens and image sensors that are less expensive than those used in digital cameras, so image quality is a problem. Dealing with image noise is a particularly important function.

Therefore, we equipped the image processor with mechanisms to reduce luminance noise and color noise that are stronger than those used in digital cameras. To remove noise without loss of resolution, we incorporated the latest technology into the MBG046, enabling application of different methods of noise removal simultaneously to match the properties of the image.

3) Fast image processing

Products for mobile phones must be configured for connection to an application processor as the next processing stage. Unless the Bayer array signal from the sensor is converted and corrected and the result sent to the application processor as quickly as possible, there may be a delay in response-sensitive cases such as video. As shown in Figure 2, the Milbeaut Mobile achieves that speed by incorporating a function that sends the image data processed by the image processor unit directly to the image output unit instead of the usual scheme of performing the various interpolation processes via SDRAM. That virtually eliminates delay due to the conversion and correction of the Bayer array signal (the delay is reduced to 1% or less of the transfer time for one image).

4) Software configuration

The software stack of the MBG046 is illustrated in **Figure 3**. The software processing that is essential to the camera system is the hardware sequence control and computation for the "3A module" (automatic white balance adjustment, automatic exposure adjustment, and automatic focusing). The hardware controller performs timing control among different independent image processing hardware devices to implement one sequence of the image processing flow. The 3A module calculates the appropriate exposure, white balance, and focal point from luminance, color-balance, and spatial-frequency information obtained from device drivers. By relegating those parts involving complex processing but light computational load to software and those parts that involve heavy-computational-load image data processing to specialized hardware, we were able to keep the computational load of the software light while maintaining image processing performance. That makes it possible to assign CPU resources to additional software image processing (motion compensation, face detection, etc.) and achieve a system that is both flexible and capable of advanced processing.

5. Milbeaut Mobile 3D processing functions

The configuration of a 3D video imaging system with a Milbeaut Mobile ISP is shown in **Figure 4**. In a conventional camera system, 3D video imaging is

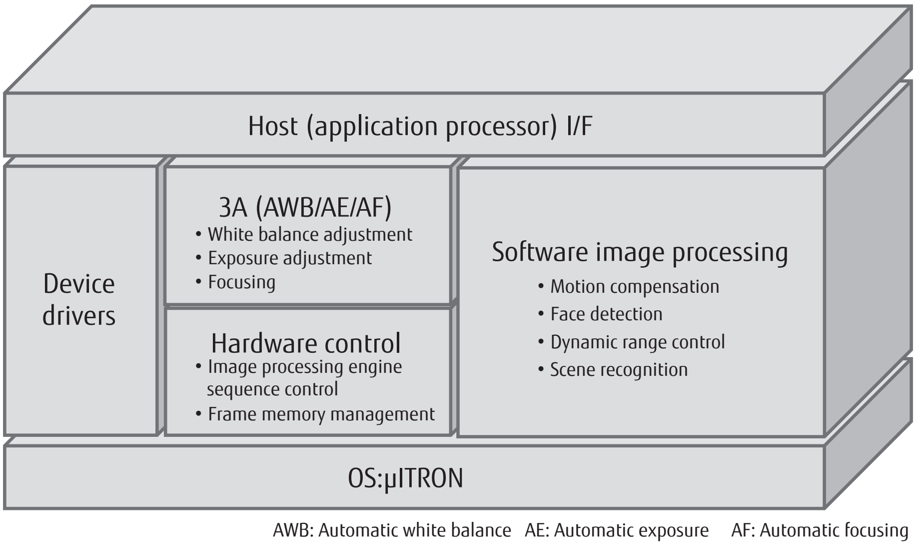


Figure 3
MBG046 software stack.

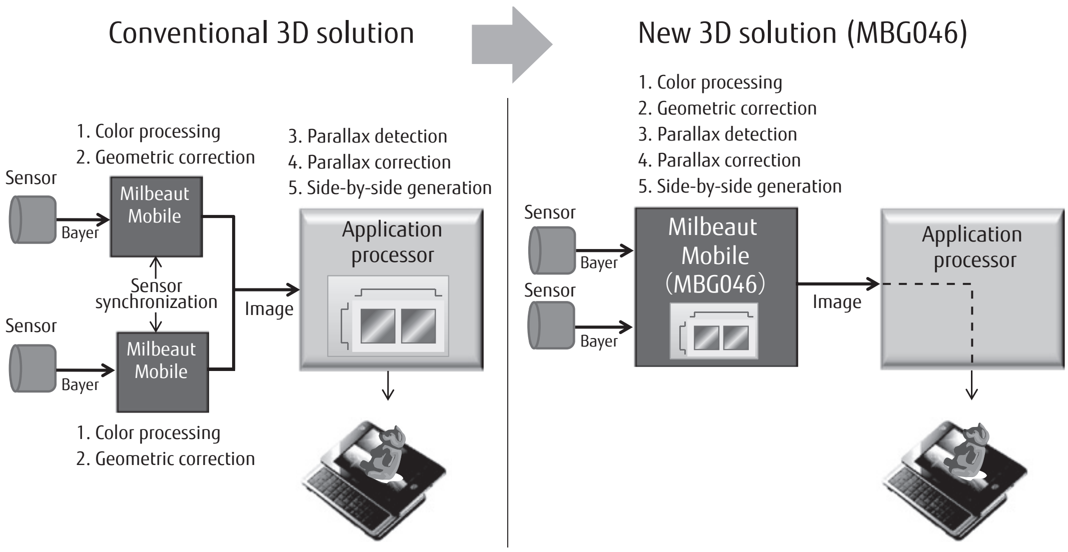


Figure 4
3D video imaging system configuration.

implemented using two ISPs, each of which processes the image data input from one of a pair of image sensors for the left and right eyes. The separate ISPs are used for processing the left and right images, and a mechanism is required for sensor synchronization between them. The correction processing needed for 3D imaging is implemented at a later stage in the application processor. Fujitsu Laboratories improved that configuration by developing a 3D correction algorithm that can do optimum 3D processing with a single ISP.

1) Geometric correction and parallax correction

3D image generation requires two types of correction.

The difference in the mounting position between the two camera modules produces differences in image height and angle between the images from the two image sensors that are input to the ISP. Correction of those differences is called geometric correction.

The difference in the angle at which an object in actual 3D space is seen by the left and right eyes in accordance with distance, which is called parallax, is the basis for human depth perception. Excessive parallax may cause fatigue when viewing 3D, so parallax correction is required.

2) 3D video processing flow

The 3D video processing flow implemented in the MBG046 is shown in **Figure 5**. First, it is necessary to prepare correction data for each individual difference to be used in the geometric correction. Because the camera modules are mounted in fixed positions, the correction processing for that difference is done once, and the result is stored in non-volatile memory for use in later imaging. That correction value is obtained by imaging a flat-screen test chart and then calculating an error value from height and rotation deviations.

Next, the geometric correction value is used to reshape (square) the left and right images, leaving parallax as the only difference between the images. If excessive parallax is detected, a value for correcting the parallax to within an appropriate range is calculated. That value is used as the basis for the rectangle conversion. This two-pass rectangle conversion would consume processing bandwidth if performed on the original image, so single-pass processing is used. First, the geometric correction is performed on a compressed image, and the degree of parallax correction that is required is determined. That parallax correction is multiplied by the previously saved geometric correction to create a rectangle conversion that is applied to the original image. In this way, both corrections can be accomplished at one time. This more efficient use of in the processing bandwidth makes it possible to implement full high-definition 3D video imaging at 30 fps.

3) 3D display format conversion

After correction by rectangle conversion, the signal must be converted to side-by-side or another standard 3D display format for output to a 3D display. The MBG046 has two systems for this, one for image sensor input and one for internal processing. That enables integrated processing, which extends the color processing performed by an ordinary ISP to 3D processing on a single chip, thus achieving high-quality 3D video imaging. This approach also can simplify image sensor synchronization and reduce the load on the application processor.

6. Conclusion

We have described the evolution, architecture, and functions of Fujitsu's latest Milbeaut Mobile image processor for mobile phones. We can expect continued

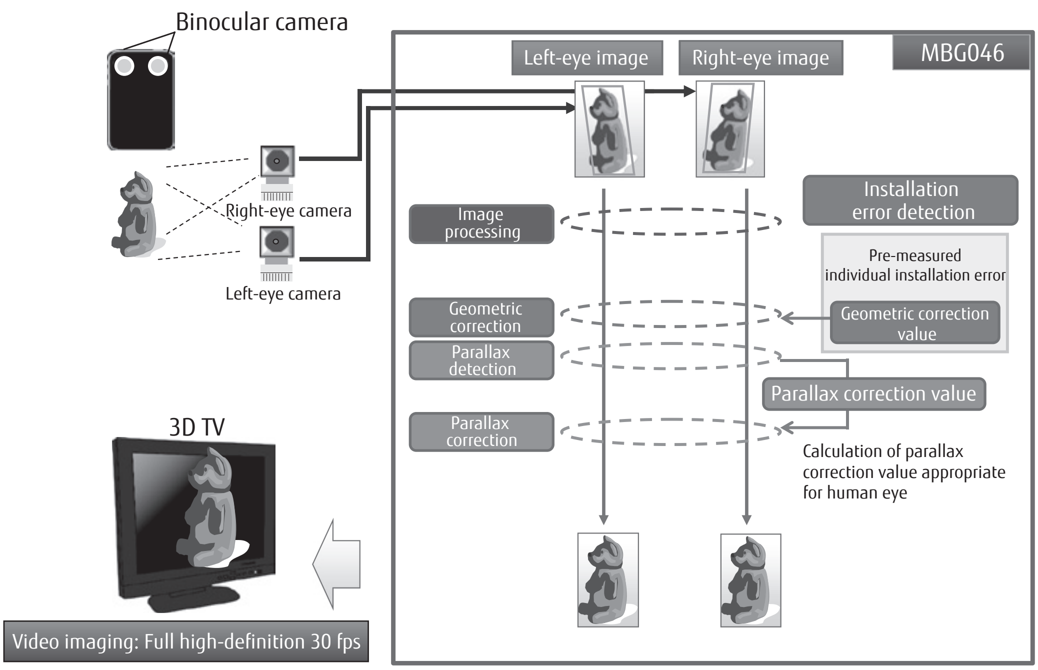


Figure 5
MBG046 3D video imaging process.

steady improvement in the performance of mobile terminals, which will lead to increasing demand for imaging processors to cope with further development of the camera function toward lower power consumption, faster still imaging, a lower camera module profile, and the higher capacity and frame rates for video data that will accompany faster network channels. Fujitsu will continue developing image signal processors that have optimum performance and functions, which will enable us to offer a reliable product line that keeps up with those trends.

Satoru Komatsu
Fujitsu Semiconductor Ltd.
Mr. Komatsu is engaged in development of the Milbeaut LSI for mobile phones.

Akira Okawa
Fujitsu Microelectronics Solutions Ltd.
Mr. Okawa is engaged in development of firmware for the Milbeaut LSI for mobile phones.

Mitsumaro Kimura
Fujitsu Microelectronics Solutions Ltd.
Mr. Kimura is engaged in development of firmware for the Milbeaut LSI for mobile phones.

Hideaki Miyashita
Fujitsu Microelectronics Solutions Ltd.
Mr. Miyashita is engaged in development of firmware for the Milbeaut LSI for mobile phones.