CprE 488 – Embedded Systems Design

HW-2: Digital Camera Sensors

Assigned: Friday of Week 4
Due: Friday of Week 5
Points: 10

1) CPU Architecture. Why are ARM processors significantly more prevalent in modern embedded systems than comparable processors from Intel (e.g. Intel Atom-based products)? Provide at least two reasons. What are three meaningful differences between the ARMv8 ISA and x86-64? Be specific.

2) Digital Camera Sensors. A digital camera uses an array of photo-sensors to capture an image. When the shutter button is pressed, the exposure process begins, and light is directed through a lens to the individual sensors, each of which measures the resulting intensity. The relative quantity of photons at each sensor site are read as electrical signals and collected as digital values, the precision of which is determined by the bit depth.

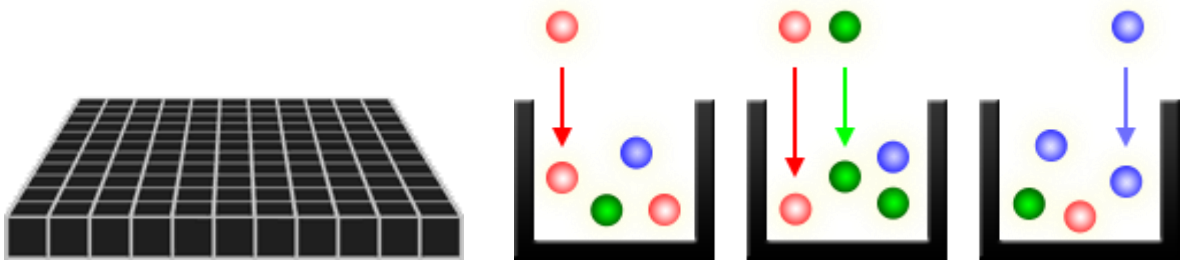

Figure: Visualization of sensor array and light as captured into individual sensor cavities. Figures and descriptions are based on [1] and [2] – check these links for additional information.

However, the photosites illustrated above would only be able to capture grayscale images, since the sensors are unable to distinguish between the red, green, and blue intensities of the luminous exposure. To capture color images, a filter has to be placed over each cavity that permits only particular wavelengths of light. Most digital cameras only capture one of the three primary colors at each site, and so they discard (roughly) two-thirds of the incoming light. Consequently, the camera has to approximate the other two primary colors in order to have a full color for each pixel. The most common type of color filter array is called a "Bayer array", as is shown below.

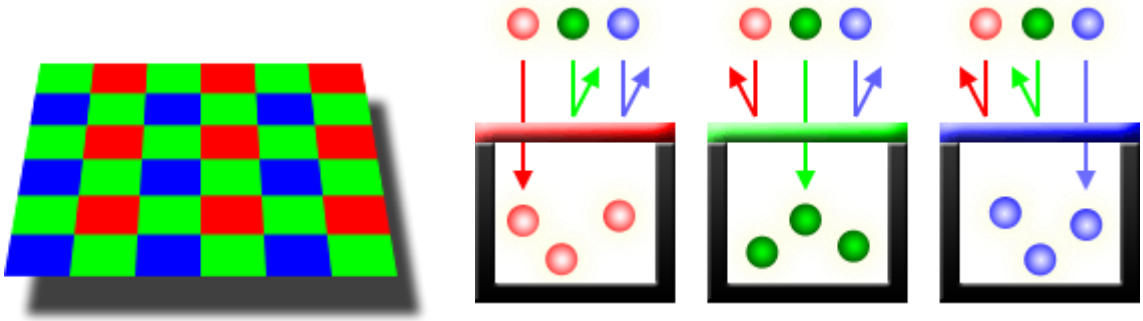

Figure: Color Filter Array illustrating a Bayer pattern, and Red, Green, and Blue filtered light sensors.

The Bayer filter uses a simple strategy: capture alternating red, green, and blue colors at each sensor, with twice as many green filters as red and blue. Briefly explain why more green sensors are allocated than red/blue. Specifically, the Bayer filter pattern is a repeating 2x2 mosaic pattern of light filters, with green filters at opposite corners and red and blue in the other two positions. This pattern means that at any photosite location, one color can be measured directly while the other two will have to be interpolated. This interpolation process (also referred to as "demosaicing") averages the values for the matching neighbor pixels in a 3x3 grid surrounding the center pixel. Provide a C pseudo-code implementation of CFA demosaicing, assuming an input array of 8-bit pixels representing the light intensities of a 1080p image.

Next, consider the design of an FPGA-based embedded system that implements the main functionality of a digital camera. Specifically, consider the following data processing and memory management steps:

- A shutter button triggers light capture through a 1080p sensor array. Assume a high-speed camera that can capture 30 frames per second.
- 8-bit grayscale values are streamed sequentially from the sensor array to the FPGA, where the Bayer CFA is first applied, producing 24-bit RGB pixel values.
- The resulting 24-bit 1080p image is connected to a Video Direct Memory Access (VDMA) module on the FPGA, which streams the values to a framebuffer DRAM.
- A CPU residing on the FPGA reads values from the framebuffer and performs some subsequent processing on the pixels, converting them from a 24-bit RGB format to a 16-bit YCbCr format. These 16-bit pixels are stored in a second framebuffer.
- A second VDMA module streams the 16-bit 1080p image to an HDMI controller that is located off-chip. The connected monitor refreshes at a rate of 60 frames per second.

Draw a simple diagram illustrating the interconnection between the various components in this camera design. What are the off-chip bandwidth requirements of this system? Be specific, and show your work.