HIGH-SPEED X-RAY IMAGING AT NSLS

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Abstract

We describe two projects currently underway at National Synchrotron Light Source (NSLS). The first is an inexpensive yet high-performance image acquisition system utilizing a low-cost firewire camera, a PMC firewire controller, EPICS [1] and the in-house written real-time RTEMS-mvme5500 Board Support Package. The BSP, EPICS, and RTEMS[2] software and firewire drivers demonstrate a high throughput of image display for the 1024x768x8bit mode of 30 frames per second (fps) of data transfer, while triggering EPICS display at 30 Hz simultaneously. The second is the readout system for the LCLS X-ray Active Matrix Pixel Sensor (XAMPS) detector. The specification of the detector readout requires a 1024x1024x14bit image to be stored to disk at 120 Hz, an average data rate of 252 Mega Bytes/sec. A faster SBC was chosen to be interfaced with a FPGA based PMC card and Fiber Channel storage system. This cost-effective prototype will function efficiently and reliably as a data acquisition system for the implementation of the XAMPS detector developed at the NSLS. Modern software and the use of commercial hardware technology has cut our cost of both systems, and delivered excellent performance.

INTRODUCTION

The control system at NSLS beam lines has been running EPICS/RTEMS since 2003[3]. Thus, it was decided that both image acquisition systems will follow the same model for system integration. An in-house written RTEMS-MVME5500 Board Support Package (BSP) [4][5] was developed because Motorola had announced the end-of-life for the MVME2307 board. At this point, we have two different imaging projects in progress. One is a PMC based firewire controller combined with the Motorola MVME5500 Single Board Computer (SBC) for data acquisition from firewire cameras. Another one is a prototype image processing system to test and verify the XAMPS detector that is being developed at NSLS for LCLS.

IMAGE PROCESSING FOR FIRWIRE CAMERAS

At the EPICS3.14.8.2 based VME micro level, the RTEMS device drivers for the PMC based firewire controller, and libraries for the IIDC1394 based cameras have been written in-house to be integrated into the RTMS-MVME5500 control system. The Operating System Independent (OSI) layer facilitates the porting of the above two layers to other real-time OS. The device drivers are written to work with any generic PCI based firewire controller. The two layers of software are further developed, and interfaced with the EPICS firewire device/record support routines and *.edl GUI files that were contributed by Diamond Light Source (UK). The firewire interface device is isochronous and has a DMA engine to move the image data, instead of consuming CPU power, which allows time for the software to process the EPICS video while each frame of data is being transferred via DMA. Optimization, image techniques and real-time programming at the RTEMS driver/library/BSP levels provide the software the capability to trigger the camera at 30 fps and EPICS display at 30Hz simultaneously for the 1024x768x8bit mode (video mode) under the limited 100MHz network bandwidth and indeterministic network environment. Thus, the system does not have to run in a private network. Thus, the system does not have to run in a private network. The mvme5500 BSP is written for hard real-time application to ensure the fastest service to the highest priority IRQ, if presented.

System Description/Performance/Example

Figure 1 demonstrates the block diagram of the image processing system for firewire cameras. Table 1 shows the actual throughput of the network interfaces on MVME5500, while triggering the cameras and EPICS display at various rates for the 1024 x768 x 8bit video mode. The Linux command 'gkrellm', which provides a GUI display to monitor the system and network performance on the PC, is used as the benchmark software. The data mode has the 1024x768x16 bit of data stored in FITS formatted files for off-line data analysis.

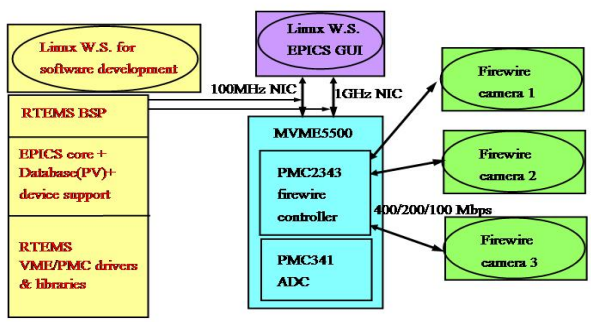

Fig. 1 Low-cost image processing for EPICS/RTEMS applications

Table 1: Network throughput of RTEMS-mvme5500 BSP while capturing camera data at various frame rate

Frame Rate	On-chip 100MHz	PCI-1GHz NIC
Camera 7.5 fps	~6.0 Mbytes/sec	~6.0 Mbytes/sec
Camera 15.0 fps	~8.7 Mbytes/sec	~12.0 Mbytes/sec
Camera 30.0 fps	~9.9 Mbytes/sec	~15.0 Mbytes/sec

The Linux PC workstation GUI for image display/setup

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utilized the EPICS/EDM tools [6] (Figure2) and video widget. EPICS/MEDM tools [7] are utilized for sliders and pull-down menus to be user friendly. Red Hat Linux and BOOTP are used for RTEMS software development and boot/load, while the beamlines PCs are running Debian Linux and DHCP.

Figure 2 is the image of an x-ray beam from the NSLS storage ring. PMC2343 is the firewire controller that is used for taking this image. The structure visible in the image comes from blemishes in a beryllium window coating. The firewire camera is here built into an x-ray microscope consisting of a high-resolution x-ray scintillator and a 1:1 imaging lens. Although this image is a static image, and doesn't take advantage of the high speed, it is clear that applications such as x-ray microtomography would benefit from its high throughput.

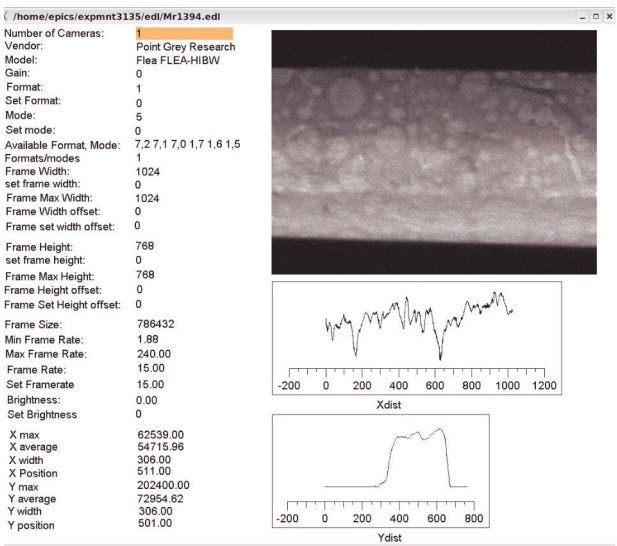

Figure 2: X-ray image of blemishes in the coating of a beryllium window.

IMAGE PROCESSING FOR XAMPS DETECTOR

BNL is in the process of designing a fast, high dynamic range x-ray detector for the LCLS project at SLAC [8]. The requirement of the detector is 1) 1024 x 1024 x14 bits of detector arrays, 2) 120 Hz of triggering rate, 3) 252 Mega Bytes/sec of data rate, and 4) data storage at a rate faster than 252 Mega Bytes/sec for 24 hours/7 days of operation.

The scope of the work at NSLS is to provide an image processing system for testing the detector designed at BNL. We decided to use a Commercial-Off-the-Shelf (COTS) storage solution for this project. Although Ethernet is the obvious protocol to use in consideration of its wide-area network distribution and the portability of its protocol, at the time of the project planning and perhaps even as of today, there was/is no commercial Ethernet based mass storage system available which supported raw data transfer, thus bypassing the disk system embedded operating system. The only option would be to use a file system, which would be too slow for the requirement. Although SLAC is developing a flash memory based mass storage system which will be suitable for this purpose, it is not yet available. Fibre Channel (FC) disk storage offers a cost effective yet reliable and realistic COTS solution to the problem. Figure 3 is the block diagram of the image processing system for testing the detector.

Although a closed source vxWorks driver is included with the purchase of the Fibre Channel PMC, we need an RTEMS driver. A Non Disclosure Agreement (NDA) needs to be signed to obtain the technical datasheet so that one can write a device driver for the RTEMS OS. So far, the coding of the FC disk driver is 50 % completed.

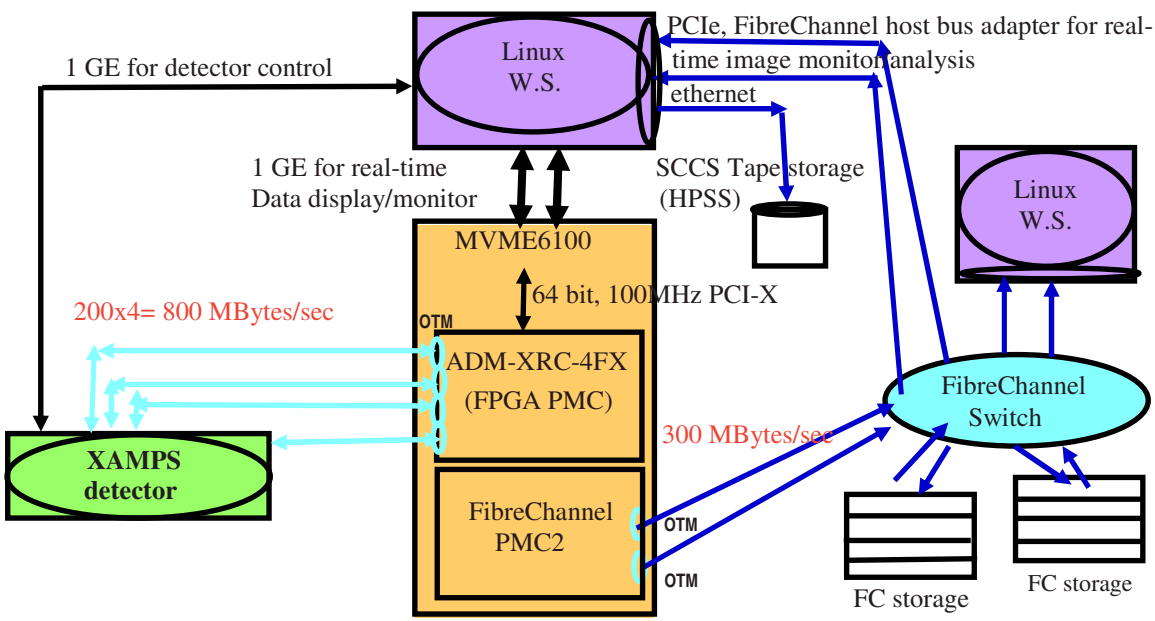

Figure 3: Block diagram of image processing system for testing the XAMPS detector

According to the performance benchmark from the manufacture, only raw data transfer will meet the specified system speed requirement. We propose to implement a pseudo file system, using a system of pointers to the raw storage accessed from the users' workstation. Should a network based solution be required, the Fibre Channel PMC could be replaced with a 10 GHz Ethernet PMC.

This work for XAMPS detector was performed in support of the LCLS project at SLAC.

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