IEEE 1394 CAMERA IMAGING SYSTEM FOR BROOKHAVEN'S BOOSTER APPLICATION FACILITY BEAM DIAGNOSTICS *

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Abstract

Brookhaven's Booster Applications Facility (BAF) will deliver resonant extracted heavy ion beams from the AGS Booster to short-exposure fixed-target experiments located at the end of the BAF beam line. The facility is designed to deliver a wide range of heavy ion species over a range of intensities from 10^3 to over 10^8 ions/pulse, and over a range of energies from 0.1 to 3.0 GeV/nucleon. With these constraints we have designed instrumentation packages which can deliver the maximum amount of dynamic range at a reasonable cost. Through the use of high quality optics systems and neutral density light filters we will achieve 4 to 5 orders of magnitude in light collection. By using digital IEEE1394 camera systems we are able to eliminate the frame-grabber stage in processing and directly transfer data at maximum rates of 400 Mb/sec. In this note we give a detailed description of the system design and discuss the parameters used to develop the system specifications. We will also discuss the IEEE1394 camera software interface and the high-level user interface.

Table 1: Parameters for flags

Location	Camera	Beam Size (90% full width)		Intensity (ions/pulse)
		Horiz. (mm)	Vert. (mm)	
D6 Sept.	Dage™ 70R	25	25	10^8
Quad. 1	Dage™ 70R	60	120	10^3-10^8
Dipole 1	1394	17	75	10^3-10^8
Oct. 1	1394	90	8	10^3-10^8
Oct. 2	1394	20	90	10^3-10^8
End	1394	200	160	10^3-10^8
Window	none	200	160	10^3-10^8
Target	1394	200	160	10^3-10^8

1 INTRODUCTION

BAF is designed to support a wide range of ion species, over a large range of beam intensities and energies. This places a demanding set of constraints on the beam line instrumentation. In order to meet these constraints a standard instrumentation package has been designed, which will include flags (chromium doped aluminum oxide illumination screens), segmented wire ionization chambers (SWIC), ion chambers, and scintillation counters. All the instruments are remotely retractable, inside the beam line vacuum enclosure. Table 1 lists the approximate location of each instrument package, the predicted beam sizes, and the type of camera to be used. The first two cameras are not IEEE1394, since these reside in or close to the Booster tunnel and will be exposed to much higher radiation levels, requiring special cameras.

Using a fully digital camera system has two big advantages over analog RGB systems. First, the A/D conversion is performed close to the CCD sensor, keeping the amount of electronic noise to a minimum. Once digitized the signal is immune to noise. Second, unlike analog camera systems, digital systems do not suffer from pixel jitter. Each captured pixel value corresponds to a well-defined pixel on the CCD chip. In addition, high quality CCD sensors have large dynamic ranges and produce excellent images in low light environments.

The IEEE1394 interface is a high performance serial bus interface [1, 2] that is capable of 400 Mbit/sec data transmission. The interface is a low cost peripheral bus which uses a read/write memory architecture that allows for isochronous service (uniform in time, recurring at regular intervals). Therefore, data streams between devices in real time with guaranteed bandwidth and no error correction. IEEE1394 complies with the IEEE1212 CSR [3] architecture standards, which means standardized addressing, well-defined control and status registers, standardized transactions, and compatibility with other IEEE bus interfaces.

IEEE1394 is a mature technology supported by almost all modern computer operating systems, including VX-Works, Microsoft Windows, Sun Solaris, and Linux.

An advantage of Linux, for digital video, is that the entire IEEE1394 interface exists as loadable modules to the kernel. A very simple set of libraries allow control and data transmission from an array of digital cameras. This report describes the digital video architecture for BAF and the low-level software interface for control and data transmission.

* Work performed under the auspices of the U.S. Dept. of Energy.

2 HARDWARE ARCHITECTURE

IEEE1394 is a serial, un-supervised bus, in which devices are hot pluggable. It uses 64-bit fixed addressing (per IEEE1212 standard) in which there are three parts to each packet of information, the bus id, the physical id, and 48 bit storage area. A node id is defined by putting together the bus id and the physical id. Devices can be interconnected as shown in figure 1.

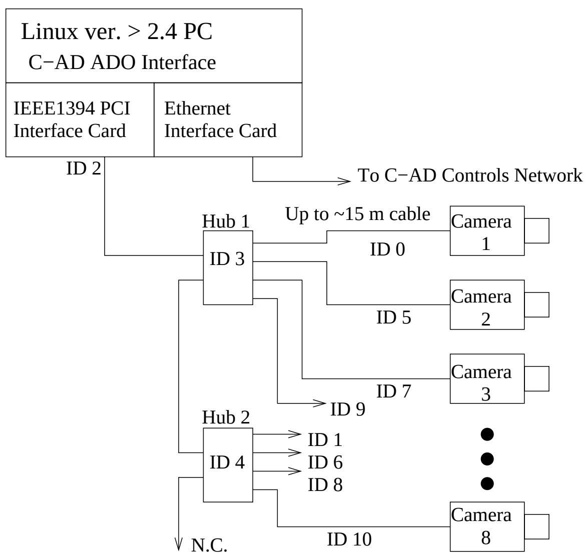

Figure 1: IEEE1394 Camera configuration for a single host. ID's are physical id's assigned by the bus.

IEEE1394 cables transmit data up to 400 Mbits/sec over 4.5 meters. Longer cable lengths can be achieved by using higher quality cable (to comply with electrical specifications) or by allowing a lower bit rate. For the BAF video system we can do both, since we do not need the maximum bit rate. This allows us to extend the cable lengths from the standard 15 feet per hop, up to 100 feet or more per hop. In the laboratory we have found we still get good reliable images using Belden 9104 CATV cables up to 120 feet. Standard IEEE1394 cables come in two basic flavors: 4-pin connectors and 6-pin connectors. 4-pin connector wires can transmit data only. 6-pin connectors include two additional wires for powering devices. All IEEE1394 industrial cameras take 6-pin connectors. Power to the cameras can be supplied through a hub, which can take up to 4 cameras, or through the PCI card. Using hubs prevents PCI card load-down and allows for many cameras.

The most important feature of the IEEE1394 bus is the implementation of a memory read/write communication architecture. This means distributed systems with global memory architectures can be mapped without translation. In addition, almost all devices today implement an open host controller interface, allowing a single driver interface to the operating system for all devices. The topology of this serial bus is a backplane environment multi-drop bus: this is identical to the more common ethernet topologies. Since the addressing is fixed 64 bit, in which the first 16 bits identify a node, then up to 64k nodes can exist on a single bus. More specifically, since the address is broken up into a bus identifier (10 bits) and a physical identifier (6 bits) there can be 1023 buses each with 63 nodes. The final 48 bits are used for addressing the node memory/register space.

Digital cameras come in two basic types. Consumer digital video cameras (CDV cameras) are consumer market video recording devices. Digital video cameras (DV cameras) are machine vision market devices which do not include recording media. Normally CDV cameras compress image data before writing to tape (or whatever media is used). DV cameras do not compress the image data, and so maximum image quality is preserved for each individual frame.

For the BAF video imaging system we will use commercial grade DV cameras. For system development we have been using the Sony DFW-V300 digital camera. This camera is capable of operating at 30 frames per second in VGA (640x480),8 bit resolution format, non-compressed YUV digital output (luminance and chrominance, typical of PAL European formats, as opposed to RGB (red,green,blue) factors used in computer monitors). It has a standard C-mount optical interface, aluminum die-cast chassis, and a 6-pin IEEE 1394 cable interface. This camera is built according to the IEEE-based digital camera specification version 1.04 [4]. For the production imaging system we are investigating the Sony DFW-V500 digital camera as well as Basler DV Cameras. The Sony DFW-V500 camera is similar to the DFW-V300 except it uses a CCD that allows for primary color filtering, interline transfer progressive scan, and utilizes square pixels. In addition the Sony unit includes an external trigger for asynchronous trigger operation. For all cameras, frame rates, white balance, shutter speed, sharpness, hue, saturation, brightness, and gain are all software controllable. The Sony cameras have a minimum sensitivity of 6 lux. The DFW-V500 weighs 305 grams, while the DFW-V300 weighs 200 grams. Operating temperature ranges from -10 to 50 degrees C. The DFW-V500 is built according to the IEEE-based digital camera specification version 1.20 [5]. Basler A300 series cameras are also industrial grade cameras that feature square pixels, external triggering, and interline transfer progressive scan CCDs.

The DFW-V500 and Basler cameras external triggers follow the version 1.20 camera specification [5] and uses a 4 pin connectors. Each also includes a programmable integration time window.

3 SOFTWARE ARCHITECTURE

Although Linux is a monolithic kernel, it allows dynamic loading and unloading components of the operating system as they are needed. These dynamically loaded components are called modules and are typically used for device drivers, pseudo-device drivers such as network drivers, and file systems. Once a Linux module has been loaded it is as much a part of the kernel as any normal kernel code.

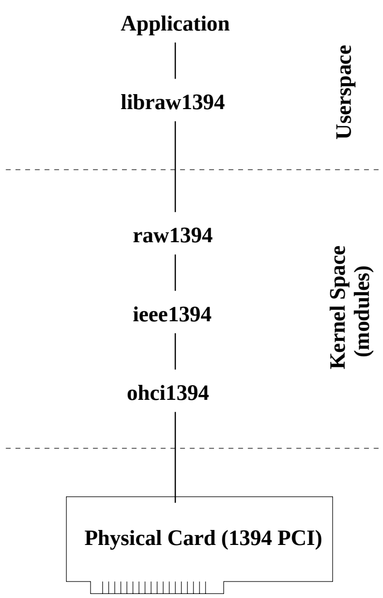

Figure 2:

All the drivers required for IEEE1394 support can be loaded as modules. This is very useful, since these components are still a relatively new technology and they can contain bugs. If the digital video system begins to behave incorrectly then unloading and loading driver modules can quickly get it going again.

Since the IEEE1394 bus is a serial bus, all the device drivers are written to connect to character type devices (which is the same as for a network card). There are two basic device files used to communicate to 1394 devices. The /dev/raw1394 device is used to communicate directly to devices by addressing a specific device with a device specific command. The /dev/video1394 device is used to interface directly to video device memory space via DMA (direct memory architecture). Figure 2 shows the device driver hierarchy as currently implemented in Linux.

In the case of digital video there exists a library, written on top of the libraw1394 library, called libdc1394 (digital camera). This library contains all the function calls required to control and obtain video output from a DV type camera. This library will also be the primary interface between the C-AD control system ADOs and the IEEE1394 subsystem hardware.

4 SYSTEM INTEGRATION

The IEEE1394 camera system will be integrated with the rest of the C-AD controls infrastructure using a PC running Linux (ver. $\geq$ 2.4.4) and the C-AD control system. The existing Flag Profile Monitor (FPM) application, which is currently used for the ATR and SEB video frame grabbers, will provide the high level User Interface. An Accelerator Device Object (ADO) manager [6] will serve as middleware, providing a software abstraction of the information available from the libraries for the camera subsystem hardware. This allows the FPM program, and other general purpose configuration and diagnostic applications, to interact with the camera in a standard way.

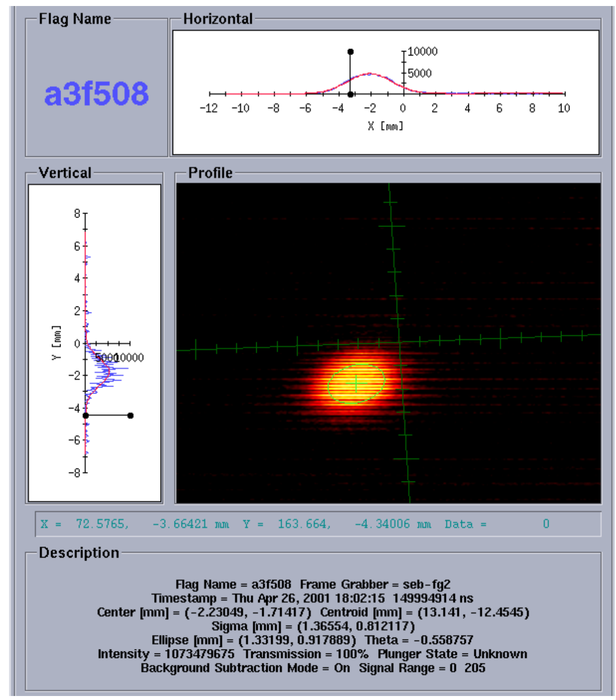

Figure 3: High level FPM application interface

5 CONCLUSIONS

By utilizing a completely digital video system we can achieve a lower noise higher performance beam imaging system. In addition, by avoiding the use of a video frame grabber, we can build a versatile system at a lower overall cost, and still seamlessly integrate to the existing high level profile application used for other C-AD flag systems.

6 REFERENCES

[1] IEEE Computer Society, "IEEE Std 1394-1995, IEEE Standard for High Performance Serial Bus", New York, August 1996.

[2] FireWire System Architecture, second edition, IEEE 1394a, MindShare, Inc., Don Anderson, Addison Wesly Longman, Inc., 1999

[3] IEEE Computer Society, "IEEE Std 1212, Control and Status Register (CSR) Architecture for microcomputer buses", New York, 1994.

[4] 1394 Trade Association, "1394-based Digital Camera Specification, ver. 1.04"

[5] 1394 Trade Association, "1394-based Digital Camera Specification, ver. 1.20", July 23, 1998.

[6] L.T. Hoff and J.F.Skelly, "Accelerator Devices as Persistent Software Objects", Nucl. Instr. and Meth. in Phys. Res. A 352 (1994), 185-188