

# APPLICATION OF THE IEEE-1394 AND THE GIGE VISION DIGITAL CAMERAS FOR DIAGNOSTICS IN TAIWAN LIGHT SOURCE

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## Abstract

Digital camera has been adopted for the booster, storage ring and transport-line diagnostic at the Taiwan Light Source. The system provides low image distortion and lossless image transmission over long distance. The system is integrated with commercial software in the control system. The fully remote control supports to various operations and functional applications. These applications include of screen monitors equipped in the booster and storage ring, wider dynamic range sensors and highly flexibility control for the emittance measurement in the transport line, the booster synchrotron and the linear accelerator. System configuration and present status will be summarized in this report.

## INTRODUCTION

Fluorescence screen/OTR and synchrotron radiation monitors are mostly employed at synchrotron based light source to measure beam profile and beam size of the accelerator system in order to optimize performance, check routine operation and study various beam physics. These tools are beneficial to characterize and analyze properties of electron beam. For example, the beam emittance is calculated from the measured beam size.

Digital cameras were adopted to enhance functionality of accelerator diagnostics [1-4]. The major upgrades of data acquisition and analysis have been implemented. The main goals are to increase the signal transmission quality, the dynamic range, the linearity of the profile monitor, and the superior supports for data analysis.

Using a fully digital camera has two major advantages compared to an analogue CCD camera. First, the A/D conversion is performed closer to the CCD/CMOS sensor and therefore it minimizes electronic noise. Once the digitized signal is immune to noise, we can implement long haul ( $10\text{ m} \sim 10^3\text{ m}$ ) applications in accelerator diagnostics. Various long hops solution is supported by the IEEE1394A/B interface. Noise immunity and isolation are provided by this solution that must be favourable in the accelerator environment. Second, unlike analogue camera systems, digital systems do not suffer from pixel jitter. Each captured pixel value corresponds to a well-defined pixel on the CCD/CMOS chip. The IEEE-1394 interface is a hot swappable and self-configuring high performance serial bus interface that is capable of 400 Mbit/sec data transmission and will be enhanced to 3.2 Gbit/s for the next generation products. The interface supports asynchronous (guaranteed delivery) and isochronous (guaranteed bandwidth and latency) data transfers. By applying digital IEEE1394 camera system, we are able to eliminate the frame-grabber stage of

processing and directly transfer data at maximum rates of 400 MB/sec. IEEE1394 general purposed CMOS cameras (Prosilica CV640,  $659 \times 494$   $4.65\ \mu\text{m}$  square pixels) were chosen for screen monitor application. There is no frame grabber or additional power supply required. Frame rates of up to 30 fps can be achieved adequately in the full frame.

The GigE Vision standard from the Advanced Imaging Association (AIA) is a new interface standard for the latest vision of cameras with high performance. GigE Vision with combined features of high data rates (required for uncompressed video or imaging applications), ubiquitous computer interface hardware, low cost cabling, and widespread popularity makes Gigabit Ethernet an attractive interface option for accelerator applications. The GigE Vision standard including of both the hardware interface standard (Gigabit Ethernet) and the communications protocol can be utilized for controlling and communication of cameras. The GigE Vision camera control registers are based on a command structure called GenICam which is administered through the European Machine Vision Association (EMVA). GenICam seeks to establish a common camera control interface so that the third party software can communicate with the cameras from various manufacturers without customization software driver. GenICam is incorporated as a part of the GigE Vision standard. GigE Vision is analogous to FireWire's DCAM (IIDC) that is beneficial to facilitate system integration and thus reduce costs.

## APPLICATIONS OF IEEE-1394 AND GigE VISION CAMERA AT TLS

FireWire camera was adopted for synchrotron radiation at the booster synchrotron and the storage ring very successfully since 2003 [1]. Qimaging QICAM 12 bits camera was selected to capture synchrotron radiation profile. Parameters of the camera are completely programmable so that this is very useful to accommodate with various beam conditions and effectively increases reliability.

FireWire CMOS camera was adopted for the transport line screen monitor since 2004 [2] as shown in Fig. 1,2 and 3. Functionality is satisfactory while the only problem is less reliability near the injection kicker of the storage ring. The problem might be caused from bad grounding of the kickers and the cameras which might be hanged due to the noise induced by the long IEEE-1394 cable. After the kicker grounding improved and the camera with IEEE-1394B fibre interface replaced, the reliability is increased drastically.

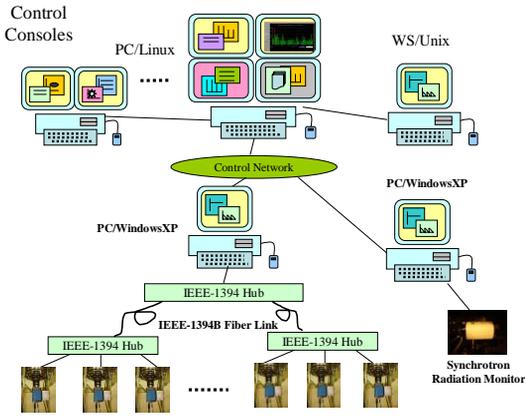


Figure 1: Topology of the IEEE-1394 camera installation.

camera power is applied to keep from this interference and improves the reliability helpfully.



Figure 4: A GigE Vision camera installed at exit of 50 MeV linear accelerator for test.



Figure 2: The VI for transport line screen monitors operation.

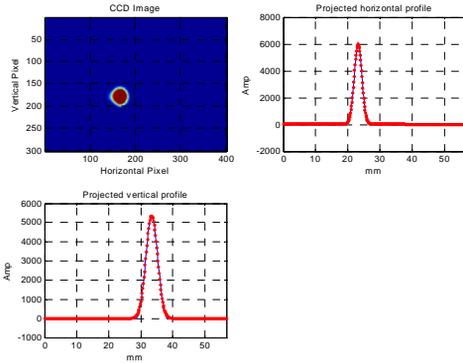


Figure 5: Profile measured by the GigE Vision camera.

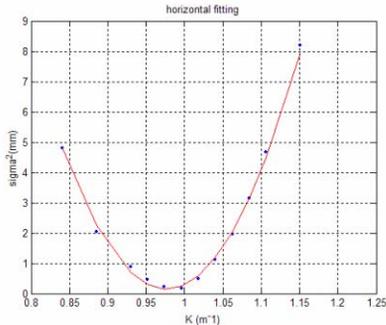


Figure 3: Example of transverse beam emittance measurements at transport line by using quadrupole scan method. Fitted emittance is  $\epsilon_x = 238$  nm-rad.

The new GigE camera interface is also applied for preliminary evaluation. Set up of the experiment is shown in Fig. 4. Figure 5 shows a typical profile measurement result. Emittance is measured by the quadrupole scan method in the exit of the 50 MeV linear accelerator. The beam profile as a function, one of nearest quadrupole strength was measured as shown in Figure 6. The profile image is captured and analyzed by using Matlab scripts. Emittance will be immediately adjusted and reduced from the machine parameter by the measured data. Performance and reliability of the GigE Vision camera is evaluated. Since the camera is installed near the klystron modulator, the camera is occasionally hanged during klystron power off. A far away klystron of external

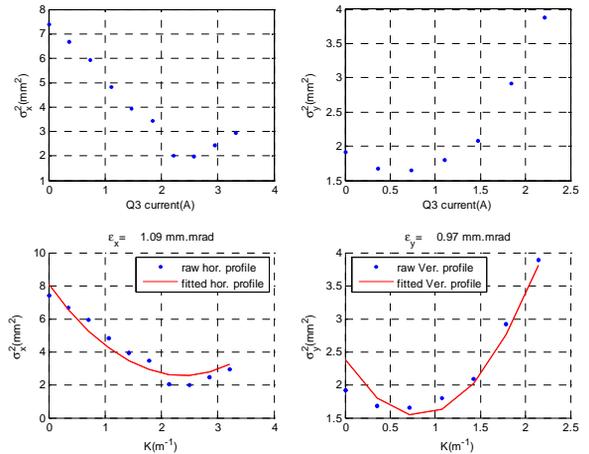


Figure 6: Measured horizontal and vertical emittance of the 50 MeV lianc by quadrupole scan method. The fitted normalized emittance is  $\epsilon_x = 1.09$  mm-mrad and  $\epsilon_y = 0.97$  mm-mrad in the horizontal and vertical respectively.

### OPERATION EXPERIENCES

Both of IEEE-1394 cameras and GigE Vision cameras were tested and applied for several diagnostics for the

TLS. Some of the experience is summarized in the following paragraphs.

### *Control System Integration*

To simplify the control system integration, a PC/running Windows/XP was adopted as a server for FireWire cameras and GigE Vision cameras. There are few drivers supporting both kinds of interface. The standard DCAM camera driver with LabVIEW and other COTS softwares are supported for FireWire camera. The GigE standard camera driver is being developing now. We use a non-standard windows XP/Linux camera driver in this report. The user interface was developed by LabVIEW and Matlab to support various experiments and remote controls.

### *Cabling*

Maximum copper cable length in the FireWire is around 10 meters with full speed. Hub is essential to extend the length of links. For long haul transmission, IEEE-1394B fibre link can be used. This fibre link is also useful for hostile EMI environment near the kickers. The connection for GigE Vision camera can be CAT5e or CAT6 Ethernet cables with RJ-45 connectors up to 100 meters. Gigabit Ethernet provides high performance camera interface to convey control parameters and image information up to 100 meters long using inexpensive CAT5e or CAT6 cabling. Such long cable lengths are not generally possible with other kinds of interface. For the hostile EMI environment, this kind of connection sometimes will deteriorate the camera reliability. Remote camera power control is still essential for these cases.

### *Operation Performance*

Performance of the IEEE-1394 and GigE Vision camera seems not bad. Exposure condition can be controlled remotely and as a consequence, it is very helpful for diagnostic applications with various beam conditions. Image quality is good and irrelevant to the distance of links.

### *Reliability Issues*

Reliability of FireWire camera and GigE Vision camera seems no big difference. The FireWire primary problem is resulted from the rigidity of the connectors and power supply problem between several layers hub. At the initial stage, the unreliability mainly comes from the bugs of the device driver. After the bugs are removed, the reliability seems not bad. However, there is a micro-controller inside. If unintentional high field noise due to a fault of the kickers grounding causes camera to be hanged, it is no way to recovery without power reset [4]. To remedy this disadvantage, a remote power on/off control was implemented.

### *Radiation Damage Issues*

The FireWire cameras have been operated over two years, there are no severe damages observed. Similarly, the GigE Vision cameras have been operated over 6

months, no observable radiation damage was observed. So, the radiation damages of digital cameras are similar with those of the analogue cameras from last decade experiences.

## **SUMMARY**

FireWire camera and GigE Vision cameras are tested at TLS for several diagnostic applications. Their setups allowed images to be transmitted digitally, removing the request from cumbersome frame grabbers and coax switches. Furthermore, the simplicity of triggered acquisition made this mode to be a standard rather than a special case. Both FireWire cameras and GigE Vision cameras with the TLS control system allow seamless integration with control room displays and are easy to access image for various machine studies. Experiences gain from these experiments and image quality are excellent. Varying exposure time is very helpful to increase the dynamic range. The only shortage is less reliable than the analogy camera. This can be modified by the aid of power reset. Both kinds of interfaces will be suitable for the newly proposed in the 3 GeV Taiwan Photon Source.

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