THE DIGITAL CAMERA APPLICATION IN THE TAIWAN LIGHT SOURCE

C. H. Kuo, Y. T. Yang, J. Chen, S. Y. Hsu, D. Lee, K. H. Hu, C. J. Wang, K. T. Hsu

NSRRC, Hsinchu 30076, Taiwan

Abstract

Digital camera has been adopted for the booster, storage ring and transport-line diagnostic recently at the Taiwan Light Source. The system provides low image distortion transmission over long distance. The system is integrated with control system. Each screen monitor equip with a digital camera. These screen monitors are used for beam profile measurement and help injection condition optimization. Wider dynamic range and highly flexibility of the digital gated camera provide various functional enhancements. System configuration and present status will be summary in this report.

INTRODUCTION

Using a fully digital camera has two major advantages over analog CCD camera. First, the A/D conversion is performed closer to the CCD/CMOS sensor, keeping the amount of electronic noise to a minimum degree. Once the digitized signal is immune to noise, we can implement long haul (10 m ~ 10^3 m) applications in accelerator researching field. Various long hops solution is supported by the IEEE1394A/B interface. Noise immunity and isolation provided by this solution must be welcome in the accelerator environment. 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/CMOS chip. The IEEE1394 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 next generation products. The interface support asynchronous (guaranteed delivery) and isochronous (guaranteed bandwidth and latency) data transfers. By using digital IEEE1394 camera system [1,2], 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 x 494 by 4.65 μm square pixels) [1] were chosen for screen monitor application. Progressive scan interline CCD camera (Q-Imaging QICAM, 1392 x 1040 4.65 μm square pixels) [2] are used for synchrotron radiation monitor with 12-bit digital output. There is no frame grabber or additional power supply required. Frame rates of up to 100 fps can be achieved with adequate binning and ROI selection.. Intensify gated CCD camera are also used for low light applications.

Imaging applications in the accelerator community are most often utilized to measure beam profile and interference fringes. The beam profile may convert form fluorescence, various optical diagnostics [3]. Usually, fluorescence screen/OTR and synchrotron light source radiation monitor is used to measure size of beam profile in order for performance optimization, routine operation, and various beam physics studies in the accelerator. This tool has been useful for characterizing properties of electron beam analysis. For example, the beam emittance is calculated from the measured beam size.

SYSTEM STRUCTURE

There are about fifteen IEEE-1394 cameras [4] were installed for the screen monitor of the transport line and storage ring. All of these cameras are distributed in a large area beyond copper wire can cover, three to four near-by cameras are grouped and connected to central hub by IEEE-1394B fiber link for long distance transmission. To simply cabling, multiple nearby cameras are cascading together. Only one camera is active in the cascading chain, transmission bandwidth is shared by all cameras in cascading when system is initializing. All screen monitor are controlled by one computer. Since only one camera is used, the main bus bandwidth in used by only camera. Synchrotron radiation monitor for the booster synchrotron and storage ring are stand alone station to acquire image and to do analysis.

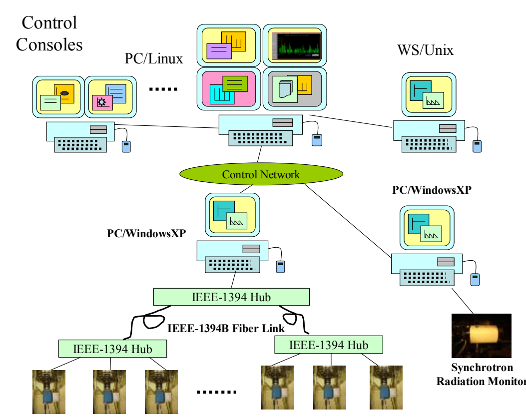

Figure 1: Topology of the IEEE-1394 camera installation.

The copper cable is suffered for longer distance transmission especially near the pulse magnet power supplies. Data stream is deteriorated sharply by the operation of pulse magnets for the cameras nearby. The camera may hang and need power reset to assume its operation occasionally. After this problem was identified, the topology of the camera array has been changed slightly to ensure the reliable operation of the whole system. Camera radiation damage is similar with analog camera. Some damage pixels are observed due to radiation [5]. Thin lead enclosure is help to keep from this slightly damage.

Based upon experience during last two years, major disadvantage of IEEE-1394 based camera are the noise immunity of form pulse magnet operation. Short cable is preferred. Multiple nearby cameras are cascading together by the simple cabling. Transmission bandwidth is shared by all cameras in the cascading bus.

Several 1394 hubs are applied in this install as shown in the Figure 1. The main issues are from 1394 copper cable specification and installation environment. The standard 1394 copper cable is defined up to 5 meter. This cable length isn't enough to real situation. The cameras are divided to several groups with the hub and optical fiber transceiver in the transport line. This layout also keeps from kicker pulse magnetic field interference.

Since the camera is comply with DCAM (IIDC 1.31) digital camera standard. The protocol defines the exchange of data with IEEE 1394 cameras. However, DCAM isn't only defined in the video stream provided by the camera, but is also the camera parametric control (for instance brightness, shutter, white balance, exposure time, …etc.). This DCAM driver based on windows PC is upgraded from 1.30 to 1.31 by to improve functionality which is lake in the old driver 1.30. The old driver is supported in the plug and play operation. The existent devices are automatically renamed to a new device name if there is any device is failed or disappeared in the bus. This mechanism leads uncomfortable form maintenance point of view. The new driver overcomes these problems.

SYNCHROTRON RADIATION MONITOR FOR THE BOOSTER SYNCHROTRON

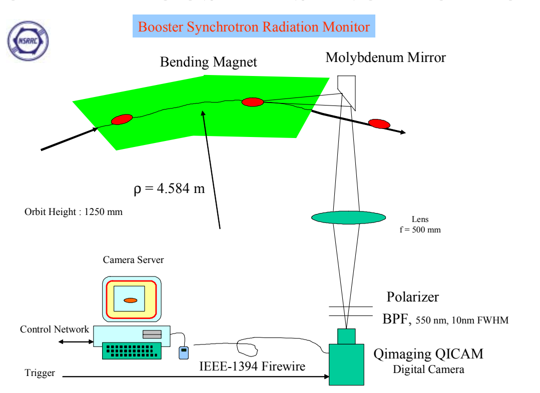

Figure 2: The system block diagram of the booster synchrotron radiation monitor.

Since the booster synchrotron is a 10 Hz machine, the injected beam is accelerated from 50 MeV to 1.5 GeV within 50 ms. Exposure time should be as short as possible for energy revolving measurement. External trigger of the camera is synchronized to the booster 10 Hz clock. By adjusting 10Hz delay times, the different beam energy profile is captured by the camera. Available tools can adjust 10 Hz delay time, camera exposure time, beam size analysis and provide networking service. Remote consoles can access all information by client program. This system layout is shown in Figure 2. An example of the measurement is also shown in Figure 3. The vertical beam size is reduced when energy increased due to synchrotron radiation damping. Multiple exposures can be used at low energy to measured low intensity synchrotron radiation light. Multiple exposures are also increase dynamic range without scarified linearity especially for low light application.

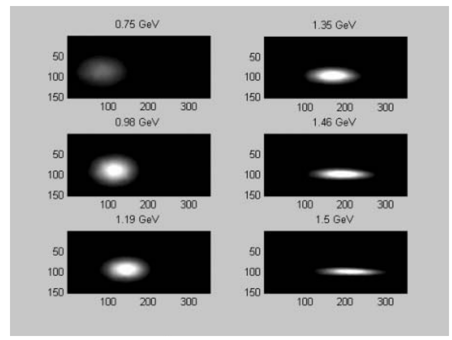

Figure 3: An example of observed beam profiles during ramping with various energies. With 2x2 binning, the pixel size is 9.4 µm x 9.4 µm. Exposure time is 0.5 ms.

APPLICATION FOR TRANSPORT LINE BEAM EMITTANCE MEASUREMENT

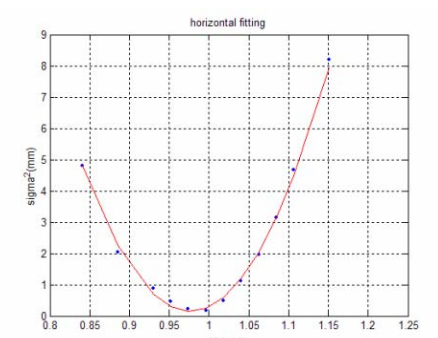

Figure 4**:** Example of transverse beam emittance measurements at transport line by using quadrupole scan method. Fitted parameter of A = 255.22, B = 0.98, C = 0.15, giving emittance ε_x = 238 nm-rad.

Transport line screen monitor have been upgraded to IEEE-1394 cameras. All cameras are external trigger by the timing system. The exposure time of the camera can be adjusted according beam intensity. Multiple exposures are also support for low light applications. Emittance of the transport line was measured by quadrupole scan method. Measured horizontal beam size as function of quadrupole strength is shown in Figure 4. The data are fitted by the quadratic fitting function in following form [6]:

$$\Sigma_{11} = A(K - B)^2 + C$$

Where A, B, C are fitted parameters, K is the quadrupole strength. Emittance can be calculated by the relationship

$\varepsilon = \sqrt{AC} / S_{12}^2$. Figure 4 showed the measured beam size as function of quadrupole setting. The fitted A,B,C parameters are also calculated. Fitted emittance is 238 nm-rad.

PERTURBATION OF INJECTION KICKERS ON THE STORED BEAM OF THE STOARGE RING

Intensified gated camera was used to measure turn-by-turn beam profile at synchrotron radiation port of the storage ring to investigate the bump closure of the injection local bump produced by four injection kickers. In the figure 5, shows the beam profile image of consecutive 5 turns with stored beam during kickers fired. Image are spread about 4 mm in horizontal direction and 1 mm in vertical direction by this non-closure bump. This diagnostics system may be used as the injection kickers tuning complementary tools. The injected beam can also observed by this tools for optimize the injection conditions.

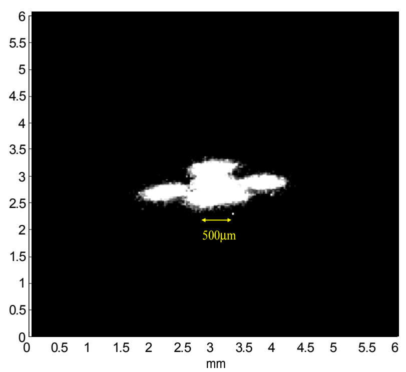

Figure 5: The turn-by-turn beam profile of the stored beam was observed by the synchrotron light monitor. This monitor is outside the local bump form by the injection kickers. The bump is not a closure bump.

GAP VOLTAGE MODULATION STUDY

Intensified gated CCD camera [2] was used for low light application. Here is an example to observe turn-by-turn beam profile of the storage ring after setting RF gap voltage modulation magnitude to double of the synchrotron frequency ($2f_s \approx 50$ kHz), that help to relief the effect from high order mode (HOM) of the cavity and to stabilize the stored beam. Modulation depth is about 5% of the total 800 kV RF gap voltage. For turn-by-turn observation, the exposure time of camera was set to 400 ns that is the revolution time of stored beam. Trigger input to CCD camera is synchronized with the RF gap voltage modulation source. Different delay times after trigger were observed and shown as in the Figure 6. The horizontal beam size is at minimum when the RF gap voltage is minimal, and maximal beam size occurs at maximal gap voltage setting; also the period value is the same as modulation frequency. Stable horizontal beam size is obtained by low speed imaging system that enables the integration procedure performed effectively.

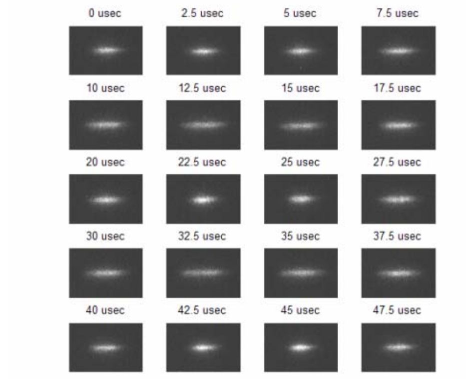

Figure 6: Observed beam profile at difference phase of RF gap voltage modulation cycle. Period of the modulation signal is about 20 μsec (50 kHz ≈ 2 f_s).

SUMMARY

The preliminary results have been shown that the functionality of the imaging system with improved performance are all accomplished by the new generation IEEE-1394 CCD camera. Developing of various application programs to support new imaging system is underway and it will also provide user-friendly interface for all kind of applications

REFERENCES

[1] http://www.prosilica.com.
[2] http://www.qimaging.com.
[3] M. Ferianis, "Optical Techniques in Beam Diagnostics", Proceeding of the EPAC'98 and reference therein, 1998, pp. 159-163.
[4] C. J. Wang, et. al., AIP Conf. Proc. 732 (2004) 462.
[5] G. Rehm, AIP Conf. Proc. 732 (2004) 407.
[6] M.G. Minty, F. Zimmermann, "Measurement and Control of Charged Particle Beams", Springer-Verlag, Berlin, Heidelberg, New York, 2003.