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WEB STREAMING INTEGRATION FOR THE TLS BEAM SIZE MONITORING BROADCAST SYSTEM

L. P. Hsu, C.Y. Liao, C.Y. Wu, J. K. Liao, Z. Q. Wu
National Synchrotron Radiation Research Center, Hsinchu, Taiwan, R.O.C.

Abstract

The beam size monitor (BSM) broadcast system at the Taiwan Light Source (TLS) has traditionally used analog coaxial cables and modulators to transmit measurement images and data to control rooms and beamline stations via televisions and tuners. While simple and network-independent, this setup suffers from low resolution, frequent interference, and aging hardware with no ongoing maintenance. This paper presents a lightweight, non-intrusive upgrade that replaces the original system with a web-based real-time streaming solution. By capturing the existing output from the measurement system and streaming it using standard web technologies, users can access beam size visuals on any browser-enabled device, gaining better image quality and improved stability while eliminating traditional broadcast maintenance. With plans underway to retire TLS in the near future, this solution offers a fast, low-risk, and cost-effective modernization path without altering existing instruments or computing environments. The system is currently under testing, and this paper describes its architecture, implementation, and preliminary results.

INTRODUCTION

The Taiwan Light Source (TLS) is a third-generation synchrotron radiation facility operating at a beam energy of 1.5 GeV. Reliable beam diagnostics are essential to ensure optimal machine performance. Beam size monitoring is a critical role in beam tuning, stability assessment, routine operations, and various beam physics studies. Traditionally, beam size images at TLS have been transmitted through analog video modulators to multiple monitoring stations via coaxial cables. These stations are equipped with analog televisions or signal receivers. However, the original analog broadcasting system presents several limitations. The image resolution is constrained by analog standards, restricting the ability to present detailed information. In addition, long-distance analog signal transmission is susceptible to noise and attenuation, degrading data quality. Aging hardware further complicates maintenance and increases the risk of unexpected failures, posing challenges to continuous operation. This work proposes a lightweight, non-intrusive web-based streaming solution aimed at enhancing the quality of beam size images while minimizing interference with the existing instrumentation system. The upgrade targets improvements in image resolution and system stability, reduction in maintenance overhead, and greater accessibility to beam monitoring data through standard web browsers.

SYSTEM ARCHITECTURE

The synchrotron radiation monitor system [1,2] consists of image forming optics, a CCD digital camera, and image processing tools. A local Windows-based server hosts a LabVIEW network server environment, which is responsible for camera operation and system management. This environment integrates multiple functionalities such as the camera driver interface, neutral density (ND) filter adjustment through a serial bus, image acquisition, preliminary data pre-processing, and subsequent image analysis and display. The system also employed traditional analog television display as a means of real-time monitoring, allowing operators to directly observe the beam profile without the need for computational post-processing. The traditional analog broadcast system is illustrated in Fig. 1.

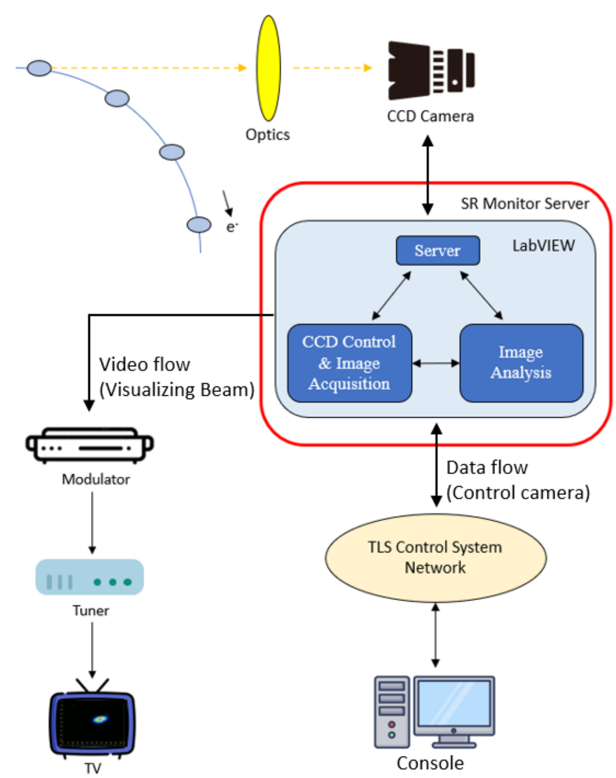

Figure 1: The traditional analog broadcast system architecture of the Synchrotron radiation monitor system.

In the upgraded beam size monitor (BSM) broadcast system, web-based real-time streaming was achieved without modifying the existing diagnostic instrumentation or computational infrastructure. To accomplish this, the video signal was directly captured from the DVI-I output of the original SR monitor server. In conventional analog transmission systems, long-distance signal delivery often

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introduces challenges such as degradation in image quality, electromagnetic interference, and noticeable color distortion. To address these limitations, a converter module was installed within the same rack, enabling DVI-I signals to be converted into both HDMI and VGA outputs. The VGA port provides a convenient means for local debugging and on-site verification of the image stream, while the HDMI output is directed to a high-performance video capture device supporting 1080p at 60 Hz for subsequent digital processing.

Web-based image streaming is handled by a high-performance x86-based single-board computer (SBC), with an average power consumption of approximately 15 W. A small fan is sufficient to maintain stable operating temperatures. The SBC interfaces with the capture hardware via USB and connects to the control network via RJ-45 GbE. The system runs Linux Lite, a lightweight Linux distribution based on Ubuntu LTS, chosen for its high stability, low resource consumption, and extensive software support—well-suited for web service applications. The complete hardware architecture is depicted in Fig. 2.

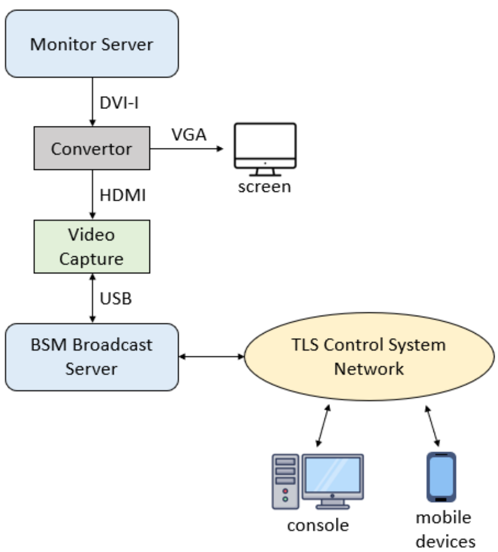

Figure 2: The synchrotron radiation BSM broadcast system architecture.

SOFTWARE ARCHITECTURE AND STREAMING WORKFLOW

The beam size monitor broadcast software is designed to operate as a continuously running service that acquires images from a video capture device and updates the most recent frame in real time. If no valid data stream is detected, the software periodically attempts to reconnect and reinitialize the image source until the device becomes responsive. Prior to transmission, each captured frame undergoes a sharpening step using convolution-based filters, which enhances fine image details and improves the visibility of beam profile features. The processed frame is then compressed into the widely supported JPEG format, allowing efficient delivery to the web-based front end for display.

The BSM broadcast system is implemented using Python, Flask [3], and OpenCV [4] to enable real-time video streaming to standard web browsers [5]. OpenCV, an open-source computer vision and image processing library, provides a rich collection of algorithms that cover both fundamental operations—such as image filtering, edge enhancement, and color space transformation—as well as more advanced tasks including feature detection, object recognition, camera calibration, and even 3D reconstruction.

Flask is a lightweight and flexible web application framework written in Python. It supplies essential web functionality such as HTTP request routing, session and response handling, and HTML template rendering. Owing to its modular and extensible architecture, Flask enables developers to incorporate additional services or third-party libraries, making it well suited for rapid prototyping and long-term maintainability.

In this implementation, OpenCV is primarily utilized for image acquisition from the capture device and for applying sharpening filters that emphasize the spatial structure of the beam profile. A multi-threaded approach is adopted to manage image acquisition and processing separately from the main execution thread. This approach mitigates the risk of blocking operations and contributes to consistent real-time performance under continuous streaming conditions. Each processed frame is encoded as a JPEG image and transmitted to the web browser using Flask. The transmission strategy relies on frame-by-frame delivery, thereby enabling low-latency live streaming within standard browser environments without reliance on proprietary plug-ins. A program flow chart is shown in Fig. 3.

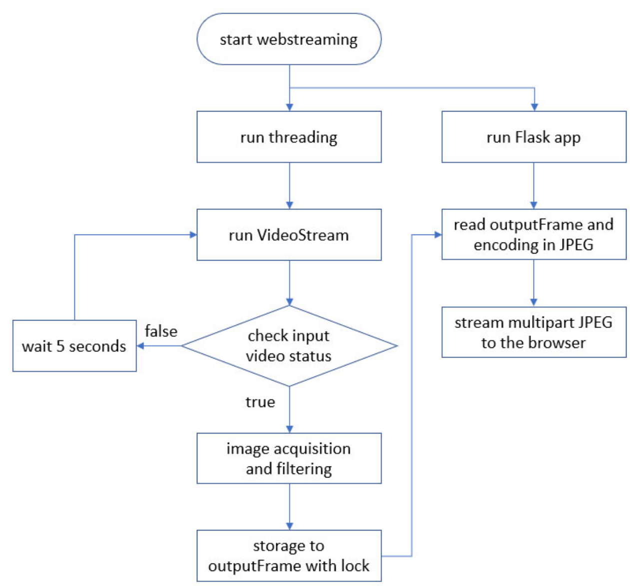

Figure 3: The software architecture of the BSM broadcast system.

RESULTS AND EVALUATION

Performance testing indicates that each streaming session requires approximately 22.4 Mbps of sustained network bandwidth. This value was obtained by averaging

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multiple measurements under steady-state streaming conditions, with variations typically within ±1 Mbps depending on concurrent network activity. To further evaluate scalability, tests were performed with 10 simultaneous viewers connected through a standard 1 Gbps control network link. The system maintained stable operation throughout these tests, without noticeable frame loss or performance degradation. These results confirm that the streaming solution can reliably support the routine monitoring needs of accelerator operators and also demonstrate its potential for multi-site collaborative operation, where several remote users may access the BSM feed concurrently for diagnostic.

End-to-end latency was measured using browser developer tools by recording the time between the initial HTTP request and the first server response. The observed average latency was approximately 120 ms under typical load conditions. This latency is influenced by the load on the control network switches and the current processing status of the BSM streaming server. Such latency remains well within the acceptable range for real-time beam monitoring tasks.

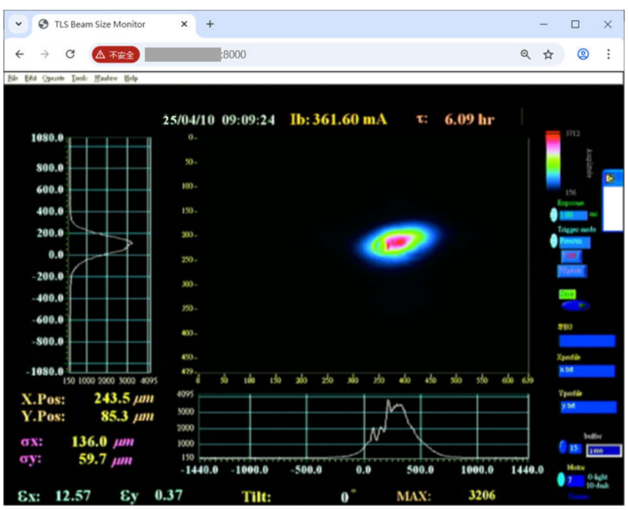

Figure 4: A web page of synchrotron radiation beam size monitor system during TLS normal operation.

The streaming system operated at 10 Hz with a resolution of 1080 × 810 pixels, a configuration selected to achieve a compromise between image clarity and bandwidth efficiency. A comparative analysis against the original analog video system demonstrates a significant improvement in image quality, particularly in terms of resolution, edge sharpness, and noise suppression. Representative frames captured from the live web-based stream demonstrate the BSM's capability for real-time monitoring of beam presence and spatial distribution. Figure 4 shows the BSM capturing an active particle beam, represented by a visible beam spot indicating the transverse beam profile.

Beyond short-term performance, long-term stability evaluation was carried out to assess system reliability under continuous operation. The BSM web-streaming service was operated continuously for more than one week, during which multiple clients accessed the stream simultaneously at various times of the day. Throughout this extended test period, no frame drops, buffering delays, or service interruptions were observed. CPU utilization on the SBC remained consistently below 45 % even under peak access conditions, indicating sufficient resource headroom to accommodate additional users or higher-resolution configurations in future deployments.

CONCLUSION

This work demonstrates a successful, lightweight integration of web streaming technology into the TLS beam size monitoring broadcast system. The upgrade offers a cost-effective alternative to original hardware replacement by reusing existing instrument outputs and utilizing readily available commercial and open-source components, making it well suited as a transitional solution before the decommissioning of TLS. Beam size images can now be accessed in real time on any browser-enabled device without the need for dedicated hardware or software, with both wired and wireless connectivity supported for improved accessibility. The system delivers digital streaming at 1080p/10 Hz, providing significantly enhanced resolution and sharpness; beam boundaries and shape details are more clearly discernible, facilitating operator judgment and analysis. Moreover, by eliminating the limitations of the analog broadcast system—such as interference, aging equipment, and coaxial cable maintenance—the network-based approach achieves higher stability and reduced operational burden.

REFERENCES

[1] C. H. Kuo *et al.*, "Status of Synchrotron Radiation Monitor at TLS", in *Proc. EPAC'06*, Edinburgh, UK, Jun. 2006, paper TUPCH095, pp. 1232-1234.

[2] C. H. Kuo *et al.*, "Application of the IEEE-1394 and the GigE Vision Digital Cameras for Diagnostics in Taiwan Light Source", in *Proc. PAC'07*, Albuquerque, NM, USA, Jun. 2007, paper FRPMN085, pp. 4270-4272 doi: 10.1109/PAC.2007.4439992

[3] Flask website, https://flask.palletsprojects.com/en/stable/

[4] OpenCV, https://opencv.org/

[5] Pi Video Surveillance, https://github.com/pornpasok/opencv-stream-video-to-web