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A GENERIC REAL-TIME SOFTWARE IN C++ FOR DIGITAL CAMERA-BASED ACQUISITION SYSTEMS AT CERN

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Abstract

Until recently, most of CERN's beam visualisation systems have been based on increasingly obsolescent analogue cameras. Hence, there is an on-going campaign to replace old or install new digital equivalents. There are many challenges associated with providing a homogenised solution for the data acquisition of the various visualisation systems in an accelerator complex as diverse as CERN's. However, a generic real-time software in C++ has been developed and already installed in several locations to control such systems. This paper describes the software and the additional tools that have also been developed to exploit the acquisition systems, including a Graphical User Interface (GUI) in Java/Swing and web-based fixed displays. Furthermore, it analyses the specific challenges of each use-case and the chosen solutions that resolve issues including any subsequent performance limitations.

INTRODUCTION

A Beam Observation System, referred to as BTV (Beam TV) at CERN, plays a crucial role in capturing beam images throughout the accelerator complex. This is accomplished by intercepting the trajectory of the beam within the vacuum chamber using a screen. When the beam particles interact with the screen, they emit visible light in direct proportion to their local intensity. Subsequently, a dedicated detector, such as a camera, can be employed to observe the resulting footprint of the beam through a specialized viewport and optical pathway [1]. Until recently, only analogue cameras have been used in the CERN accelerator complex, which were either Charge-Couple Device (CCD) cameras or vidicon tubes [2]. As CCD and vidicon camera technologies continue to become outdated, maintaining the current beam visualisation systems at CERN becomes progressively challenging. This issue is compounded by the need for extra cameras due to the growing interest in deploying beam observation systems in new areas throughout the facility.

It was therefore decided to use the GigE digital camera models from Basler [3] with Complementary Metal Oxide Semiconductor (CMOS) sensors for all new installations, as well as to gradually replace the obsolete analogue equipment in existing locations if the opportunity arises.

Digital cameras are proven to have better image quality (signal-to-noise ratio, dynamic range, sharpness) than their analogue predecessors [4]. In addition, there is no need for additional dedicated hardware for the Analogue-to-Digital Conversion (ADC) and the synchronization of the image acquisition with the beam passage.

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INSTALLATIONS

Digital cameras have already been installed in several locations at CERN, thus requiring the specification of a new acquisition system. This system aims to combine legacy capabilities along with additional functionalities taking advantage of, where possible, new features offered by digital cameras compared to the analogue ones.

SPS Beam Dump System (SBDS)

A BTV monitor was installed at the location of the new SBDS to ensure the safe operation of the system and its components by capturing an image of the particles before impacting the dump target. In this way, the dumped beams, including their shape and precise position in relation to the target, can be continuously monitored and subsequent injections can be inhibited in case of operational problems [5].

Since this system is linked to the safe operation of the SPS, it should always be online. Furthermore, to ensure the best possible image is provided for detecting issues with the dump, it should continuously acquire images. Then, upon receiving a timing event (e.g. that the beam was dumped) the first non-saturated image should be selected, published and stored for post-mortem analysis.

Advanced Wakefield Experiment (AWAKE)

The AWAKE experiment depends strongly on its imaging systems in order to be able to operate. They are used to measure the exact shape and position of the various beams (i.e. proton, electron and laser) so that they can be properly and efficiently aligned [6]. As a consequence, the images should be constantly acquired at the laser's repetition rate (10 Hz) which is the fastest rate of the three beams. Additionally, the large sensors of AWAKE's cameras result in large images, thus large data throughput [7].

Despite the images being acquired at a rate of 10 Hz, during normal operation, only the image capturing the SPS proton extraction is of interest to the experiment. The synchronization of the image acquisition and the SPS extraction events is therefore crucial.

Finally, AWAKE is a harsh environment for the digital cameras as many are installed very close to the beam lines and are very susceptible to Single-Event-Upset (SEU) underscoring the need for a robust recovery mechanism.

CERN Linear Electron Accelerator for Research (CLEAR)

Similar to AWAKE, CLEAR also depends on several cameras for its efficient operation. Since the facility is very versatile, accommodating a variety of experiments during

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the year [8], cameras are essential for monitoring the attributes of the beam being delivered to the clients as well as the alignment of all components in the facility.

In CLEAR, the images are usually acquired at 1 Hz (or 10 Hz in specific cases) using an external trigger that is synchronised with the beam. Occasionally, the image acquisition can also be on-demand and triggered by the users.

Antiproton Decelerator (AD) / Extra Low Energy Antiproton (ELENA)

A set of 4 BTV monitors are used to ensure the proper operation of AD and ELENA by providing beam size measurements [9]. Although the synchronisation of the image acquisition and the beam passage is normally accomplished via an external trigger, timing cabling is not available in all BTV installations. It is therefore essential for the acquisition system to be able to acquire images on-demand (e.g. via software trigger) and synchronously to the beam.

High-Radiation to Materials (HiRadMat)

HiRadMat is equipped with 6 BTV monitors to provide beam profile measurements to the operations team helping them deliver high quality beam to their users [10]. The acquisition system is the typical one triggered externally at a low rate i.e. few seconds.

R&D

Although BTVs are the most common use-case for cameras, they are not the only ones.

A digital camera is already installed as part of the new Beam Gas Curtain (BGC) monitor in the Large Hadron Collider (LHC). This instrument was installed in 2022 to be evaluated as a minimally invasive transverse profile measurement instrument for the High Luminosity LHC upgrade [11]. It acquires images in free running mode at the rate of 1 Hz.

Another camera is installed in the proton Irradiation facility (IRRAD) [12] for verifying the potential use and performance of an optical fiber together with a camera as a beam loss monitor. The images are acquired synchronously with the beam via an external trigger.

ACQUISITION SYSTEM

Despite the diversity of the requirements, efforts have been made to deliver a modular acquisition system for all digital cameras which accommodates all the specifications. Such a system is organised in two layers as follows:

Hardware

Each location can have one or more cameras installed which can be powered either via Power over Ethernet (PoE) or via a dedicated 12 Volts Direct Current (DC) power supply. For controlling the PoE case a RUCKUS [13] 12 or 24 port switch is used. For the dedicated supply, either custom electronics that were designed for the legacy BTVs [1] are used or ready-made solutions from GUDE are utilized [14].

The computer used for the data processing is usually a VME front-end computer or a rack-mounted industrial PC. In AWAKE however, due to the increased computing power needed to cope with the current large data throughput (1 GB/s) as well any future expansion, three powerful SuperMicro rack-mounted 64-core CPUs are used.

The front-end computers have two network mezzanines. One is typically faster (i.e. 10 Gb/s) and is dedicated to the communication with the camera(s). The other can reach 1 Gb/s and is used for connecting the system to CERN control system. The AWAKE servers have (at least) two Ethernet cards capable of 10 Gb/s.

In some cases (e.g. SBDS, AD) a timing receiver is also installed in the front-end computers to integrate the CERN central timing to the system. When such a receiver can't be installed due to hardware limitations (e.g. AWAKE) but the timing integration is still required, it is achieved via a software timing subscription in the real-time server.

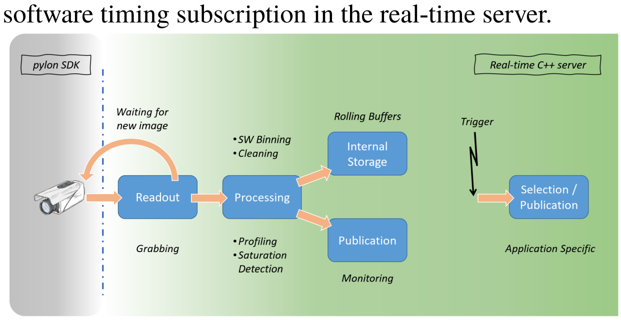

Figure 1: Image acquisition software model.

Software

The real-time C++ server responsible for coordinating the acquisition process is designed with the Front-End Software Architecture (FESA) framework [15] and the *pylon* Software Development Kit (SDK) [16] from Basler is used to accomplish low-level camera access.

The acquisition process is image driven and is organised in blocks that can be seen in Fig. 1. In order to improve the server's performance and avoid its blockage and consequently a potential image loss, each of the blocks run on a separate thread and when possible, in parallel.

Finally, every instance of the software for each camera runs on a separate Linux process to further improve the server's performance in multi-camera installations.

Image Acquisition Trigger The image acquisition at the camera can be triggered in three different ways:

- *Externally* using a coax cable to connect a physical trigger to the camera. This is the most common and accurate way to synchronise the image acquisition with an external event (e.g. beam passage). A delay at the camera level can be used to compensate for any potential delay imposed by the cable's length.
- *Manually* using the software trigger at the camera. Although this is very useful for testing, it can also be used in a synchronous mode with a bigger jitter compared to

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the external trigger in the absence of the latter. This is achieved at the real-time server by listening to timing events in order to run the manual triggering routine synchronously to such events.
- *Internally* using the camera's clock to define the desired acquisition rate. This rate is configurable and depends on the camera's electronics, the size of the acquired frame and the selected exposure time. This is useful to achieve the maximum possible acquisition rate to minimise the uncaptured time as it is required in the case of SBDS.

Readout The server receives the consecutive images through interrupt notifications generated by the CPU. It continuously grabs the incoming images and transfers them to intermediate storage, ensuring the camera's buffer is quickly cleared, thus maintaining constant readiness for the next image acquisition.

Processing The copied images are subsequently provided to the analysis block for processing. Multiple pixel scanning operations occur simultaneously to improve performance and thus handle high acquisition rates.

The *binning* of the image (i.e. reducing its size without losing too much information) in software is such an operation. It is achieved by combining a selected amount of neighbouring pixels horizontally and vertically into a single one by summing or averaging their values.

Although the digital cameras also support binning at the hardware level, it is not always preferred compared to its software equivalent. When binning in hardware, the actual image that is transferred to the server is reduced. While this can be generally considered positive, the loss of the full frame resolution might be an issue. In such cases, it is preferred to transfer the full frame to the server for analysis and use a binned copy of the image for quick displays.

Another operation called *image cleaning* is used to improve the signal-to-noise ratio of the acquired image. In this process, an empty image (i.e. an image when the beam is not present) of equal size of the acquired image is used as a reference to catch any residual background light. Subsequently, the value of each pixel of the reference image can be subtracted from the corresponding pixel of the acquired image, effectively minimising its background noise.

Furthermore, *image profiling* is fundamental in almost any image based acquisition system as it extracts the valuable information from an image, thereby diminishing the amount of data transferred to the clients.

It is essentially the horizontal and vertical projection of an image that are obtained by summing the values of its pixels in each column and row accordingly. Those two curves can then be used for further analysis of the data depicted in the image (e.g. curve fitting, standard deviation, max etc.). The server calculates the horizontal and vertical profiles of both the original and the binned image.

Finally, *saturation detection* is accomplished by scanning the individual pixels of an image to find the maximum value. In a saturated image, this value will align with the maximum output of the camera's ADC, which is 4095, representing the highest value within a 12-bit range.

Internal Storage After processing, the images can be fed to the internal storage block to keep a history. This is useful in cases where the maximum capture time is required, like in SBDS where the system constantly waits for an event to happen without knowing a priori when it will occur.

The images can therefore be saved in one of the software's rolling buffers until a configurable event triggers (e.g. a beam dump in the case of SBDS) when the image saving routine will be directed to the next available buffer.

The total number of rolling buffers is configurable and there is always an active one exclusively employed for image storage, inaccessible to the user whereas the rest host the history of N such events. The capacity of each rolling buffer can be adjusted, allowing for up to 100 images to be stored, categorized into pre-trigger and post-trigger segments. Finally, all the images of the rolling buffers, except the active one, can be retrieved for inspection before they are overwritten.

Image Selection & Publication After processing, the images can also be configured to be published to the CERN control system. This option essentially creates a stream of images whose purpose is twofold:

- In standard installations (e.g. AD, ELENA, HiRadMat) where the acquisition rate is relatively low, it can serve as the main publication method.
- However, in installations with high acquisition rate (e.g. AWAKE - 10 Hz, SBDS - 35 Hz), this is not very useful or even sustainable. In such cases, the images are continuously acquired in full resolution and binned in software. Eventually, only one will be selected to be published separately. Nevertheless, the stream of binned images can be used as a sanity check of the acquisition system.

In order to select and publish the appropriate image in the aforementioned setups, the server listens to an external trigger, e.g. that the beam was extracted or dumped.

In the most general case as in AWAKE, it publishes the last acquired image in full resolution after waiting a configurable amount of time for fine synchronisation.

In the case of SBDS however, where the internal storage is used, the trigger initiates the selection process, which keeps track of the number of received images until the rolling buffer reaches its capacity. Once that limit is reached, the buffer is frozen, and the system switches to the next available one. The first image in the rolling buffer (post-trigger) that is not saturated is selected for publication and storage in the logging and Post-Mortem database. An example of this process is depicted in Fig. 2 with the first (saturated) image in the rolling buffer on top and the sixth (the first non-saturated) in the same buffer at the bottom [17].

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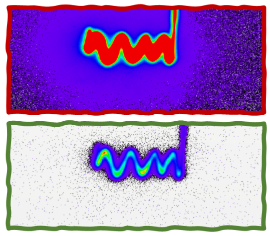

Figure 2: Example of the automatic image selection with a Fixed Target dumped beam in SBDS [17].

Internal Watchdog Digital cameras are particularly vulnerable to SEUs due to the effect of radiation to their electronics. Although the number of SEUs can be minimised by protecting the camera's installation (e.g. adding shielding or using an optical line to install it far away from the radiation source), it is still very important to monitor the system's health with an internal watchdog mechanism.

Such mechanism is based either on:

- the acquisition status where the image reception rate is tracked and compared with the expected one
- the camera status in the cases where the acquisition rate is not known in advance (e.g. AD, ELENA, HiRadMat). In such cases, the camera settings can periodically be read out and checked for consistency with those stored in software

To complement the status validation, the mechanism includes a remote power reset of the camera to recover from any unexpected instability.

Image Calibration As most BTVs are used for transverse profile measurements (e.g. beam shape and size, etc.), the mapping of the image to a real physical quantity is essential. The FESA server therefore supports image calibration i.e. the translation of the image's pixels to millimeters (mm).

Limitations

One of the main limitations of such an acquisition system is the bandwidth required to transfer the images from the camera to the FESA server and from the server to the users. Furthermore, the synchronisation of the images to the timing events is of equal importance.

Bandwidth A typical size of an image in full resolution is 1936 × 1216 pixels. When MONO8 (i.e. 8-bit Monochrome) encoding is used at the camera for acquiring and storing the images, roughly 2.3 MB will be transferred to the FESA server for processing. Accordingly, when MONO12 (i.e 12-bit Monochrome) encoding is used, 3.5 MB will be transferred to the server.

Irrespective of the pixel encoding at the camera level, the FESA server uses 16-bit short buffers for storing the images that covers both available pixel encodings. However, this means that the amount of data that will be transferred from the server to each client for both cases increases roughly to 4.7 MB per image.

Since the bandwidth defines the capacity at which the network can transmit data, there are two factors that characterise the maximum amount of data that can be transferred within the hardware limitations:

- the acquisition rate that determines how fast the data is produced
- the image size that specifies how much data is produced

In most cases, the acquisition rate is specified by the required application and is hard to change as this would compromise the performance of the acquisition system. Therefore, the most preferable way to optimise the data transmission is by reducing the image size. This can be done either via hardware binning as mentioned earlier or by selecting a Region Of Interest (ROI) to essentially crop the image that will be acquired.

The network transfer can be further optimised in the case RUCKUS switches are used by enabling the Jumbo packets at the camera, switch and network card level. This essentially reduces the amount of network packet transactions improving the network performance when it is heavily loaded.

In AWAKE, which is the most challenging installation in terms of bandwidth, an ROI cannot be specified for all cameras and the full resolution is required at 10 Hz for many of the installed cameras. Moreover, despite having installed specific hardware to cope with such demanding throughput, the image acquisition is synchronous to all cameras which means that the network usage peaks at specific moments and it's not evenly distributed over time. It was observed that this leads to congestion in the RUCKUS switch, causing it to drop network packets and leading to communication issues with certain cameras at the pylon level.

A way to mitigate this issue was found, by dividing the cameras connected to each switch into two groups of maximum 8 cameras. One group starts sending the images as soon as they are acquired whereas the other waits for 40 ms before doing so, which is roughly the time pylon needs to transmit a full frame image. The network load is therefore distributed as much as possible in the 100 ms window between two consecutive triggers.

Synchronisation Since there can be a significant difference in the time an image was acquired and reached the FESA server, a synchronisation mechanism is essential to identify the events the images correspond to.

This is achieved by using the camera's timestamping mechanism which is essentially a counter since the beginning of the image acquisition. This can then be transformed into a unique identification at the FESA server level. This is accomplished by keeping a Universal Time Coordinated (UTC) timestamp as a reference of the last counter's reset and using this reference to translate the camera's counter in a UTC timestamp for all acquired images.

ADDITIONAL TOOLS

In order to fully exploit such a complex acquisition system, several additional tools have been developed.

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Power Control Software

One such tool is a C++ software designed with FESA that abstracts the various ways of controlling the power of the cameras. This software hides the underlying hardware installation (RUCKUS, BTVI, GUDE) offering a single Application Programmable Interface (API) to the users for powering on / off the cameras. It can be used either directly via the generic GUI provided by the framework or by other software via the Remote Device Access (RDA) service [18].

Expert / Operational GUI

Another tool aimed at facilitating the use of the system by the experts is a GUI developed using Java Swing and can be seen in Fig. 3. The application visualises the acquired images together with their projections on the two axes. It also calculates and plots the *Gaussian-fitted* projections to enable the quick and easy examination of the beam shape and position.

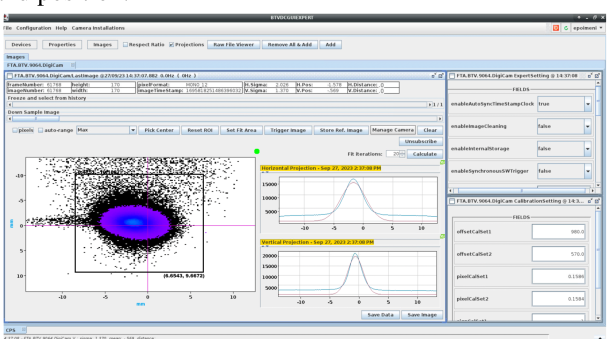


Figure 3: The expert GUI.

In addition, it displays important information about the cameras, such as the image frame size and timestamp. It also offers the ability to monitor and modify the various configuration parameters.

Some of the main functionalities offered by the GUI include the ability to monitor multiple cameras on different tabs simultaneously, change the color palette of the image and toggle the image axes between pixels or mm.

Additionally, a point inside the image's frame can be chosen by the expert. The distance from that point to the peak of the two projections can subsequently be calculated and displayed alongside the sigma and mean values of each projection.

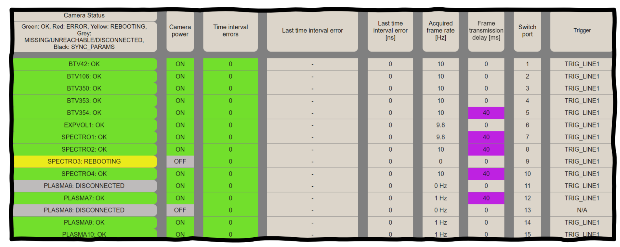
Furthermore, the GUI offers the possibility to draw a precise ROI graphically, instead of having to manually tweak the pixel coordinates, as well as allowing the user to manage the camera's power and connectivity to the FESA server effortlessly with buttons.

Finally, the application offers a way to save the images as an image file (.png) or as a plaintext file (.txt) where a 2D array is stored and each element represents the value of one pixel.

Multiple variations of the GUI have also been deployed in operation, each tailored to a specific camera installation. Such variations use the same codebase parametrised and limit the list of the available cameras according to each location, as well as the parameters that can be modified.

Fixed Status Displays

In order to have an overview of the acquisition status and the various configurations of the cameras in the numerous locations, several dashboards have been developed using the Web-based Rapid Application Platform (WRAP) [19]. An example of such a dashboard can be seen in Figure 4 which groups the necessary information of the cameras installed in one of the AWAKE servers. Such information consists of the list of the camera names, their connection status, their power status and statistics on the frame transmission including errors. It also contains important settings of each camera, such as its frame transmission delay, the port number in the switch that corresponds to it and the acquisition trigger mode.



Camera Status Green: OK, Red: ERROR, Yellow: REBOOTING, Grey: MISSING/UNREACHABLE/DISCONNECTED, Black: SYNC_PARAMS	Camera power	Time interval errors	Last time interval error	Last time interval error [ns]	Acquired frame rate [Hz]	Frame transmission delay [ms]	Switch port	Trigger
BTV42: OK	ON	0	-	0	10	0	1	TRIG_LINE1
BTV106: OK	ON	0	-	0	10	0	2	TRIG_LINE1
BTV350: OK	ON	0	-	0	10	0	3	TRIG_LINE1
BTV353: OK	ON	0	-	0	10	0	4	TRIG_LINE1
BTV354: OK	ON	0	-	0	10	40	5	TRIG_LINE1
EXPVOL1: OK	ON	0	-	0	9.8	0	6	TRIG_LINE1
SPECTRO1: OK	ON	0	-	0	9.8	40	7	TRIG_LINE1
SPECTRO2: OK	ON	0	-	0	10	40	8	TRIG_LINE1
SPECTRO3: REBOOTING	OFF	0	-	0	0	0	9	TRIG_LINE1
SPECTRO4: OK	ON	0	-	0	10	40	10	TRIG_LINE1
PLASMA6: DISCONNECTED	ON	0	-	0	0 Hz	0	11	TRIG_LINE1
PLASMA7: OK	ON	0	-	0	1 Hz	40	12	TRIG_LINE1
PLASMA8: DISCONNECTED	OFF	0	-	0	0 Hz	0	13	N/A
PLASMA9: OK	ON	0	-	0	1 Hz	0	14	TRIG_LINE1
PLASMA10: OK	ON	0	-	0	1 Hz	0	15	TRIG_LINE1

Figure 4: Online status dashboard of the digital cameras installed in the one of the servers in AWAKE.

CONCLUSION

There is an on-going campaign to replace increasingly obsolescent analogue cameras used in most of CERN's beam visualisation systems with new digital equivalents. There are many challenges associated with providing a homogenised solution for the data acquisition of such systems including the variety in hardware and in the requirements for each installation.

Despite the diversity of the specifications, a generic, modular real-time software has been developed in C++ and installed in several locations to control such systems. The software accommodates the features of the legacy acquisition systems as well as the necessary additional ones including a synchronous software trigger and saturation detection. It integrates the CERN central timing in software when the corresponding hardware is not available and maintains an internal watchdog to recover from SEUs. Furthermore, it supports network optimisation for the most challenging installations as well as precise image timestamping for synchronisation.

Lastly, additional tools have been developed to exploit the acquisition systems including additional C++ software for controlling the power of the cameras, a GUI in Java/Swing facilitating the use of the system and web fixed displays to monitor the status of each installation.

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REFERENCES

[1] E. Bravin *et al.*, "A new TV beam observation system for CERN", in *Proc. DIPAC'05*, Lyon, France, Apr 2005, paper POT030, pp. 214-216.

[2] S. Burger, E. Bravin, "A new Control System for the CERN TV Beams Observation", Rep. CERN-AB-Note-2008-041-BI, 2008.

[3] BASLER, https://www.baslerweb.com/en/

[4] C. Toapaxi, C. Eduardo, "Assessment performance and emittance measurements tests of Basler digital camera vs. the standard BTV system at CLEAR.", Rep. CERN-STUDENTS-Note-2019-045, 2019.

[5] S. Burger *et al.*, "New CERN SPS Beam Dump Imaging System", in *Proc. IBIC'21*, Pohang, Rep. of Korea, Oct 2021, paper TUPP22, pp. 254-258. doi:10.18429/JACoW-IBIC2021-TUPP22

[6] S. Mazzoni *et al.*, "Beam Instrumentation Developments for the Advanced Proton Driven Plasma Wakefield Acceleration Experiment at CERN", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper MOPAB119, pp. 404–407. doi:10.18429/JACoW-IPAC2017-MOPAB119

[7] E. Senes *et al.*, "Recent AWAKE Diagnostics Development and Operational Results", in *Proc. IPAC'22*, Bangkok, Thailand, Jun 2022, paper MOPOPT042, pp. 343–346. doi:10.18429/JACoW-IPAC2022-MOPOPT042

[8] R. Corsini *et al.*, "Status of the CLEAR User Facility at CERN and its Experiments", in *Proc. LINAC'22*, Liverpool, UK, Sep 2022, paper THPOPA05, pp. 753–757. doi:10.18429/JACoW-LINAC2022-THPOPA05

[9] L. Ponce *et al.*, "ELENA - From Commissioning to Operation", in *Proc. IPAC'22*, Bangkok, Thailand, Jul 2022, paper THOXGD1, pp. 2391–2394. doi:10.18429/JACoW-IPAC2022-THOXGD1

[10] F.J. Harden *et al.*, "HiRadMat: A Facility Beyond the Realms of Materials Testing", in *Proc. IPAC'19*, Melbourne, Australia, Jun 2019, paper THPRB085, pp. 4016–4019. doi:10.18429/JACoW-IPAC2019-THPRB085

[11] O. Sedláček *et al.*, "HL-LHC Beam Gas Fluorescence Studies for Transverse Profile Measurement", in *Proc. IBIC'22*, Kraków, Poland, Nov 2022, paper TUP17, pp. 261–264. doi:10.18429/JACoW-IBIC2022-TUP17

[12] F. Ravotti *et al.*, "A New High-Intensity Proton Irradiation Facility at the CERN PS East Area", in *J. PoS*, Jul 2015, paper TIPP2014, p. 354. doi:10.22323/1.213.0354

[13] RUCKUS Networks, https://www.ruckusnetworks.com/

[14] RUCKUS Networks, https://gude-systems.com/en/

[15] M. Arruat *et al.*, "Front-End Software Architecture", in *Proc. ICALEPCS'07*, Knoxville, Tennessee, USA, 2007, paper WOPA04, pp. 310-312

[16] pylon Camera Software Suite, https://www.baslerweb.com/en/products/software/basler-pylon-camera-software-suite/

[17] A. Topaloudis *et al.*, "Beam Profile Measurements as Part of the Safe and Efficient Operation of the New SPS Beam Dump System", in *Proc. ICALEPCS'21*, Shanghai, China, Feb 2022, paper WEPV044, pp. 764–767. doi:10.18429/JACoW-ICALEPCS2021-WEPV044

[18] N. Trofimov *et al.*, "Remote Device Access in the new CERN Accelerator Controls middleware", in *Proc. ICALEPCS'01*, San Jose, CA, USA, Nov 2001, paper THAP003, pp. 496–498.

[19] E. Galatas *et al.*, "WRAP - A Web-Based Rapid Application Development Framework for CERN's Controls Infrastructure", in *Proc. ICALEPCS'21*, Shanghai, China, Feb 2022, paper THPV013, pp. 894–898. doi:10.18429/JACoW-ICALEPCS2021-THPV013