ARG-US Remote Area Modular Monitoring: Digital Cameras for Enhancing Safety and Security

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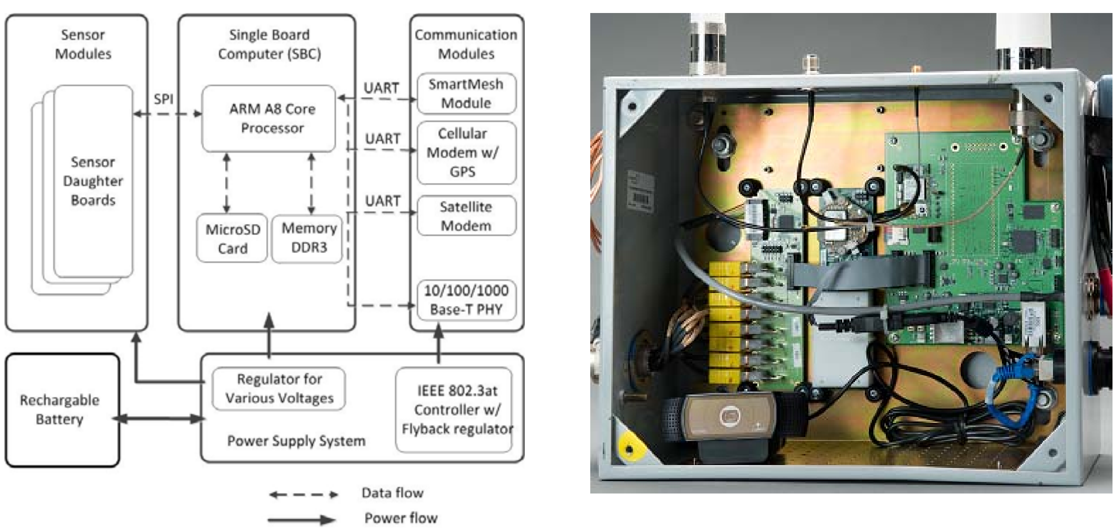
ABSTRACT

Digital cameras are incorporated into the Remote Area Modular Monitoring (RAMM) system in a radiological facility at Argonne National Laboratory. The system has been undergoing extensive operational testing, and the results obtained so far demonstrate great value in improving facility safety and security.

INTRODUCTION

ARG-US Remote Area Modular Monitoring (RAMM) is an expandable, adaptable system for monitoring critical nuclear fuel cycle facilities, such as nuclear power plants, fuel production and reprocessing facilities, spent fuel dry storage systems, decommissioned plants and facilities, and underground repositories [1, 2]. ARG-US RAMM has been developed under the auspices of the U.S. Department of Energy Packaging Certification Program, Office of Packaging and Transportation, Office of Environmental Management. The ARG-US RAMM architecture is designed on a modular platform to accommodate an expandable array of sensors that may include external thermocouples for temperature, humidity, and radiation (gamma and neutron) sensors, as well as a 3-axis digital accelerometer and an electronic loop seal. A digital camera, or optical sensor, is the latest specialty sensor incorporated into the RAMM platform. Figure 1(a) shows the block diagram of RAMM; Figure 1(b) shows a digital camera mounted on the base inside of a prototype RAMM unit.



(a) (b)

Figure 1. Block diagram of remote area modular monitoring (RAMM) (a), with a digital camera mounted on the base inside the lunch-box-sized unit (b).

The digital camera greatly enhances RAMM capabilities, providing multiple sets of “eyes” for unattended monitoring of selected areas of continuous operations. The digital-camera-equipped RAMM units enhance safety by providing views of controlled areas during facility operations—for example, they can help ensure that personnel are wearing appropriate protective clothing and gears. They also enhance security during off hours of facility operation by detecting motion and/or events and subsequently triggering an alert/alarm and enabling timely response. The following sections first highlight the initial development integration of a digital camera into RAMM and then describe implementation testing of distributed RAMM units in Argonne's Alpha Gamma Hot Cell Facility (AGHCF)—a Category III radiological facility currently undergoing decommission and decontamination. The highlights are focused on methods for image processing and video archives that pose challenges on information management and data storage. Also highlighted is the corroboration of video image data with other sensor data obtained in the continuous monitoring of the AGHCF by the ARG-US radio frequency identification (RFID) system [3].

CAMERA DEVELOPMENT INTEGRATION INTO RAMM

The sensor modules in RAMM consist of sensor daughter boards, each of which is controlled by a microprocessor that communicates with a Single Board Computer (SBC) by using the Serial Peripheral Interface (SPI) protocol (see Fig. 1[a]). A sensor module sends measured sensor values to the SBC and receives from it the control commands and operation parameters (e.g., sensor threshold values). The SBC is the controller of the RAMM unit, and it consists of an ARM A-8 core processor, a 4-GB/8-GB microSD card, and 512 MB of DDR3 SRAM memory. The abundant computational resources make it possible to support a full-blown operation system (OS) on the SBC. The Ubuntu Trusty is the OS of the SBC, and it has ported a set of interface drivers that enable control of various peripherals options for the SBC, such as SPI, Ethernet, Universal Serial Bus (USB), Inter-Integrated Circuit (I2C), and Universal Asynchronous Receiver/Transmitter (UART). The OS also contains tools that support remote application debugging, using Eclipse, which facilitates embedded code development for RAMM. Currently, each RAMM unit has two sensor daughter boards:

1. A radiation sensor board carrying a gamma dosimeter and a neutron detector and
2. A thermocouple board that has provisions for eight (8) external Type-K thermocouples and an electronic loop seal.

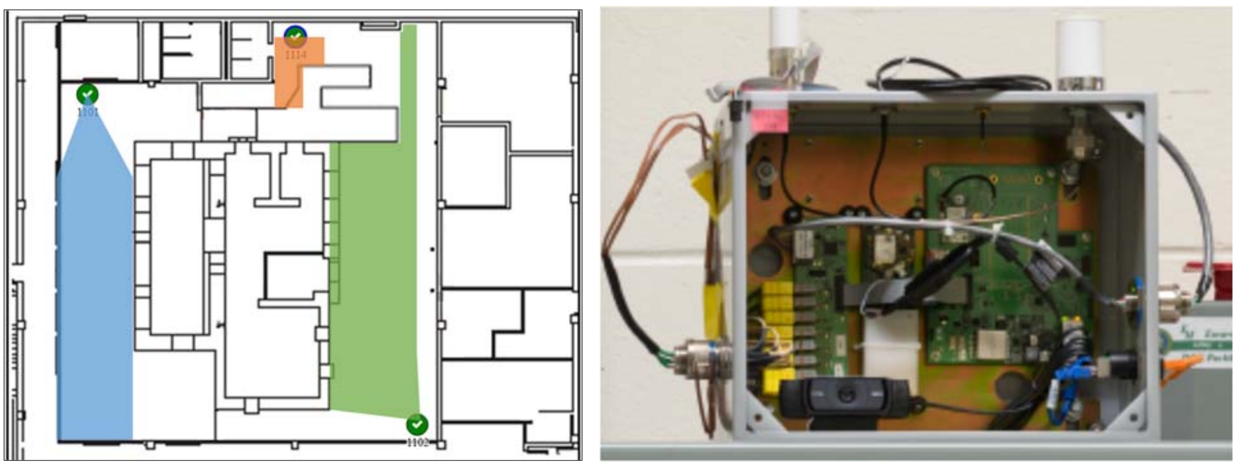
In addition, the present embodiment incorporates a 3-axis digital accelerometer and a thermistor on the SBC board. Because specialty sensors are incorporated into a RAMM unit via sensor daughter boards, they can be added to or removed from a RAMM unit according to the application environment, without any architectural change in the hardware.

A digital camera is treated as a specialty sensor for development integration into RAMM, and its selection involved mainly considerations of compatibility with existing RAMM architecture, both hardware and embedded software and their communication interfaces. For example, the size of the digital camera was a factor, because it needs to be mounted inside a RAMM unit. Power supply, connectivity, and image quality are other considerations. Early in the development process, we identified two options for the camera, either an Internet Protocol (IP) camera or a Webcam that feeds its images to the SBC and onward to a dedicated computer server, where the "captured" video images can be viewed and archived for storage. We chose USB as the communication interface because it offers the great flexibility between the camera units and the software packages available.

The Logitech HD Webcam C920, shown in Fig. 1(b), was selected; its physical dimensions (19.10-cm length × 7.20-cm width × 22.70-cm height) and weight (441.3 g) meet the size requirement for RAMM. It is full HD (up to 1920 × 1080 pixels) and therefore capable of capturing video at a rate of at least 10 frames per second (fps), along with still HD images, thus allowing for accurate measurements, potential objects identification, and motion detection. This Webcam model also has a large user-support base for software and hardware integration. Furthermore, this Webcam model is generic enough to facilitate drop-in replacement in the future, if additional capabilities in a high-performance Webcam become available.

CAMERA TESTING AND IMPLEMENTATION IN AGHCF

Figure 2(a) shows three RAMM units (#1101, #1102, and #1114) with digital cameras in the AGHCF; the shaded areas indicate the coverage of each camera. (Note: The three cameras cover nearly 100% of the accessible areas in the AGHCF.) Figure 2(b) shows RAMM Unit #1114 monitoring the glovebox and the connecting pathway between AGHCF's radiation buffer area and radiation controlled area. RAMM Unit #1114 was the first unit introduced into the AGHCF. In addition to the digital camera, the RAMM unit also has other sensors for temperature and radiation (gamma and neutron). The unit is connected to building IT via Power of Ethernet (PoE), as are Units #1101 and #1102.



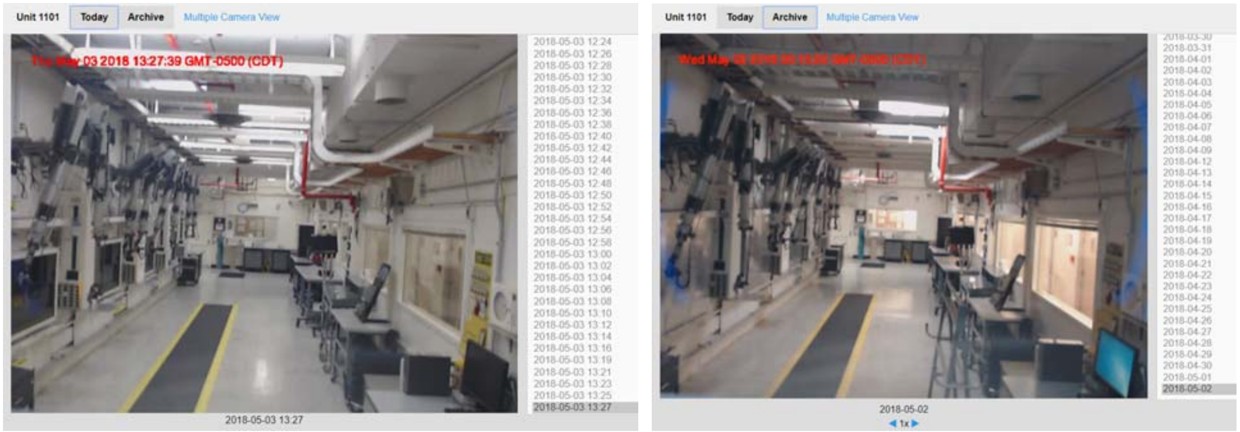
(a) (b)

Figure 2. RAMM units (#1101, #1102, and #1114) with digital cameras covering AGHCF (a) and Unit #1114 (b) monitoring glovebox and pathway.

A suite of embedded software has been developed for the SBC to operate the digital camera, including an application for capturing images at a specified interval. The SBC in the unit sends the captured images to the secured ARG-US server, where server software has also been developed to receive images and store them locally. The server then makes the images available on a web application user interface that contains many features, highlighted below.

<u>Single Camera View</u>:

Figure 3 shows a single camera (#1101) view from the web application user interface, where the tool bar at the top allows selection of the RAMM Unit, Today (Fig. 3[a]), Archive (Fig. 3[b]), or Multiple Cameras View. The list to the right of the image in Fig. 3(a) shows frames of images taken at 2-min intervals, starting Today from midnight of May 2, 2018, with the last one at the bottom of the list (shaded in grey) taken at 2018-05-03 13:27. Moving the cursor upward on the list and clicking the selection would reveal still images at earlier hours of May 3, 2018. The list to the right of the image in Fig. 3(b) shows archives of videos, with the last one at the bottom of the list (shaded in grey) being 2018-5-02. Moving the cursor upward on the list and clicking selects the video by date, similar to the click selection of still images at 2-min intervals in Fig. 3(a).



(a) (b)

Figure 3. Single camera (#1101) view from the web application user interface: (a) Today Thur May 03 2018 13:27 39 GMT-0500 (CDT) and (b) Archive Wed May 02 2018 00:15 26 GMT-0500 (CDT).

The archived videos are created by compressing the original frames of still images (720 frames) over a 24-h period. The arrows at the bottom of the webpage image in Fig. 3(b) allow for forward and backward movements of video images and pause; the 1× between the arrows controls the playback speed of the video up to 16×, which significantly facilitates the review of archived videos by zooming quickly into any “windows of interest” and providing playback at different speeds.

Multiple-Cameras View:

Multiple-cameras view of a facility is highly desirable for unattended monitoring. Figure 4 shows the web application user interface design of a 4-camera (Quad) view, including three units (#1101, #1102, and #1114) in the AGHCF and one test unit (#2107) located in another building at Argonne—all connected remotely to the secured ARG-US server via PoE.

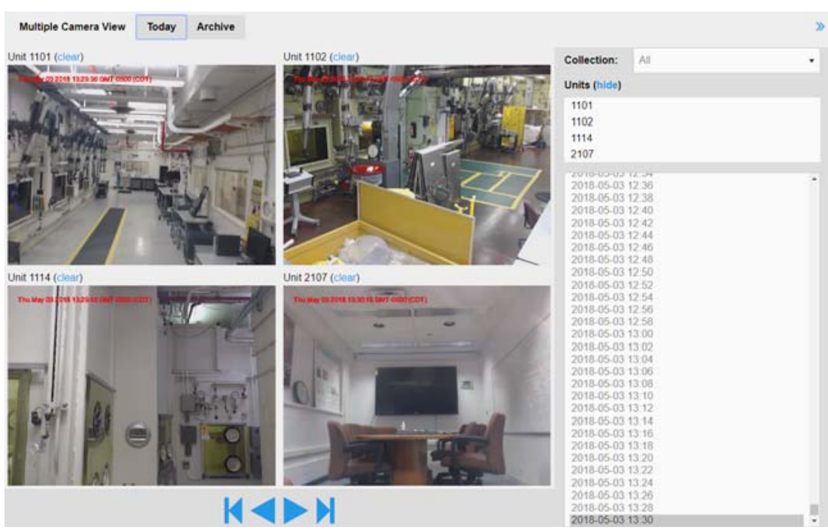
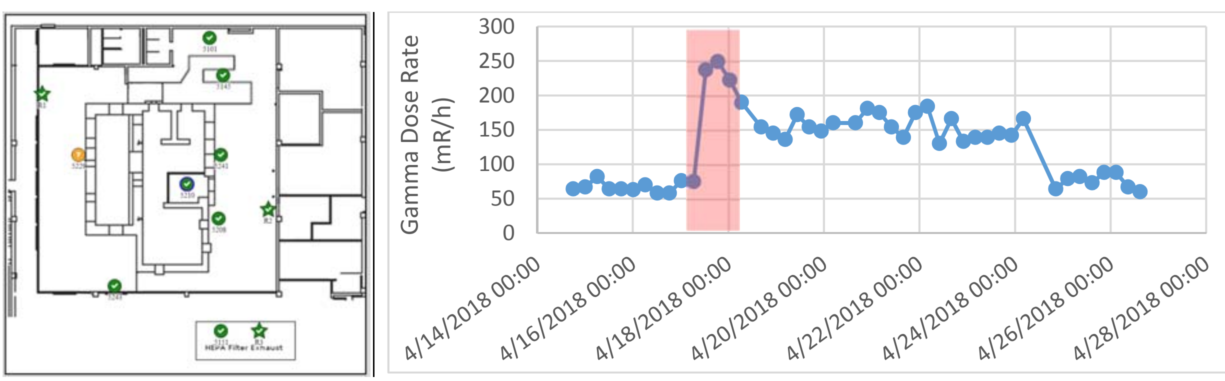


Figure 4. Quad view displaying Today (Thu May 03 2018) images of multiple cameras in the RAMM units (#1101, #1102, and #1114) in AGHCF and #2107 at another building. The current time (shaded in gray) is 2018-05-03 13:30 GMT.

Similar to the tool bar in the webpages discussed earlier for single-camera view (Fig. 3), the user interface for the web application in Fig. 4 includes additional features that allow control of multiple-cameras view. For example, the Quad view panel can show one, two, three, or four cameras by selecting the Collection search box shown to the right of the images in Fig. 4 near the top. The Units (hide) box underneath Collection displays the selected units under All, and users have the option to not show any units by clicking (hide) in the parenthesis. Users can remove each selected camera unit from the Quad view panel by clicking the Clear button next to the unit in the parenthesis. Instead of moving the cursor upward along the list at 2-min intervals to earlier times, the arrows located at the bottom of the Quad view allow users to conduct a backward search of images at earlier times of Today *for all camera units*. Examination of time stamps displayed on each of the multiple cameras in the Quad view showed that they are closely synchronized to within one minute of each other. The Quad view of multiple cameras showing videos under Archive by dates are also closely synchronized with each other, thus providing not only a global facility view of the AGHCF, but also synchronized operation down to dates, hours, and minutes in the playbacks.

CORROBORATION OF CAMERA IMAGE DATA WITH ARG-US RFID SENSORS IN AGHCF

An ARG-US RFID system consisting of eight RFID surveillance sensor tags and three readers, shown in Fig. 5(a), has been deployed in the AGHCF for continuous facility monitoring since 2013 [3]. Tags #5151, #5101, and #5210 are of particular interests to facility operation, because they are located, respectively, near the High-Efficiency Particulate Air (HEPA) Filter Exhaust, glovebox, and inside the Clean Transfer Area (CTA), where packaging and off-loading of radioactive wastes is performed routinely during normal operation of the AGHCF. All three RFID tags have gamma and neutron radiation sensors, and Fig. 5(b) shows a sudden increase in the gamma dose rates (~250 mR/h) measured by Tag #5210 on April 16, 2018. (Data collection of the RFID tags by the readers is wireless and programmed at 6-h intervals for each tag over a 24-h period.) The measured gamma dose rates then dropped in the following day and remained relatively constant for a week before dropping again to a level comparable to the gamma dose rates (~65 mR/h) measured by Tag #5210 before April 16. The archived videos were examined to help determine an explanation for the change in gamma radiation levels.



(a) (b)

Figure 5. ARG-US RFID tags and readers in AGHCF (a) and (b) gamma dose rate data for RFID Tag #5210 inside Clean Transfer Area (CTA).

Figure 6 shows a playback (at 0.25×) of the RAMM Unit #1102 video archive on April 16, 2018. The video was paused on Monday, April 16, 2018, at 13:49:04 GMT-0500 (CDT), which was 8:49 a.m. Central Daylight Time in Chicago, IL. Three workers wearing protective clothing and gear were seen engaged in packaging activities of radioactive wastes near the CTA, an activity that was corroborated with the increase of tag-measured gamma dose rates.

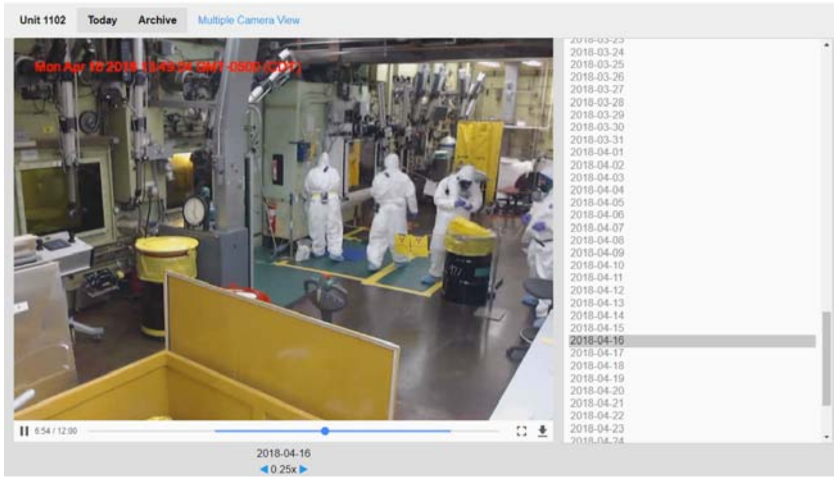


Figure 6. Archived video image of RAMM Unit #1102 showing workers engaged in packaging activties near CTA on April 16, 2018.

SUMMARY AND DISCUSSION

Initial integration of digital cameras into RAMM has been completed. The results of testing the implementation of distributed RAMM units with digital cameras in the AGHCF are reasonably satisfactory, as judged by image quality, information management, and data storage. The camera-equipped RAMM units enhance facility safety by providing a global view of all accessible areas in the AGHCF during normal operation. This global view is available at all times to facility management through the password-controlled web application user interface. Any violation of safety procedures or unsafe practices can be detected in time for corrective actions. Visual observation of operational activity, either planned or unplanned, in the AGHCF can therefore be conducted remotely for various occasions. Video archives preserve daily operations histories of the facility, and the synchronized, archived videos with adjustable playback speeds greatly facilitate the review process—especially when corroborated with other data from sensors in the ARG-US RFID tags and RAMM units. Figure 7(a) shows the ARG-US RFID Tag Unit #5101 with the

(a) (b)

Figure 7. ARG-US RFID Tag #5101 (a) and RAMM Unit #1114 (b) near the glovebox in AGHCF.

status (green for normal) of all the sensors and their current values listed. The tool bar at the top of the web application user interface allows switching to Multiple Cameras view, if there are alerts/alarms triggered by violations of thresholds for the sensors in the distributed RFID tags. The radiation sensors and the 3-axis digital accelerometers in the RAMM Unit #1114 (Fig. 7[b]) can also issue automatic alerts/alarms when any of the preset thresholds of these sensors are violated.

To enhance security during off-hours of facility operation, including weekends and holidays, detection of motion or event based on changes of intensity in camera images may be used for alarm annunciation. Figure 8 illustrates an event detection by Unit #1114, which covers the glovebox and connecting pathway in the AGHCF. Algorithms and weights are being developed to process successive video images to determine if a new captured image contained “significant” changes in intensities. Using colors as indication of changes in image intensity, Fig. 8(b) shows four different colored pixel tiles (clockwise from top: beige, yellow, orange, and red) surrounded by the background pixel tiles that are all shaded grey. The time stamps on the video images in Figs. 8(a) and 8(b) show that the event can be detected within 2 min after its occurrence. The efficiency of video image processing can be further enhanced by selecting “regions of interest” where activities are likely to occur and by eliminating comparison of background images of walls and ceiling that do not change with the sequence of frames.

(a) (b)

Figure 7. (a) Camera image from Unit #1114 before motion (event) detection on May 02 2018 08:44:52 GMT and (b) pixel-frame-based motion (event) detection on May 02 2018 08:46:52 GMT. (Colors indicate differences in changes of image intensities in successive images.)

Abilities to control digital cameras in the RAMM units directly from the web application user interface are highly desirable and remain to be exploited. Increasing the frame rate of the camera, or changing to live streaming when the situation warrants it, is one example. Another example is using the pan, tilt, and zoom (PTZ) of cameras. Audible sounds picked up by the Webcam’s microphones could be used to trigger alarms with an indicator icon on the webpage, along with concurrent alarm annunciation by automated text messages and phone calls. Finally, we believe our image processing can be further enhanced by incorporating machine learning to allow for visual accounting of assets in the vision space, a capability similar to using computer vision for facial recognition. Advanced imaging devices, such as a silicon retina imager [4], are being considered for efficient, asynchronous event-based monitoring that should complement the existing ARG-US RAMM units in the AGHCF.

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REFERENCES

1. Y.Y. Liu, K.E. Sanders, and J.M. Shuler, "Advances in Tracking and Monitoring Transport and Storage of Nuclear Materials," IAEA International Conference on Nuclear Security: Commitments and Actions, Vienna, Austria, December 5–9, 2016.
2. H. Lee, B. Craig, K. Byrne, H.-C. Tsai, Y.Y. Liu, and J.M. Shuler, "Remote Area Modular Monitoring System for Facilities and Transportation," 18th International Symposium on Packaging and Transportation of Radioactive Materials, PATRAM 2016, Kobe, Japan, September 18–23, 2016.
3. Y.Y. Liu, J.D. Hlotke, and J.M. Shuler, "ARG-US Technology for Decommissioning and Decontamination," 18th International Symposium on Packaging and Transportation of Radioactive Materials, PATRAM 2016, Kobe, Japan, September 18–23, 2016.
4. P. Lichtsteiner, C. Posch, and T. Delbruck, "A 218×128 dB 15 µs Latency Asynchronous Temporal Contrast Vision Sensor," IEEE J. of Solid-State Circuits," Vol. 43, No. 2, February 2008.