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Image-based helium spill detection during LHC warm-up procedure for Long Shutdown 2 at CERN

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Abstract

CERN long shutdowns allow maintenance and improvement of the CERN accelerator complex. During this period, part of the equipment is partially dismantled, fixed or replaced. Therefore, the liquid helium stored in the superconductive magnets needs to be extracted, warmed-up and stored outside the accelerator complex, ready to be re-injected once the maintenance operations are completed. The big calorimeters used for this process must sustain for a long period of heavy stresses caused by the high-temperature variations inside them. To detect possible breaks on the calorimeters system, which may cause helium leaks and possibly lose the entire helium reserve, an automatic image-based system has been integrated to constantly monitor the status of the calorimeters and report any anomaly to the operators, capable to analyse and stop the warm-up process by closing the appropriate valves.

The system uses three change detection methods in parallel, one pixel colour-based change detection, one optical flow-based detection and anomaly detection neural network. The pixel colour-based change detection is fast and allows the immediate response of the algorithm. The optical flow-based detection is slower and allows extracting the direction of the change, as the leaking helium will move mainly towards the ceiling.

The system runs at 10 Hz using 4K frames allowing the detection of minimal changes thanks to the high-resolution. It includes a web-interface for visualization and configuration from the control rooms, an alarm system and email and SMS notifications. Results of the system during the LHC LS2 Warm-Up process are presented in this paper.

1. Introduction

CERN, the European Organization for Nuclear Research, hosts the biggest particle accelerator complex in the world. Among the numerous accelerators, experiments and facilities, the Large Hadron Collider (LHC) rises with its unprecedented energy and dimensions. In order to ensure this high energy, 1232 superconductive dipole magnets are used to bend the particles trajectory and keeping them inside the 27 km circumference of the LHC [1].

Superconductive magnets are particular magnets working at extremely low temperature. In the case of LHC's dipole magnets, they are kept at a temperature of around 2 K using large quantities of liquid helium [2]. A cryogenic cooling circuit is deployed all over the LHC to maintain the dipole magnets in their superconducting state.

Due to the complexity of the LHC, a two years shutdown is planned after certain years of operation to ensure appropriate maintenance and improve its components. This period is referred as Long Shutdown (LS). During this period, the liquid helium stored in the LHC cryogenic cooling circuit is extracted and brought back to ambient temperature to increase the safety of the LHC facilities and to allow the maintenance of all its components.

The LHC warm-up is realized through five heating systems positioned underground along the facility, which bring the liquid helium from 2K to ambient temperature. During this operation, the heaters are subject to high mechanical stress due to the wide range of temperatures in which they operate. A mechanical failure causing a helium leak might cause the loss of the entire reserve, creating at first a safety hazard and financial loss as well.

Circuit valves are used to stop the flow inside the heaters in case of leak. The heating procedure is constantly monitored manually by an operator at each point. However, certain parts of the system lack sensors, making the monitoring challenging.

In this paper an automatic image-based leak detection system employed during the LHC LS2 Warm-Up process is presented. The system makes use of UHD surveillance cameras to detect the leak and report it to the operator as soon as possible.

The system runs in parallel on all the five heating points and the operator can interact with it through a web-interface for visualization and configuration.

2. The proposed system

The proposed system employs five UHD surveillance cameras. Surveillance cameras provide high availability and usually provide Ethernet connection, making them suitable for remote installation in inaccessible places, like underground facilities. The cameras' viewing angle is directly pointed to the heating system and wide-angle 120° lenses were chosen to ensure a complete coverage of the system. The chosen cameras provided 4K@15fps coloured streams, allowing the leak detection system to have enough details.

After the cameras installation, the automatic leak detection system was created and deployed. The system is based on the CERNTAURO robotic framework [3], which already provides various functionalities including accessing video streams, image processing [4], analysis and communication [5]. The system was deployed onto two cloud-based virtual machines, through the CERN OpenStack cloud service, to ensure higher availability and redundancy of the system. One of the main

Figure 1: The LHC helium heaters seen from the installed surveillance cameras

challenges during the creation of the detection system was its validation. In fact, it was not possible to recreate a leak condition in each facility to validate that the system was correctly detecting them.

For this reason, the automatic detection system is divided in three parts: an image-based difference detection, an optical flow detection and a machine learning recognition. The three systems run in parallel ensuring redundancy of the detection.

The image-based difference detection is used to provide fast response of the system. Every frame is compared with a reference frame and a difference threshold is pre-defined to trigger the detection alarm. As image difference is a fast computational operation, this allows the system to be very responsive to changes. However, any change in the environment such as a light change or a person passing by, would cause the alarm to be triggered. In fact, the area surrounding the heaters is not closed to the workers for the entire heating process but just for a short period of time which is considered the most critical in terms of leak hazard.

Due to this lack of accuracy of the image-based difference, a detection based on the optical flow algorithm [6] is added. This operation is slower than the image difference process, but allows to computation of the direction of the change. During a leak, the helium tends to move towards the ceiling before filling the entire room, as it is lighter than air. Therefore, the optical flow detection is used to compute the direction of the image changes and verify if they are going towards the ceiling. If the direction satisfies a pre-defined threshold, the alarm is triggered.

Finally, a machine learning-based anomaly detection is used to detect anomalies in the video stream. Due to the lack of experimental data, it was not possible to train a neural network to recognize a helium leak. This would have required a dataset of helium leaks, which was not available and it was not convenient to be created in a laboratory. An anomaly detection convolutional neural network was created and was thus, trained with images collected from the installed cameras before the start-up of the heating operation, feeding the neural network with images of what is considered normal conditions. In this way, only few anomalies were necessary to train the neural network and validate the system. The detection by the neural network is much slower than the other two algorithms but allows a third level of redundancy of the system.

Figure 2: A simulated helium leak in the LHC during a safety test

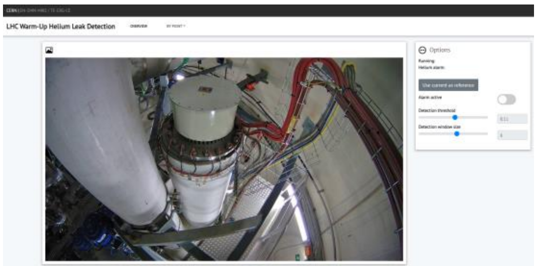

Figure 3: The web interface for interacting with the detection system

3. Operation

The system was deployed and operational for more than 4 months. During the operation period, there was no helium leak and the warm-up proceeded without any interruption. The automatic detection system sent a small amount of false positives, mainly related to objects that were left in the area or continuous light changes in the environment. The use of the CERNTAURO framework allowed the system to be completely stable for the entire operation period with little programming effort, thanks to its continuous improvements during robotic operations performed at CERN.

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