CERN

Multi-spectral analysis and machine learning for automated monitoring

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Survey, Mechatronics and Measurements

Outline

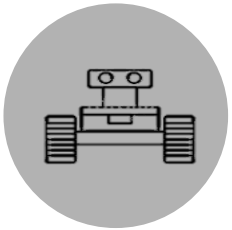
- Introduction
- Need of Robotics Solutions in Big Science Facilities
- Robotics at CERN
- Computer Aided Change Identification
    - Milestones achieved
    - On-going Work
    - Future work
- Conclusion

Introduction

- Following structural surveys, preventive measures can be taken to avoid larger infrastructural damages as well as to prevent accidents that might otherwise take place.
- Traditional methods of inspection rely on on-site visual monitoring
  - Personnel can be exposed to hazardous environments during inspections
  - Subjective survey reports, human detection errors
  - Time-Consuming
  - CERN has more than 70 km of tunnels of such harsh environments

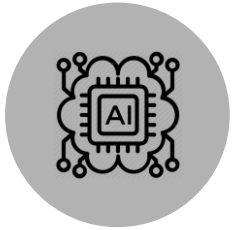
Need for an Automatic Tunnel Inspection System

SHM
Structural Health Monitoring



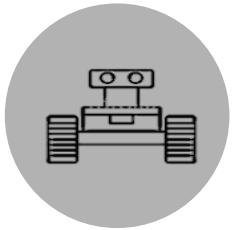
ROBOTICS

COMPUTER VISION



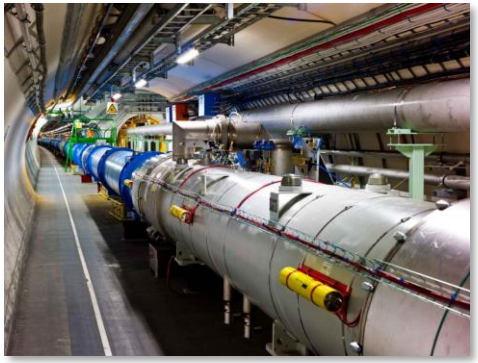
MACHINE LEARNING

Main needs for robotics in Big Science Facilities



- Non-destructive testing and inspection, remote operation and maintenance of **dangerous equipment and zones**
- In many particle accelerator facilities, nuclear and power plant, areas and objects are **not designed and built to be maintained remotely**

ROBOTICS



LHC tunnel at CERN

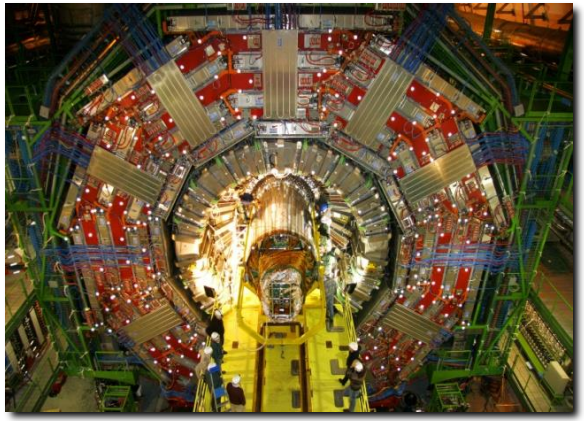
North Area experimental zone at CERN

Robotic handling of accelerator components at CERN

Challenges for robotics in Big Science Facilities

- Accessibility, radiation, magnetic disturbances, delicate equipment not designed for robots, big distances, temperature, explosive atmosphere, communication, time for the intervention, **highly skilled technicians required** (non robotic operators), etc.



Robots Pool at CERN

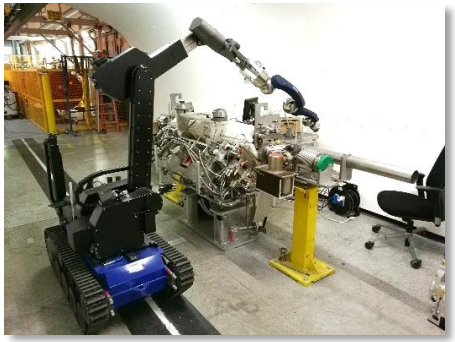
- Teleoperation is strongly increased during the last years at CERN

Telemax robot

EXTRM robot with single arm (CERN made)

The TIM (CERN made)

CRANEbot (CERN made)



Teodor robot

EXTRM robot (CERN made)

CERNbot (CERN made)

Robots Pool at CERN

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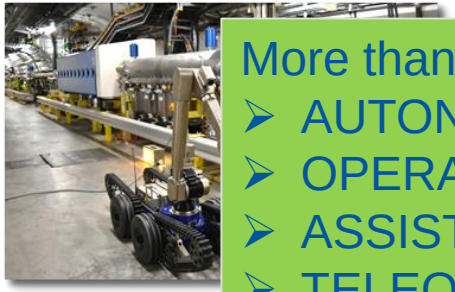


Telema

Teodor robot

More than 30 robots in operation

- AUTONOMOUS INSPECTIONS
- OPERATOR DRIVEN INSPECTION
- ASSISTED INSPECTION
- TELEOPERATIONS
- ASSISTED TELEMANIPULATION
- AUTONOMOUS REMOTE OPERATION
- SAFETY, SEARCH AND RESCUE

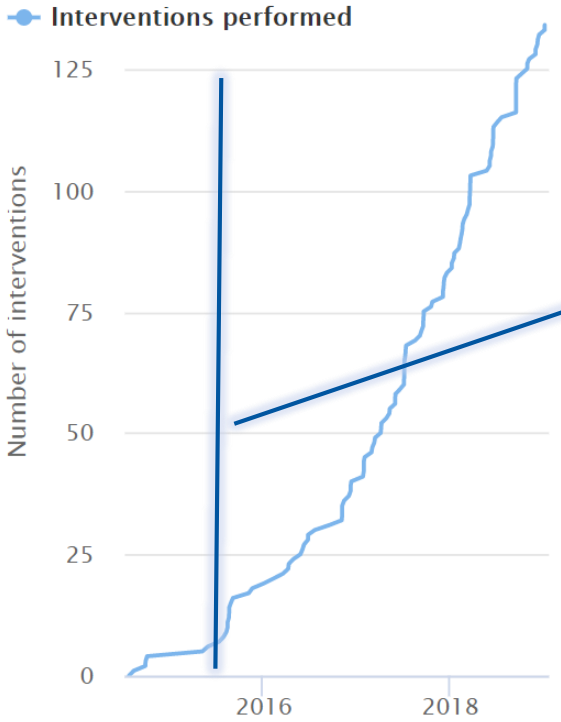
STRONG MAINTENANCE AND UPGRADE PROGRAM DEPENDING ON HOW MUCH THE ROBOTS ARE USED AND HOW THEY ARE MADE

EXTRM robot (CERN made)

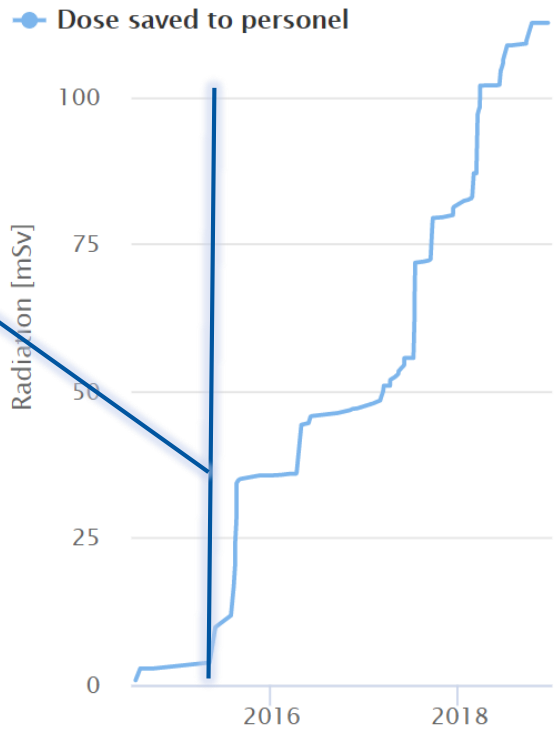
CERNbot (CERN made)

RANEbot (CERN made)

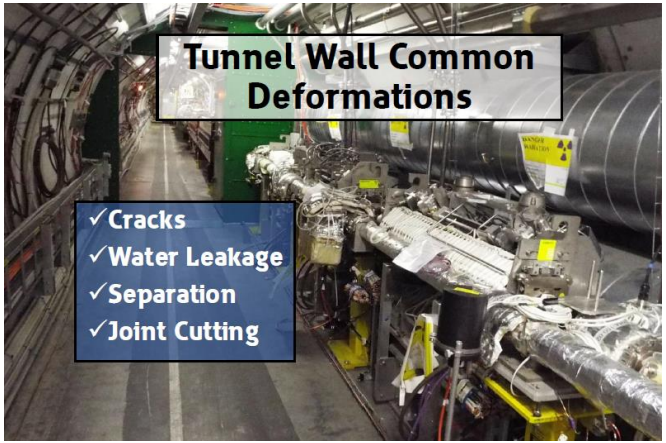
Robotic Support at CERN



Started to apply CERN custom made robotic solutions. Remote handling capabilities and modularity strongly increased!



Using Computer Vision for tunnel monitoring



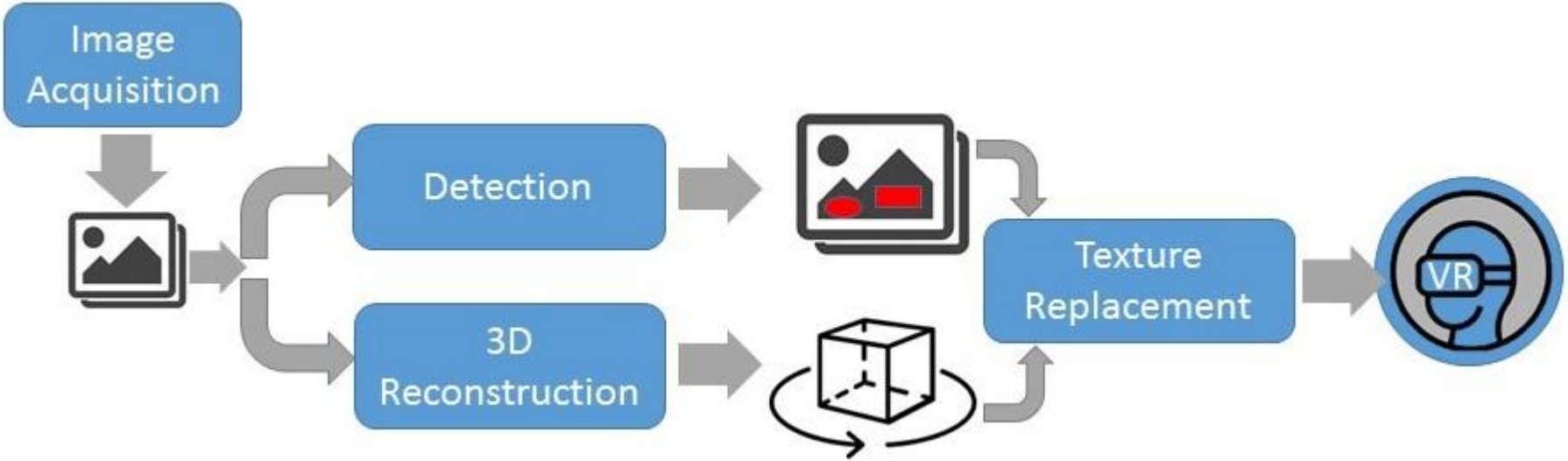
- Identify cracks and other defects automatically through image processing techniques and/or a deep learning architecture
- Automate change detection
- Display detected defects on a 3D model
- Integrate 3D model with Virtual Reality (VR) for better contextualisation

- To mitigate the disadvantages of manual inspection, during the last years, a number of computer vision-based defect detection techniques were developed.

- Here at CERN, we have been investigating the use of image processing and photogrammetry through the following:

  - ✓ State of the art study in automated tunnel inspection
  - ✓ Database of images from different locations
  - ✓ Change detection using a single camera on TIM
  - ✓ 3D reconstruction using multiple images
  - ✓ Viewing tunnel wall sections in VR
  - ✓ Distance Measurement
  - ✓ Temperature Measurement

Computer Aided Change Identification



Crack/Joint Detection using **Mask R-CNN**, from Matterport, Inc
3D Reconstruction using **Zephyr Aerial**, from 3DFlow
VR model using **Unity**

Milestones achieved

Automatic remote data capturing

Hardware, software, dataset

Automated Data Capturing

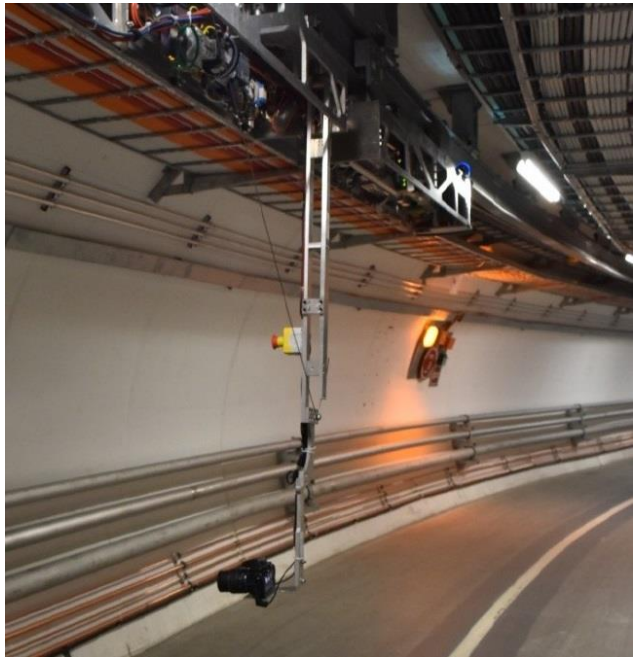
- To keep up with time and space constraints, inspection systems should be simple to set up and small in dimensions.

- We use a mobile platform to move a camera around the tunnel and captures images of the walls.

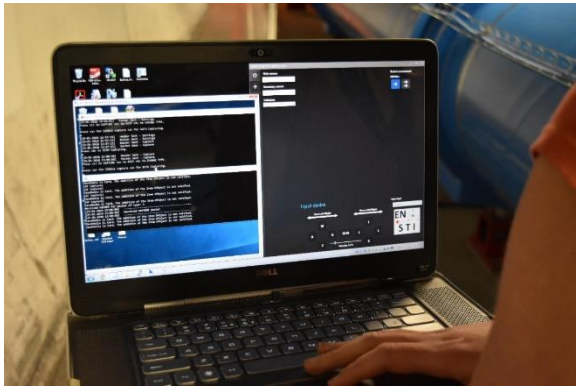
- There are currently two mobile platforms that can be used for data capturing:
  - Train Inspection Monorail (TIM)
  - CERNbot

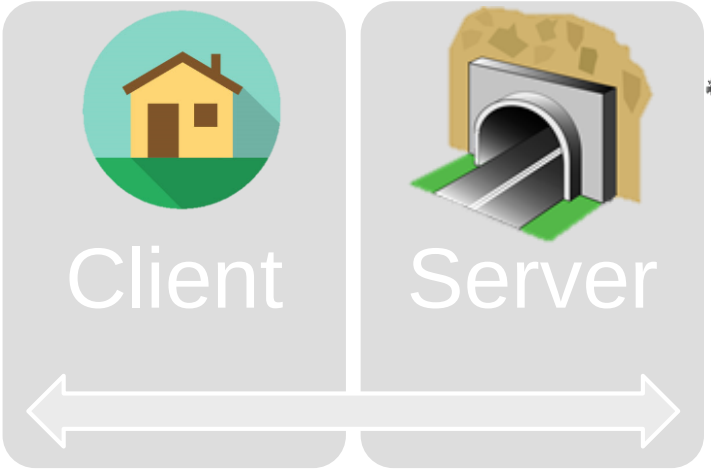
Automated Data Capturing

- Hardware
  - We used a robotic arm extending from the TIM to hold a camera
  - We designed and integrate a vertical metal structure with adjustable heights/positions and tilting holders for multiple cameras on the CERNbot
- Software
  - We developed a server-client application to send commands to the camera/s to capture the images
- Dataset
  - High-definition picture collection using TIM and CERNBot in different facilities at CERN such as in LHC, TT1, SPS etc.



Remote Image Capturing





In-house developed robotic control system that allows also commands to be sent to the camera ‘server’ to capture images/video

Mini-Computer that runs the camera ‘server’ to control the cameras

Crack Detection

Machine learning

MACHINE LEARNING

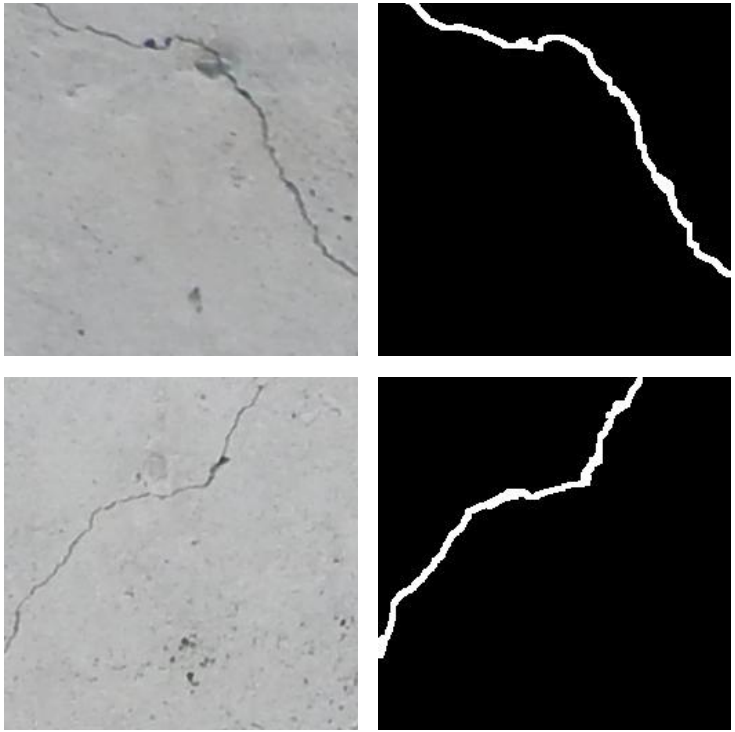
Crack Detection

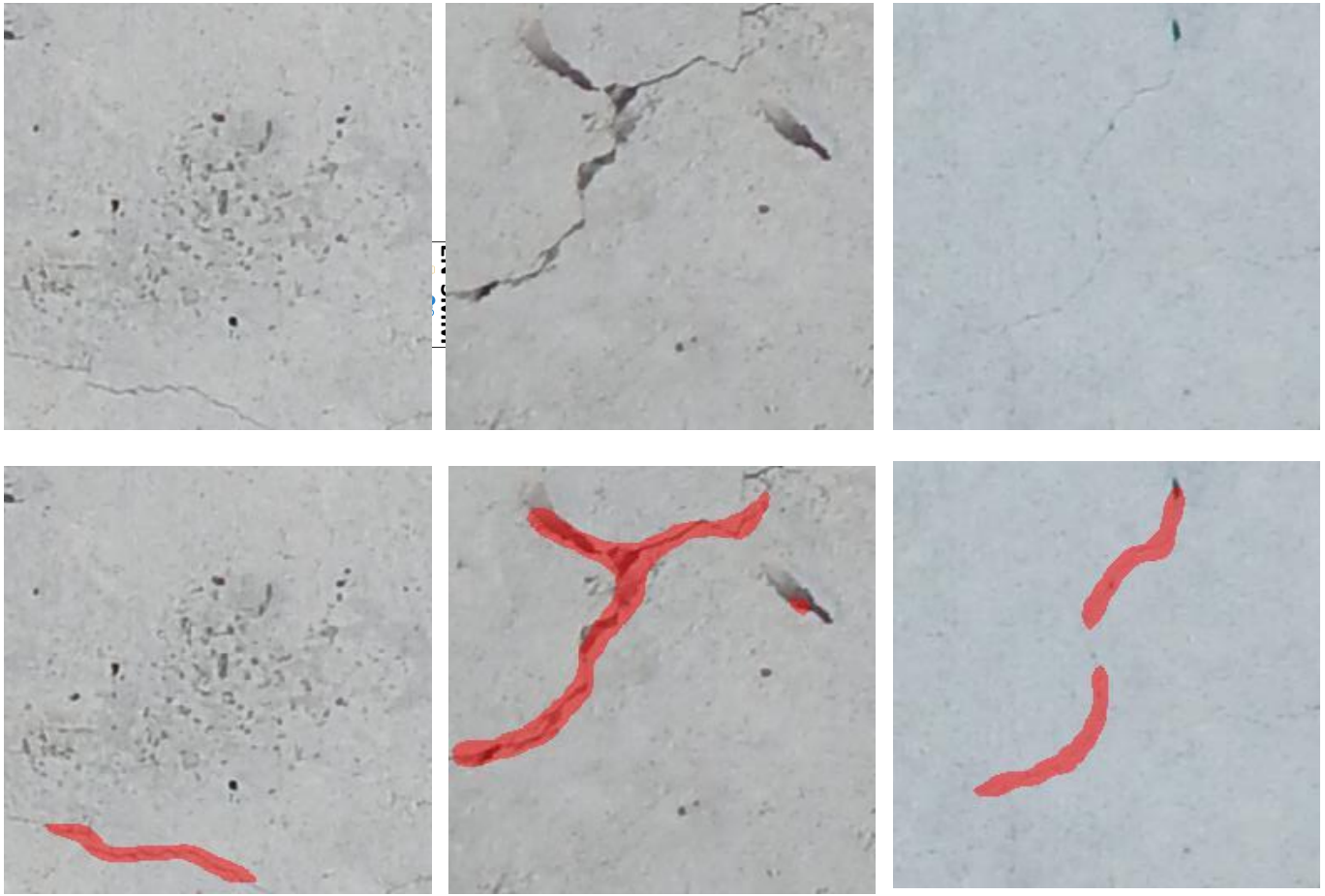
- Early works used a combination of image processing techniques such as thresholding, mathematical morphology and edge detection.

- We used the **state of the art deep learning object detector** Mask R-CNN that not only detects targets in the image but also gives the predicted mask for each target which is useful for further processing.

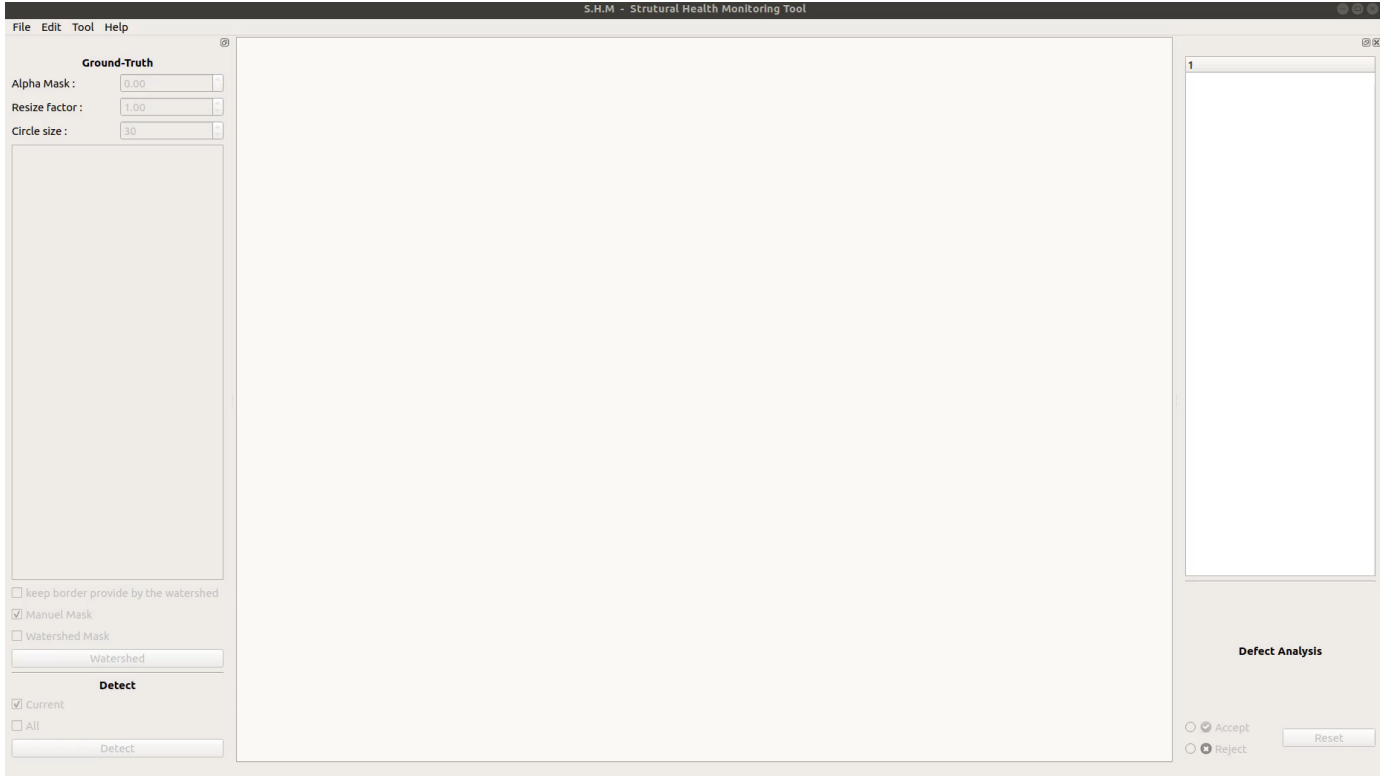
- We developed our **ground-truth dataset** used for training the object detector.

- To train the model to detect cracks, we built a dataset based on the SDNET dataset, used for training, validation, and benchmarking of AI-based crack detection algorithms for concrete.
- However this dataset provides only crack vs non crack ground-truth.
- Consequently we built a mask dataset from a subset of 200 images of this standard dataset. Once the subset was chosen, mask annotation was then conducted.





SHM-Crack Detection tool



Change Detection

Identifying changes on the wall

Change Detection

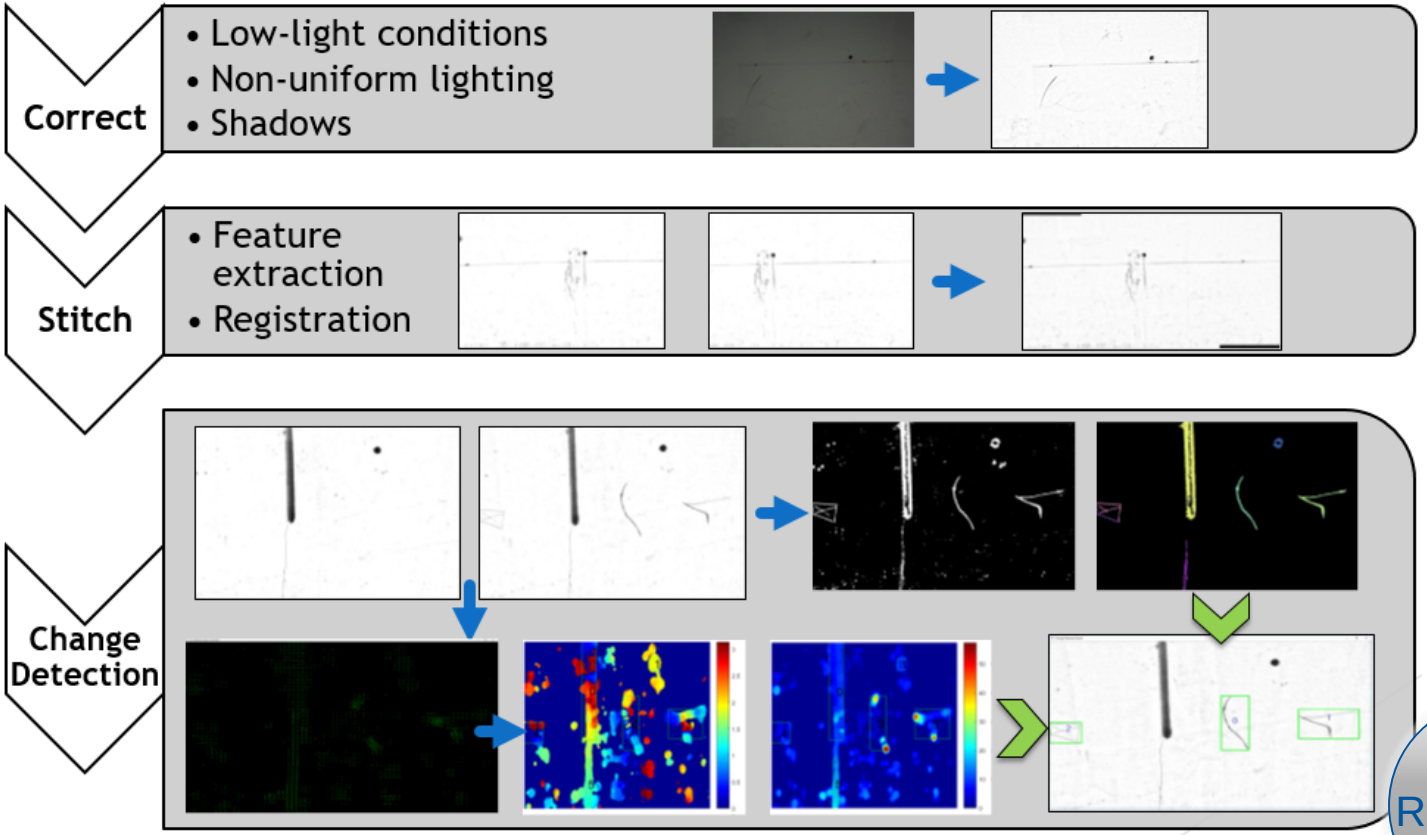
Studying the evolution of defects can give a better indication of the health status of the tunnel and its deterioration if any.

Observing the tunnel for such changes is often the work of human inspectors.

This task:

- involves a costly and time-consuming process,
- depends on the subjectivity on the inspectors' experience,
- requires personnel to access areas with adverse environment working conditions.

Automatic Change Detection

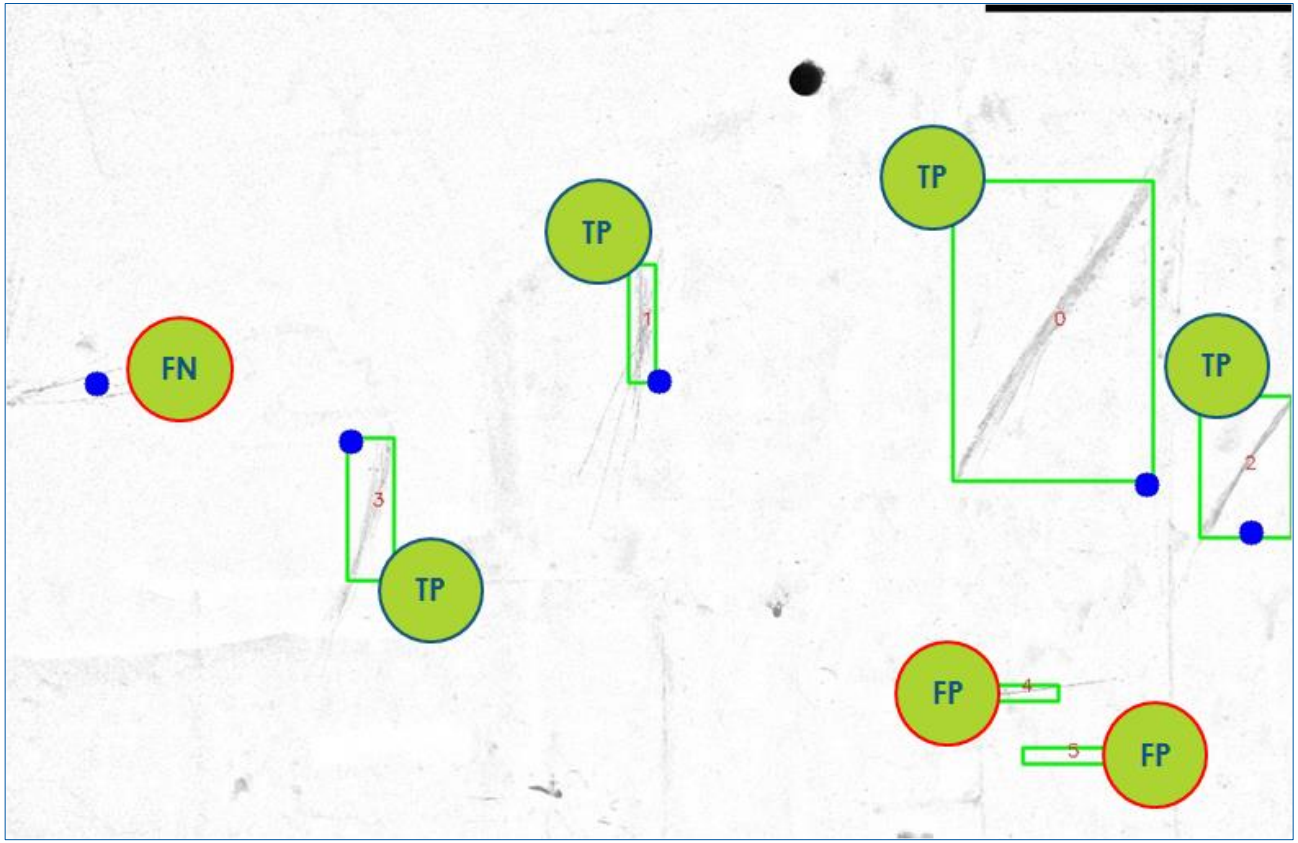


The system on average achieved:

TPR 83.5% (sensitivity)

PDR 82.8% (precision)

RESULTS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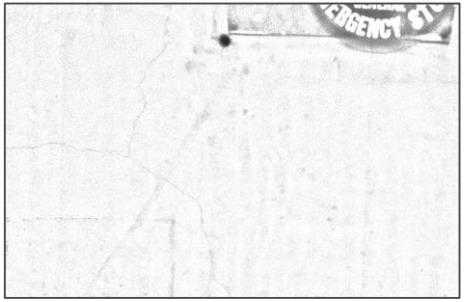
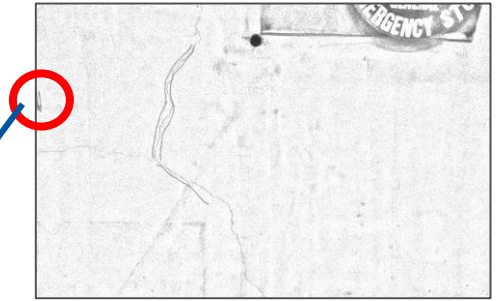




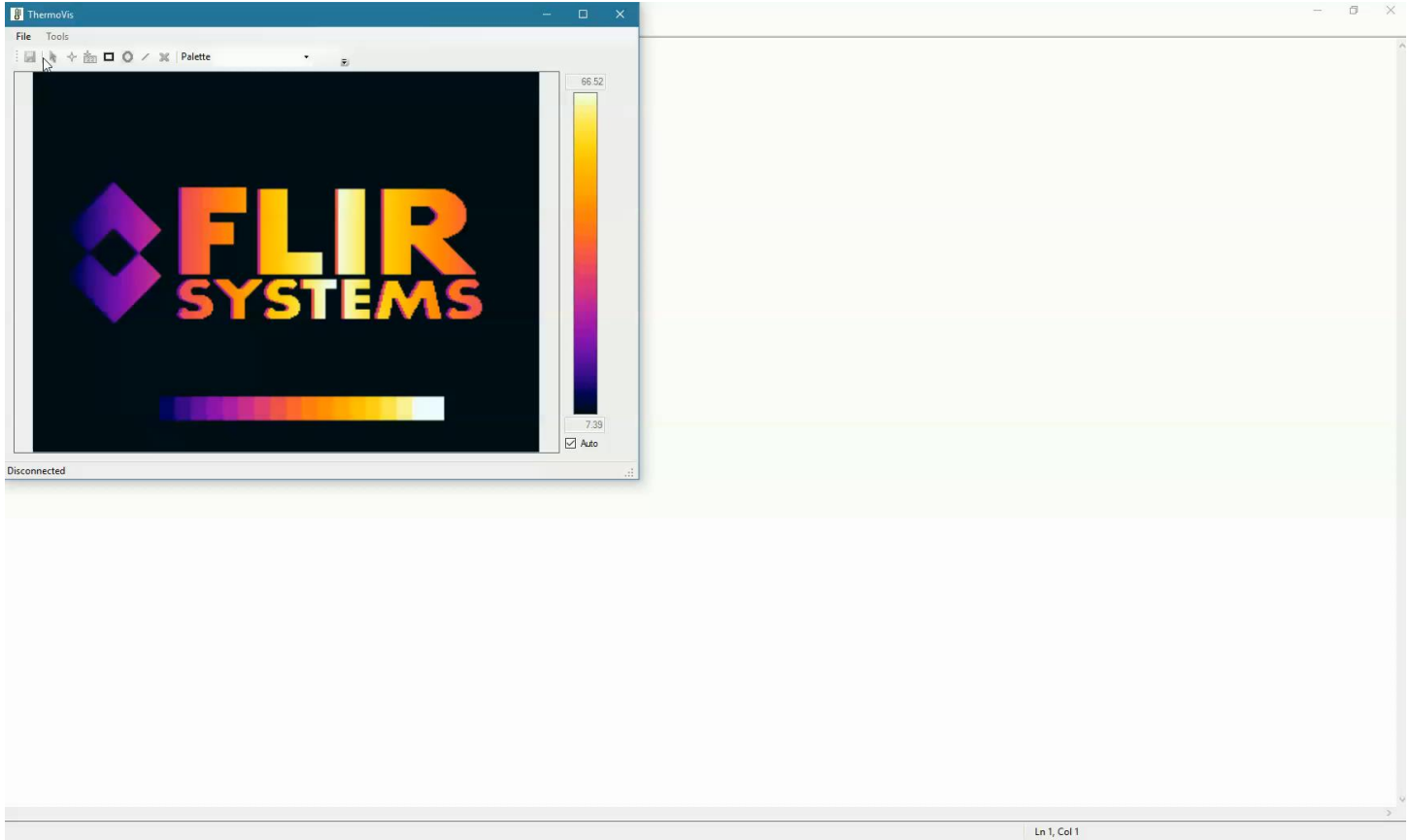
Detects changes as small as around 10 cm in any dimension

Thermal Imagery

Investigating the use of images from other spectra

Thermal Imagery

- Thermal imaging is a non-contact technology which measures infrared wavelengths emitted from objects.
- We developed an interface for the thermal camera that can:
  - Capture images
  - Record video sequences
  - Save the temperature values in ºC
  - Open already captured images and recorded videos for viewing
  - Save the temperature values in ºC of already captured images

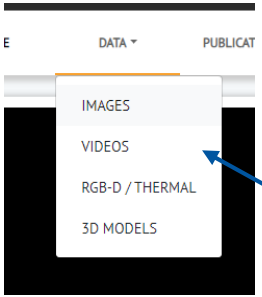

ThermoVis
File
Tools
Palette
66.52
7.39
Auto
Disconnected
Ln 1, Col 1

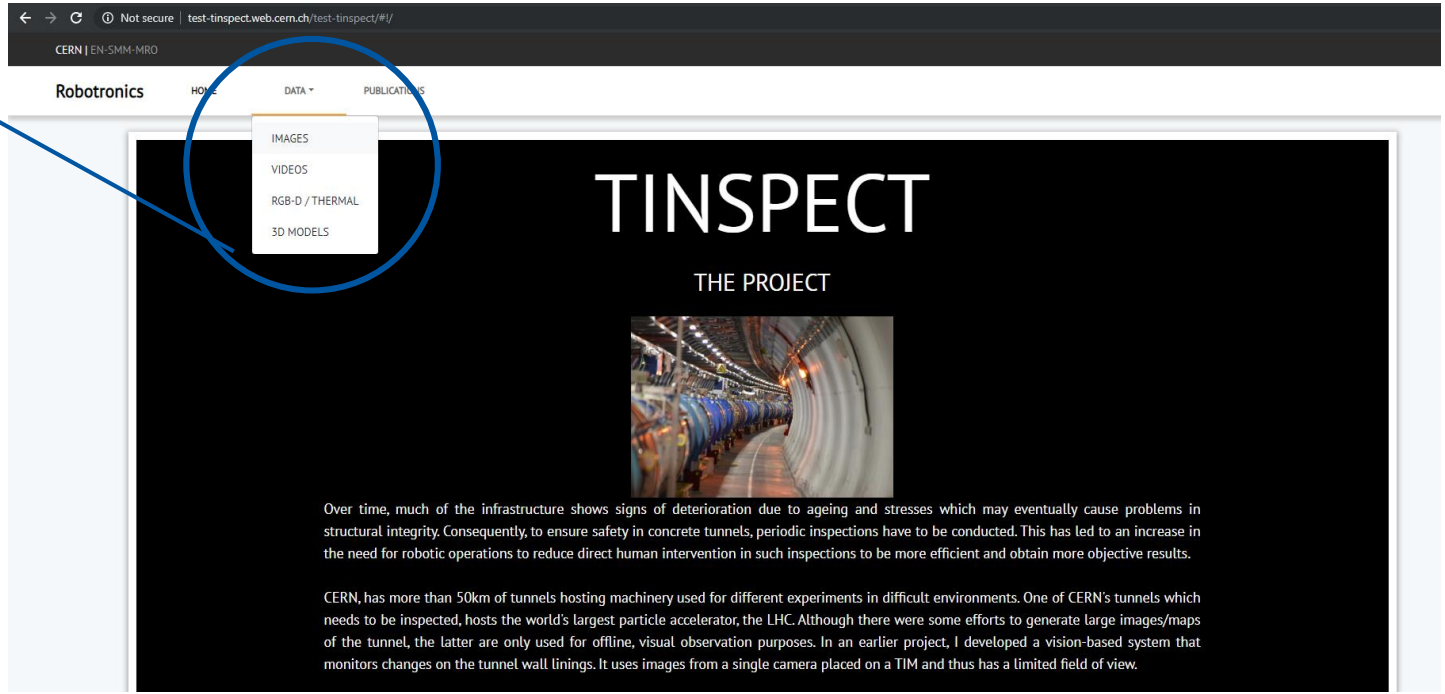
On-going Work

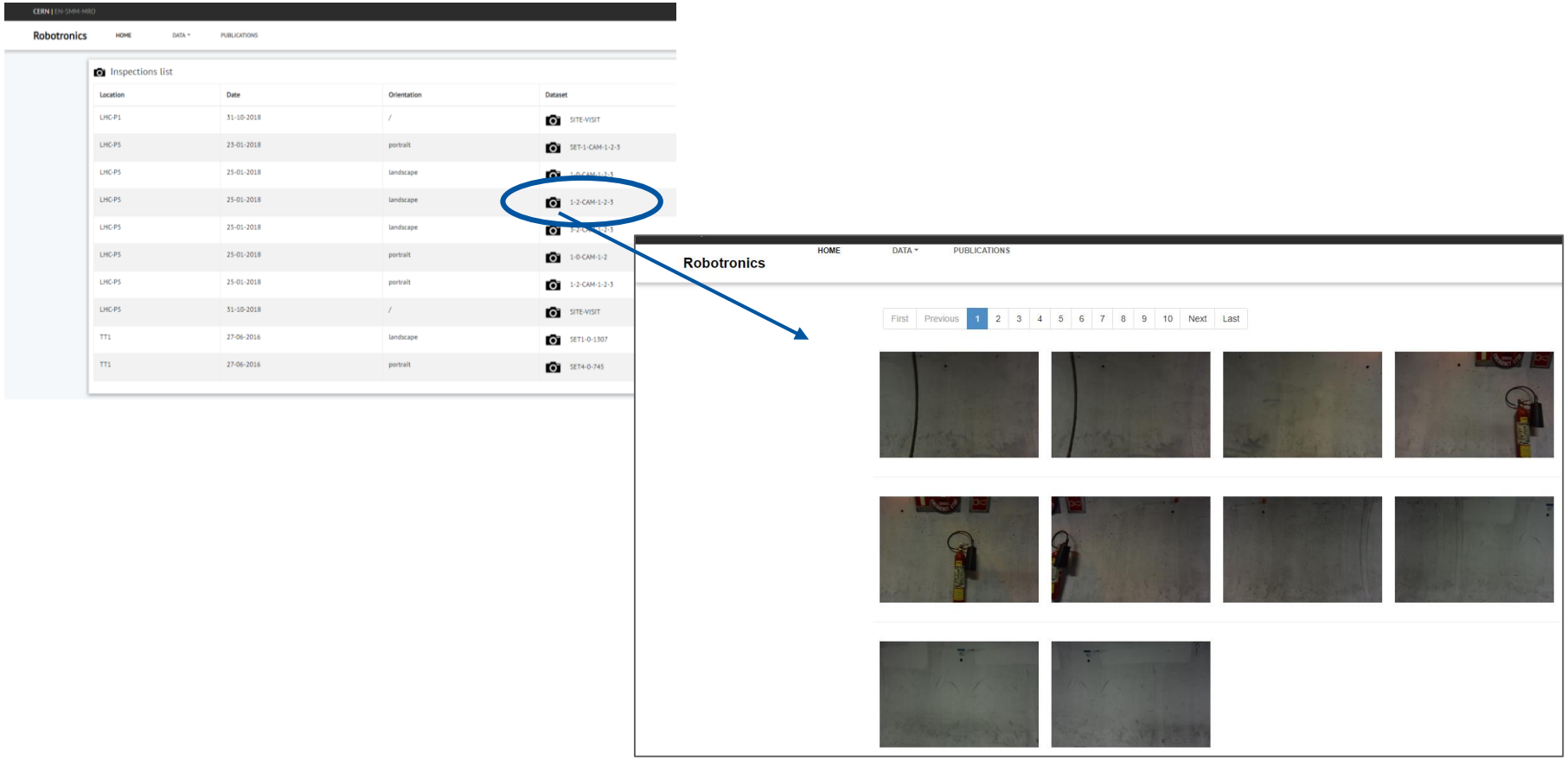
Human-Machine-Interface

Data presentation and Visualisation

http://test-tinspect.web.cern.ch/test-tinspect






CERN | EN-SMM-MRO
Robotronics
HOME
DATA
PUBLICATIONS
Inspections list
Location
Date
Orientation
Dataset
LHC-P1 31-10-2018 / SITE-VISIT
LHC-P5 23-01-2018 portrait SET-1-CAM-1-2-3
LHC-P5 25-01-2018 landscape
LHC-P5 25-01-2018 landscape 1-2-CAM-1-2-3
LHC-P5 25-01-2018 landscape
LHC-P5 25-01-2018 portrait 1-0-CAM-1-2
LHC-P5 25-01-2018 portrait 1-2-CAM-1-2-3
LHC-P5 31-10-2018 / SITE-VISIT
TT1 27-06-2016 landscape SET1-0-1307
TT1 27-06-2016 portrait SET4-0-745
Robotronics
HOME
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PUBLICATIONS
First
Previous
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Next
Last

CERN | EN-SMM-MRO

Robotronics HOME DATA PUBLICATIONS

TINSPECT

THE PROJECT

Over time, much of the infrastructure shows signs of deterioration due to ageing and stresses which may eventually cause problems in structural integrity. Consequently, to ensure safety in concrete tunnels, periodic inspections have to be conducted. This has led to an increase in the need for robotic operations to reduce direct human intervention in such inspections to be more efficient and obtain more objective results.

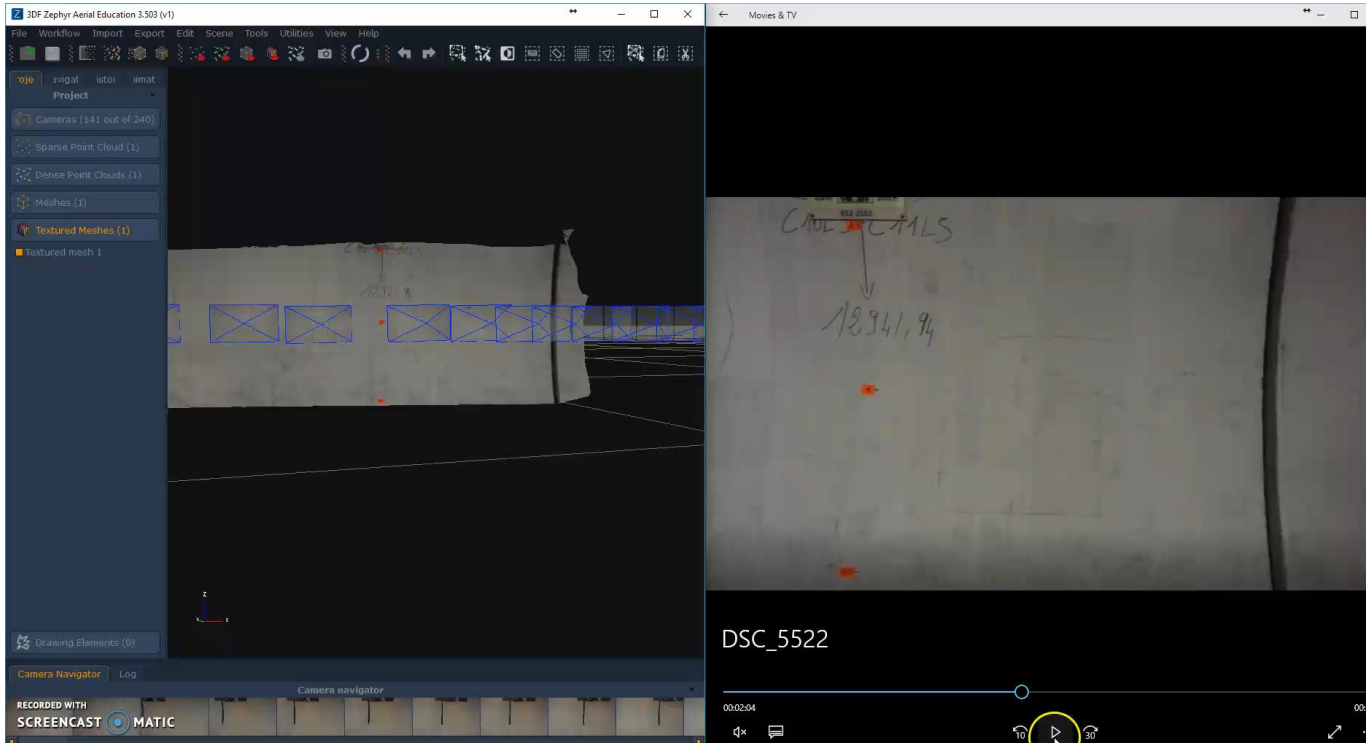
CERN, has more than 50km of tunnels hosting machinery used for different experiments in difficult environments. One of CERN's tunnels which needs to be inspected, hosts the world's largest particle accelerator, the LHC. Although there were some efforts to generate large images/maps of the tunnel, the latter are only used for offline, visual observation purposes. In an earlier project, I developed a vision-based system that monitors changes on the tunnel wall linings. It uses images from a single camera placed on a TIM and thus has a limited field of view.

The current research builds on the previous work and aims to improve on this development while focusing on the implementation of novel techniques for remote and automated tunnel change monitoring. In addition, this work seeks to use information from different sensors and combine them together in order to analyse the LHC tunnel environment. We seek to improve the state of the art in tunnel inspection methods by providing a remotely operated comprehensive framework to monitor the LHC tunnel which could be then deployed also in similar

3D reconstruction and VR

Visualisation of results

3D model


3DF Zephyr Aerial Education 3.503 (v1)
File Workflow Import Export Edit Scene Tools Utilities View Help
Project
Cameras (141 out of 240)
Sparse Point Cloud (1)
Dense Point Clouds (1)
Meshes (1)
Textured Meshes (1)
Textured mesh 1
Drawing Elements (0)
Camera Navigator
Log
Camera navigator
RECORDED WITH
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Movies & TV
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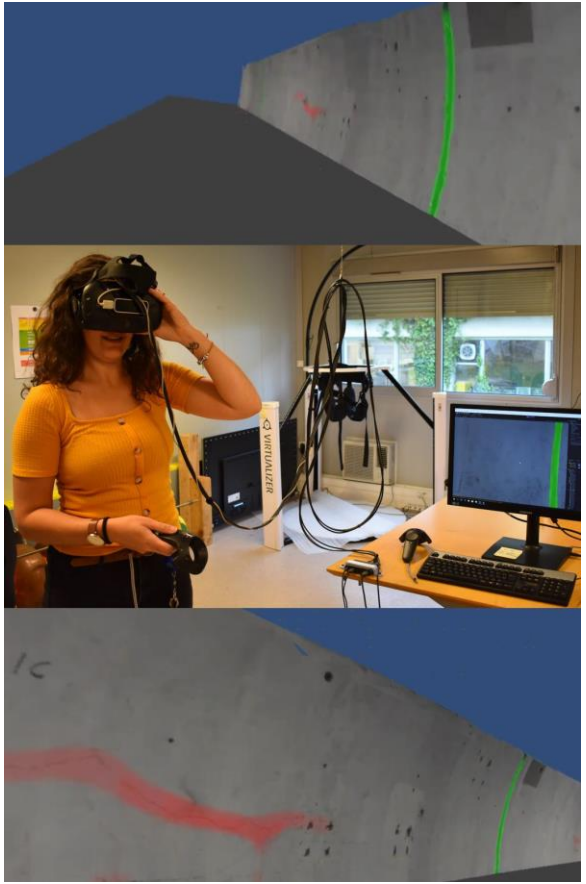
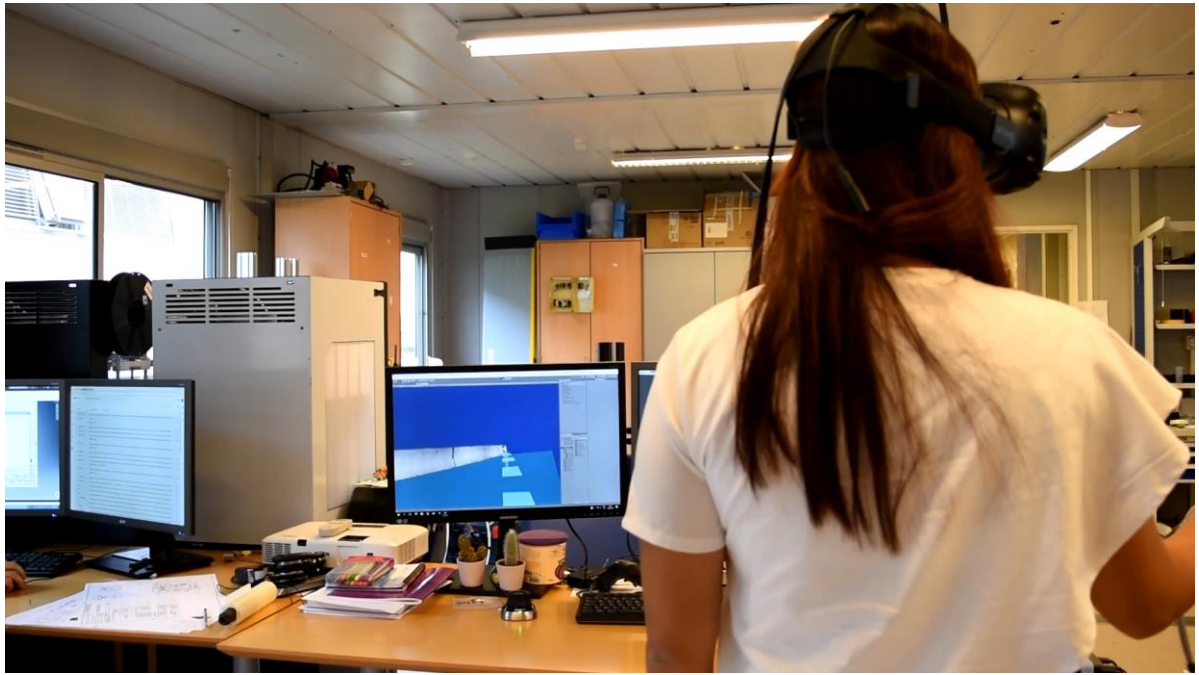
Virtual Reality

Our framework uses **Unity3D, a cross-platform game engine** to generate the virtual model and refine it by changing the scale, adding lights and other modifications through a user interface.

Viewing 3D models using VR technology:

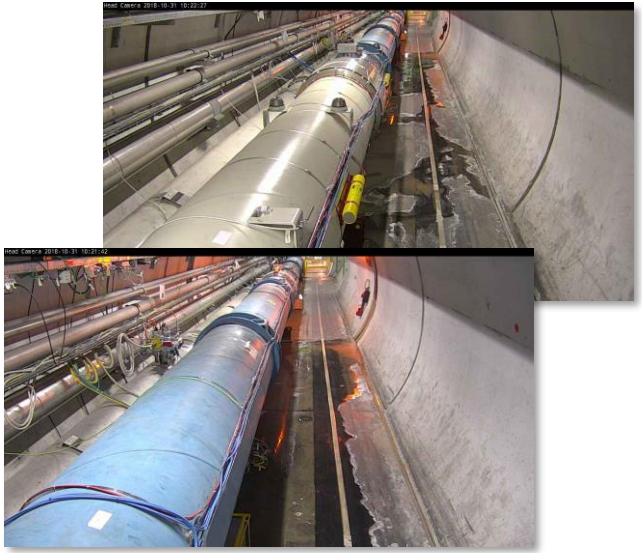
- allows personnel to **familiarise themselves to the environment** before going on a mission
- **tele-presence** comes into play, where a user is able to view and perform preliminary wall inspection remotely without visiting the actual site
- provides a **better context when viewing inspection results** such as the localisation of detected cracks with respect to their neighbourhood


VIRTUALIZER



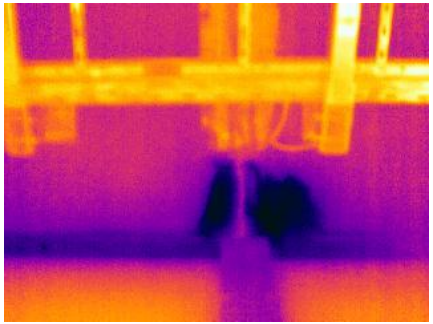
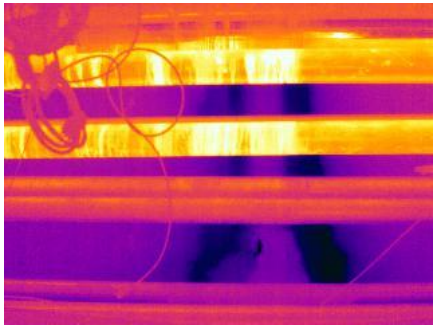
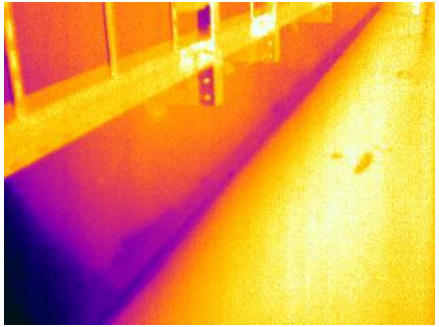
Thermal Imagery

Data collection from different points in LHC tunnel



Example of water leak found by TIM2 during TS3 2018



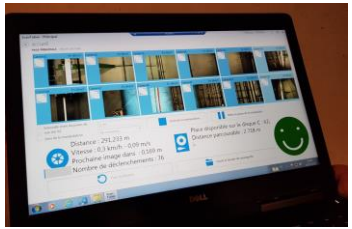
Improving the camera system

Larger field of view

An improved camera system (potential acquisition)

We have been checking out a new improved camera system from an external company. This system features:

- ❑Larger field of view (ideally full-tunnel cross-section)
- ❑Synchronisation of multiple cameras via hardware
- ❑Better 3D reconstruction (automating 3D reconstruction)



An improved camera system (potential acquisition)

Survey at time T1

Survey at time T2

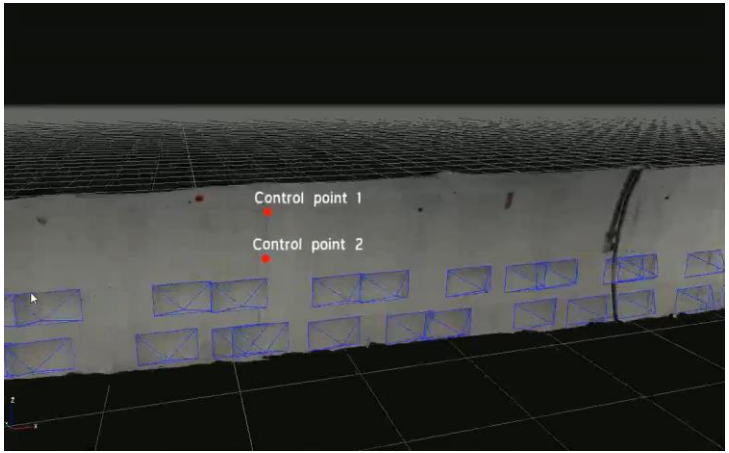
Future Work

Machine Learning

- Change detection on a larger field of view (ideally full-tunnel cross-section)
- Training of the detection model on other defect types

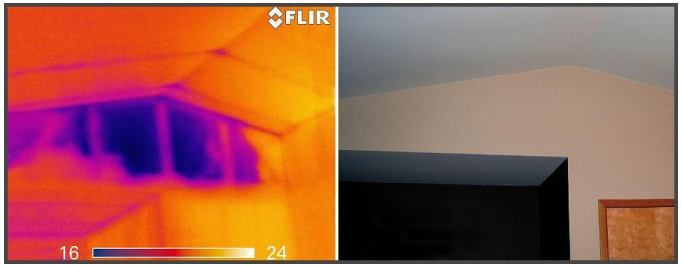
3D model and VR

- Remote measuring of defect properties such as width, length, type



Data fusion

- TIR images can distinguish targets from their backgrounds based on the radiation difference, which works well in all-weather and all-day/night conditions. By contrast, visible images can provide texture details with high spatial resolution and definition in a manner consistent with the human visual system.



- Therefore, fusing these two types of images, combine the advantages of thermal radiation information in TIR images and detailed texture information in visible images.

Conclusion

- We have designed and developed a novel system for automatic anomalous detection deployed by robots in harsh environment
- We are continuously improving tunnel structural monitoring.
- We have shown the potential in using image processing techniques for change identification.
- We have proofed the concept of using machine learning to detect fine defects such as cracks.
- We are continuously investigating the use of data fusion and machine learning for improving tunnel inspection.

Thank You

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