T-INSPECT:
A Vision-based Tunnel Structural Health Monitoring Solution using Deep Learning and Data Fusion

Summary Report, 19th March 2021

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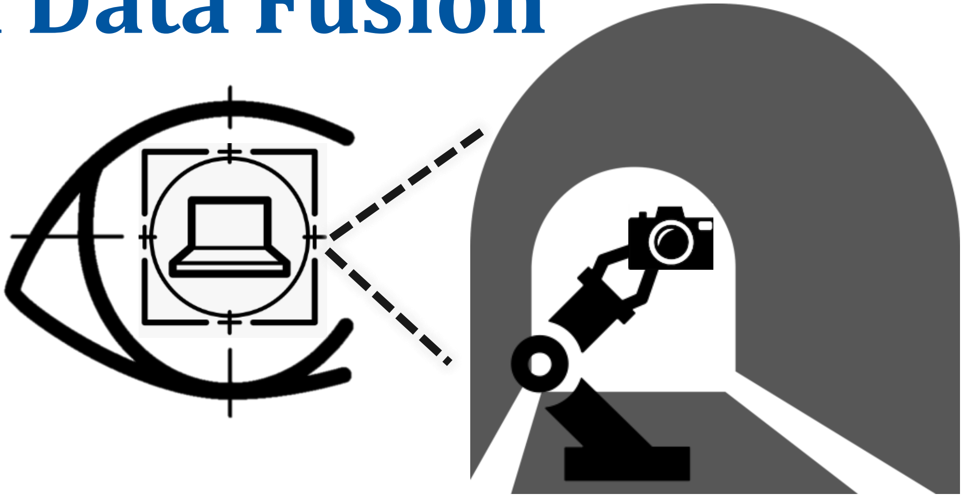

Outline

- Motivation
- Robotics at CERN
- Monitoring solution
  - Data Acquisition
  - Anomaly Defect Detection
  - Change Detection
  - Visualization for surface documentation
- Ongoing and future work
- Conclusion

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- Ongoing and future work
- Future work

Needs from SCE department

- ❑ Reduce inspection time
- ❑ Reduce personnel presence in tunnels
- ❑ Objective inspection, to reduce report subjectivity
- ❑ Change monitoring
- ❑ Visualization to aid tunnel surface documentation and analysis

SHM
Structural Health Monitoring

ROBOTICS

COMPUTER VISION

DEEP LEARNING

DATA FUSION

mechatronics and robotics for a remotely operated automatic inspection system

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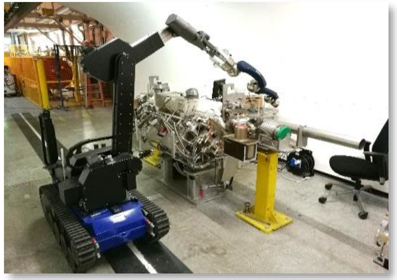
Robotics at CERN

- improved personnel safety and machine availability

Telemax

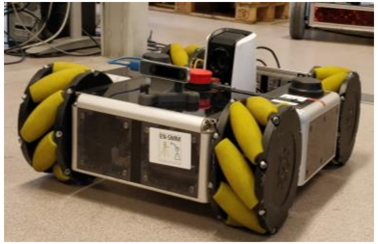
TIM (in-house)

CERNbot (in-house)



Teodor

EXTRM (in-house)



CHARMbot (in-house)

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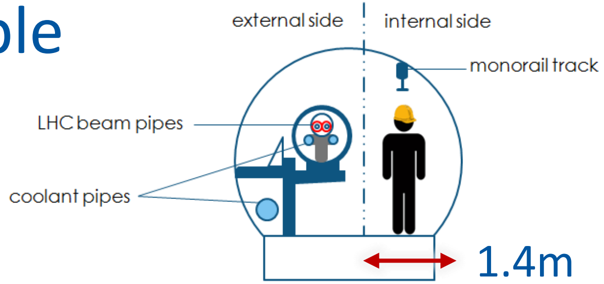
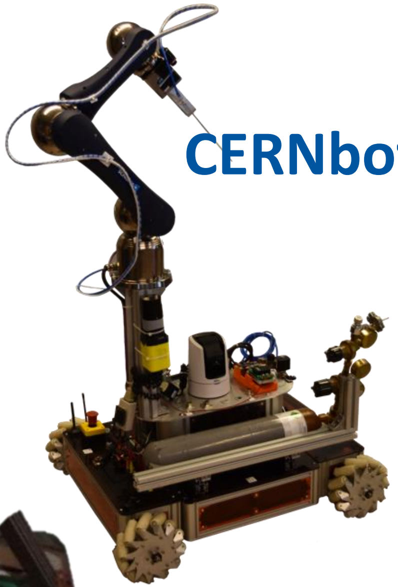
Challenges & Constraints

- accessibility during limited time windows
- difficult conditions (radiation, dust etc.)
- long distances, capture from moving robots
- low and non-uniform lighting conditions
- limited space available



Data Acquisition Setup



CERNbot

- **Phase 1 – Investigation**
  - study of possible sensors for inspection CAMERAS
  - continuous market research on inspection systems

- **Phase 2 – Implementation and testing**
  - In-house setups
    - data acquisition from a camera on TIM
    - multiple camera-setup on CERNbot
  - Commercial system
    - demo test in LHC tunnel

TIM

In-house setups

- **Software**

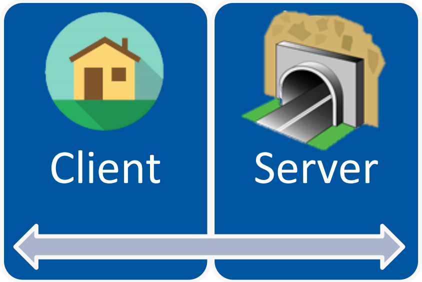
 a client-server application to send commands to the camera/s

- **Hardware**

- Setup 1: camera on the RP arm extending from TIM
- Setup 2: multiple cameras on an adjustable vertical metal structure fixed on the CERNbot

- **Dataset**

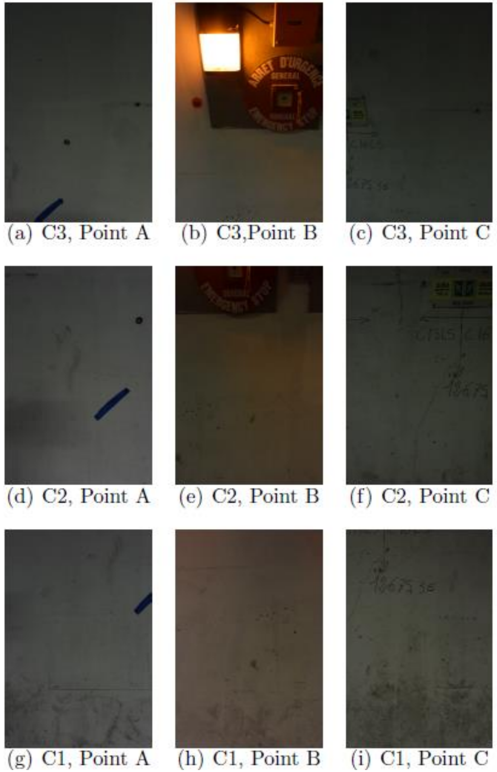
high-definition pictures in LHC, TT1, SPS



TIM

CERNbot

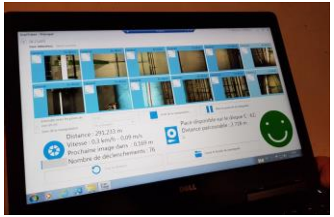
Images from the 3-camera setup



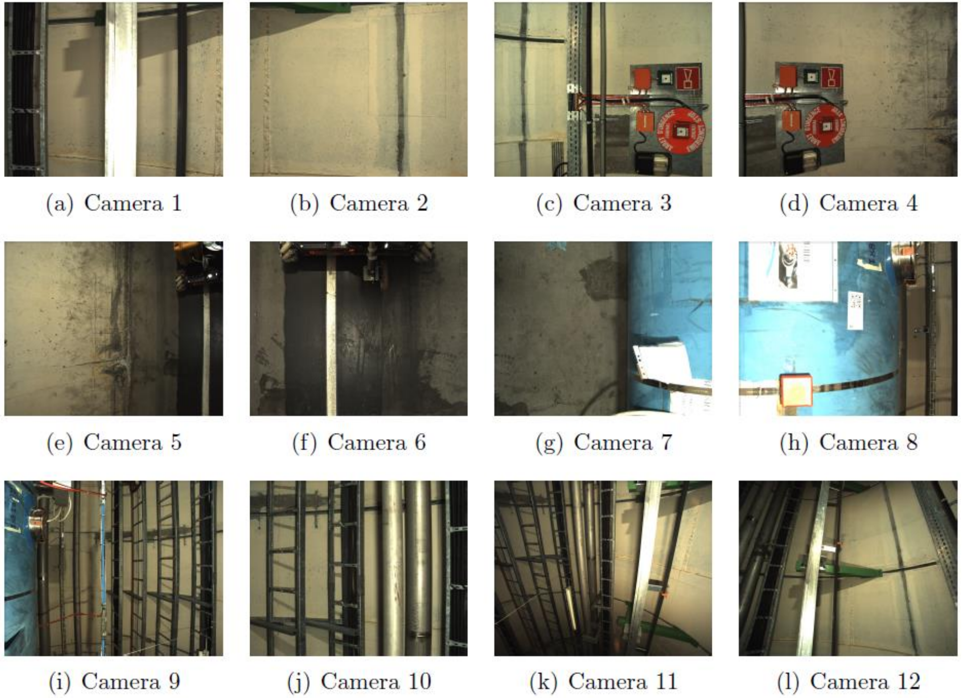
Commercial system

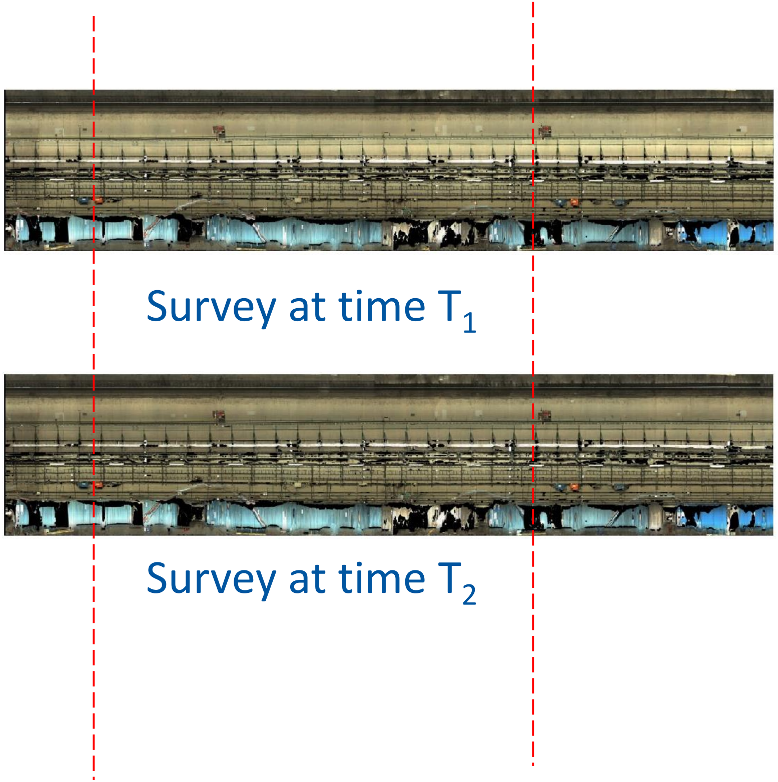
- ➢ during continuous market research, we identified commercial camera system purposely built for inspections

- ➢ this system’s package features:
  - larger field of view (ideally full-tunnel cross-section)
  - synchronisation of multiple cameras and flash lights via hardware
  - better 3D reconstruction (automating 3D reconstruction)



Images from the demo test in the LHC Tunnel





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Anomaly Defect Detection example: **Crack Detection**

- early works use image processing techniques such as thresholding, mathematical morphology and edge detection
- these rule-based approaches cannot overcome inherent challenges associated with crack images :
  - difficult topology of cracks
  - diversity of surface texture
  - inhomogeneity of cracks
  - background complexity and inference of objects with similar shape/texture to cracks such as joints
- a better approach is to use pattern recognition and/or machine learning techniques

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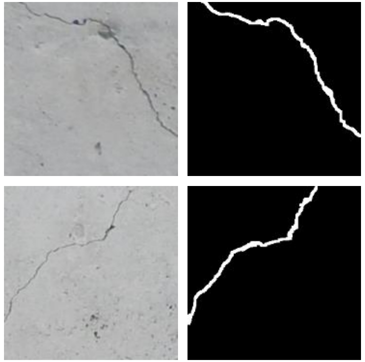
DATA FUSION

an even better approach !

Crack localisation using deep learning

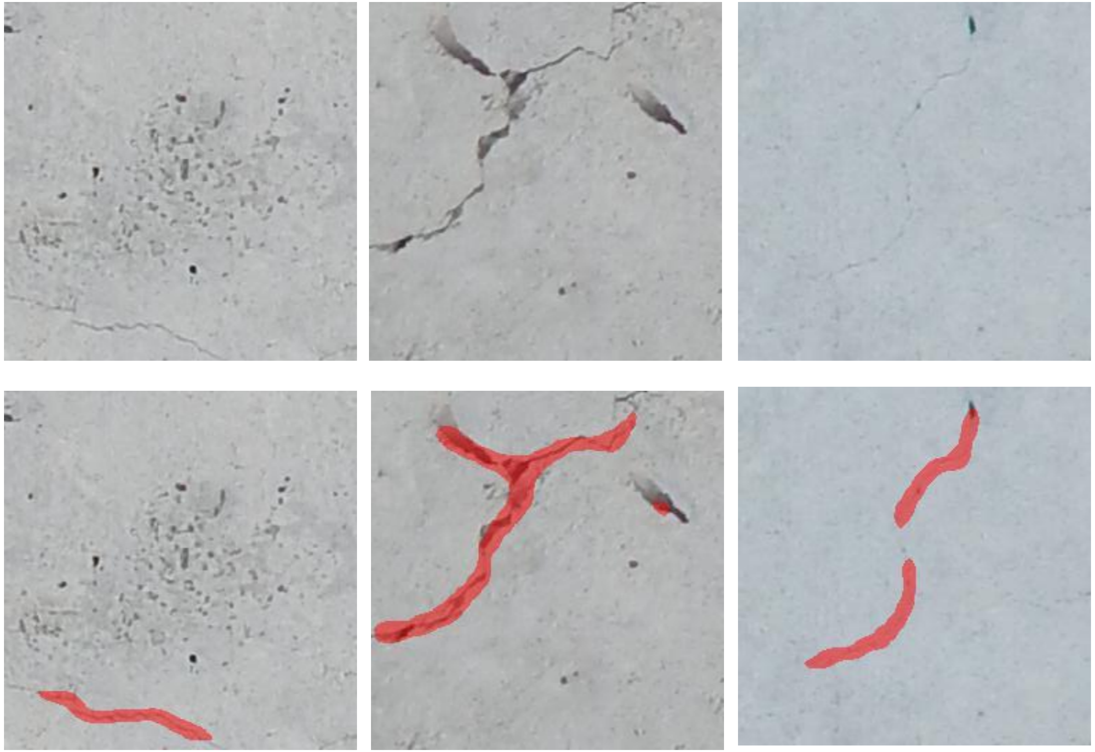
- this work uses **state of the art deep learning models**
- built a **ground-truth datasets**
  - from a standard dataset (SDNET) https://digitalcommons.usu.edu/all_datasets/48/
  - from images captured in the LHC tunnel



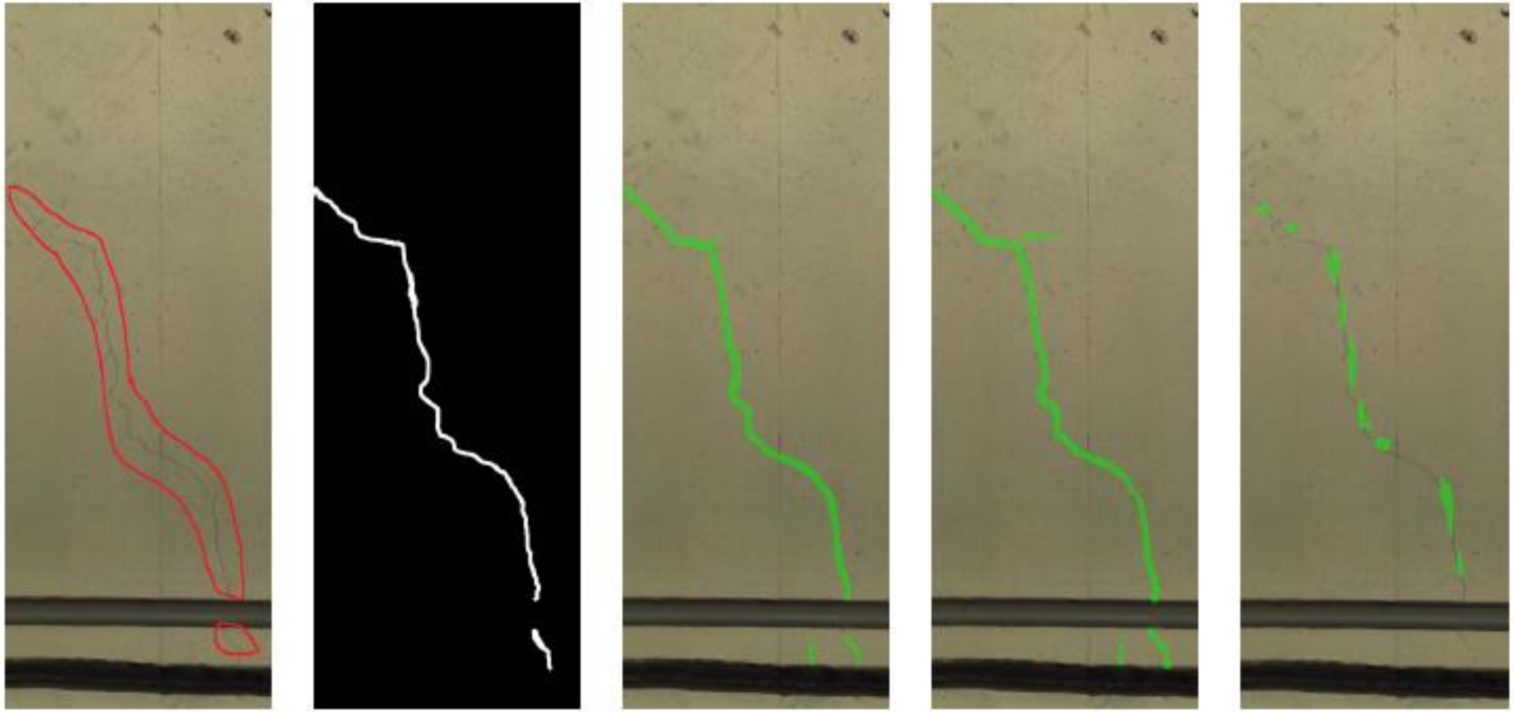
- Instance Segmentation
  - Mask R-CNN
- Semantic segmentation
  - U-Net
  - SegNet

← *better due to limited training datasets*

Detection results on images from **SDNET** dataset



Detection results on images from **LHC** dataset



(a) Crack image (b) GT (c) U-Net (d) SegNet (e) Mask R-CNN

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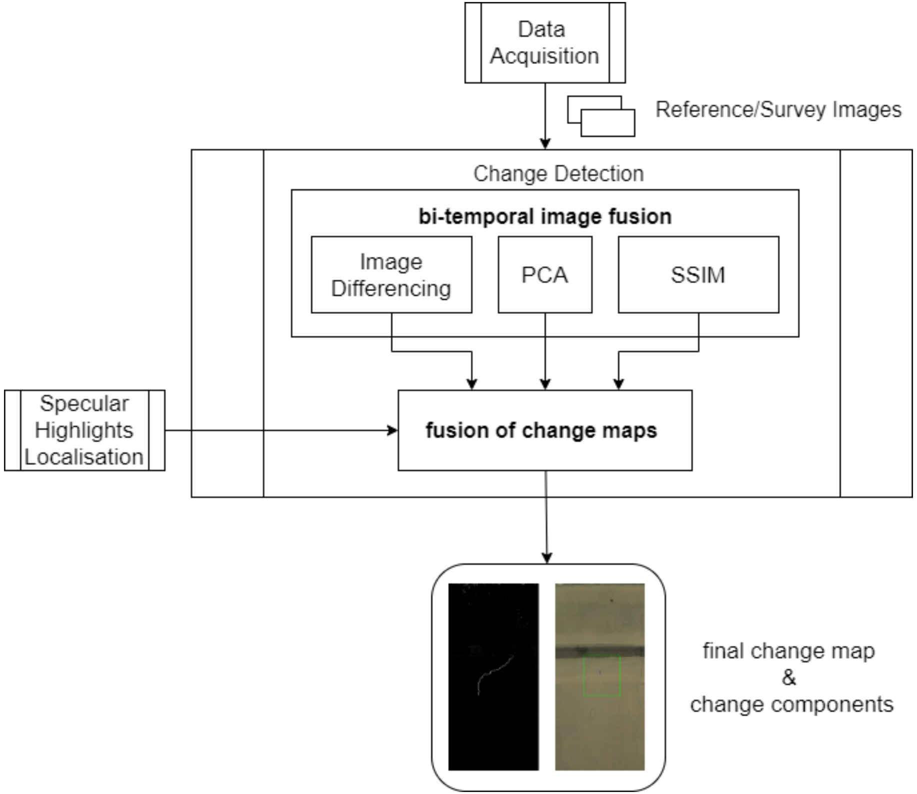
DATA FUSION

Change detection flow diagram



Images

Stage 1: pre-processing

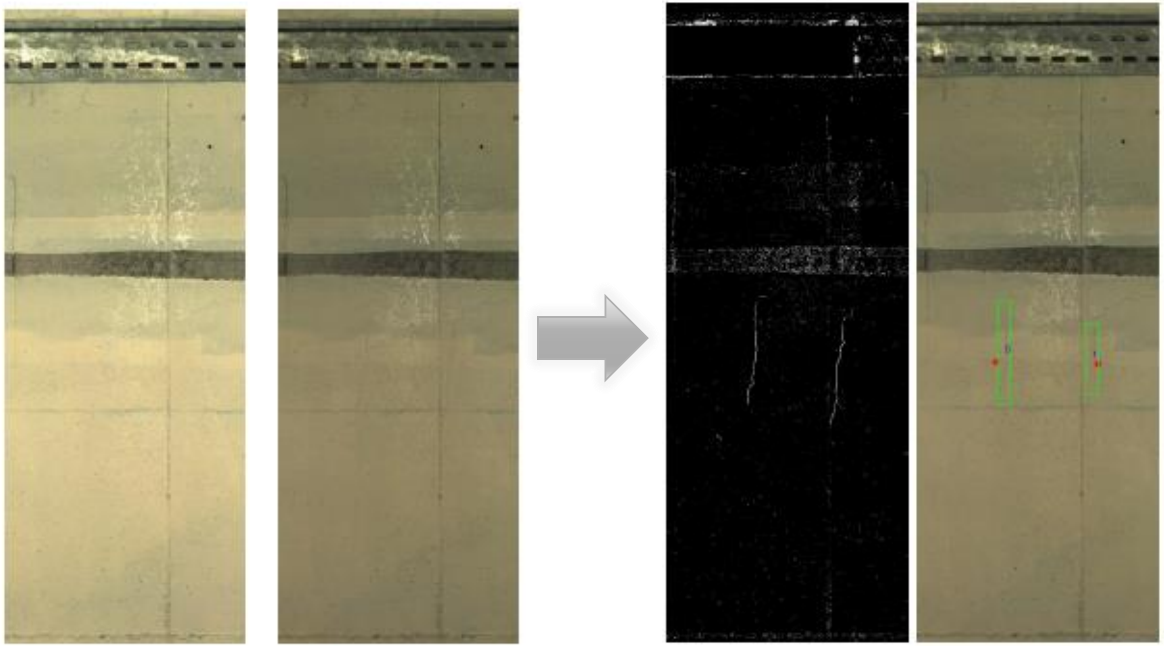
Stage 2: bi-temporal fusion

Stage 3: decision-level fusion

Stage 4: change map analysis

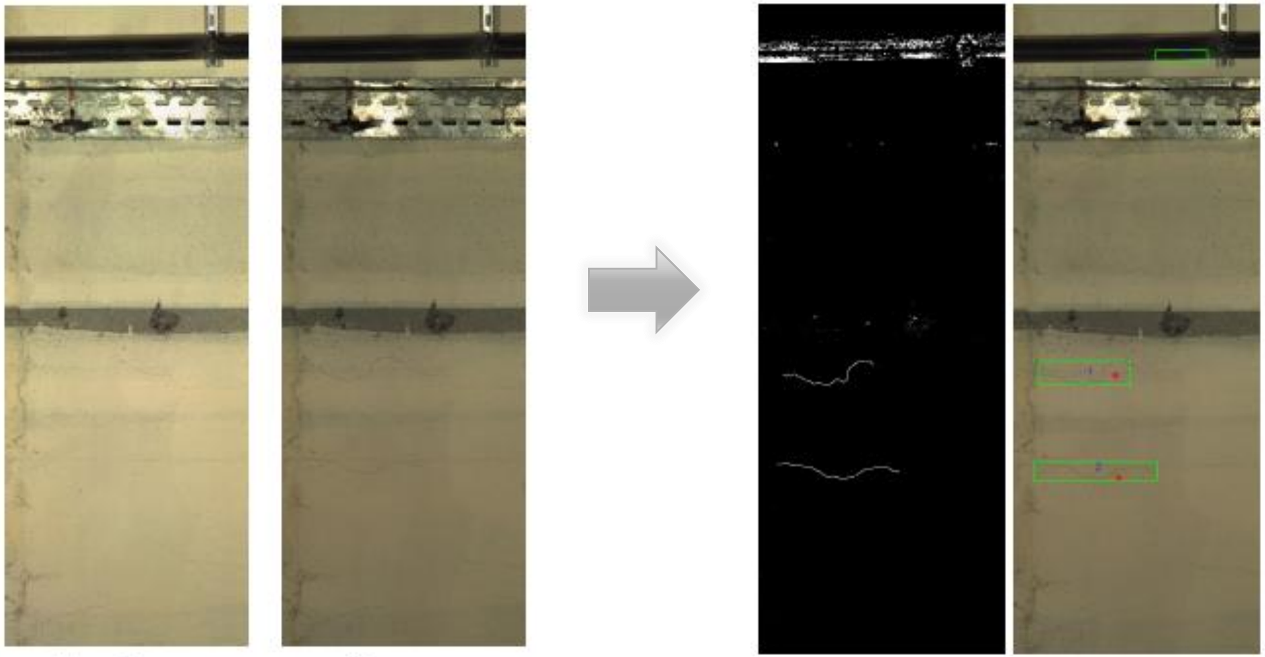
Change maps

Example 1



(a) reference (b) survey

Example 2



(a) reference (b) survey

Added benefits

- Less personnel presence in the tunnel
- Shorter inspection times

} -- ROBOTICS

- Objective inspection -- COMPUTER VISION & DEEP LEARNING ALGORITHMS

- In addition to defect detection it offers a means of monitoring the structural health -- CHANGE DETECTION

- Reliable detection -- DATA FUSION

Application of the solution in other environments

Software - Code Repositories

- **Change Detection** - CACI_Computer_Aided_Change_Identifier
  https://gitlab.cern.ch/mro/robotics/tunnel-structure-inspection/caci

- **Crack Detection**
  - Mask R-CNN - general_mrcnn https://gitlab.cern.ch/mro/robotics/tunnel-structure-inspection/generalmaskrcnn
  - Semantic segmentation - keras_segmentation
    https://gitlab.cern.ch/mro/robotics/tunnel-structure-inspection/kerassegmentation

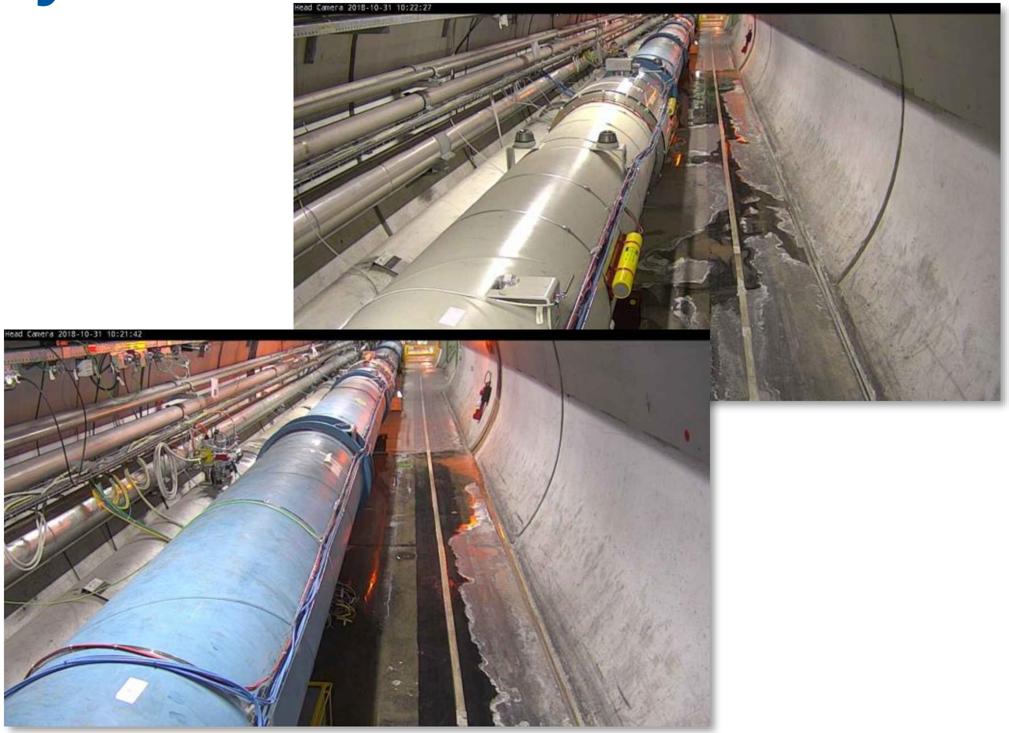
- **Specular highlights detection**
  - (experimental, no final results) using deeplab
    https://gitlab.cern.ch/mro/robotics/tunnel-structure-inspection/specularhighlightsdetection
  - Semantic segmentation (same as crack detection) - keras_segmentation
    https://gitlab.cern.ch/mro/robotics/tunnel-structure-inspection/kerassegmentation

- **Thermal camera interface** – ThermoVis (also a class in the CRF)
  https://gitlab.cern.ch/mro/robotics/libraries/thermovis

- **Nikon camera control (using Nikon SDK and their sample code)** –
  https://gitlab.cern.ch/mro/robotics/libraries/nikoncamerascontrol

Example of anomaly detected

Example of crack found using vision based machine learning techniques



Example of water leak found by TIM2 during TS3 2018

Example of water leak found by TIM2 during TS3 2018

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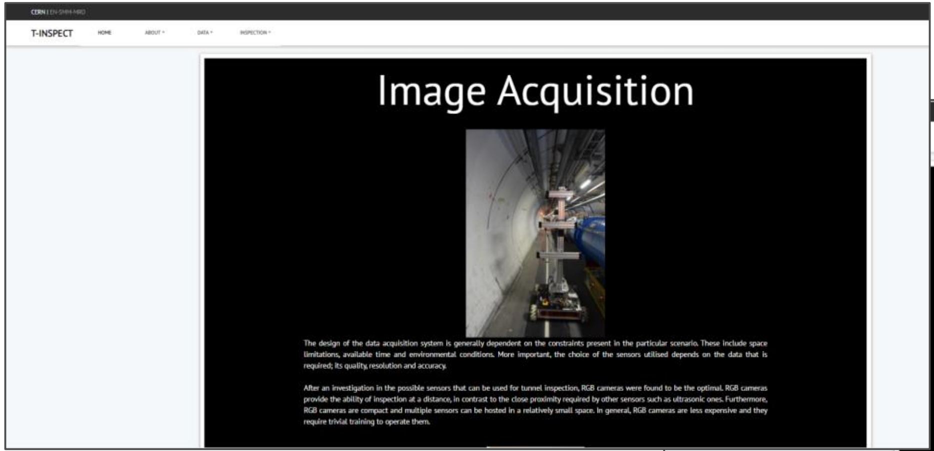
Webpage

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

General information pages



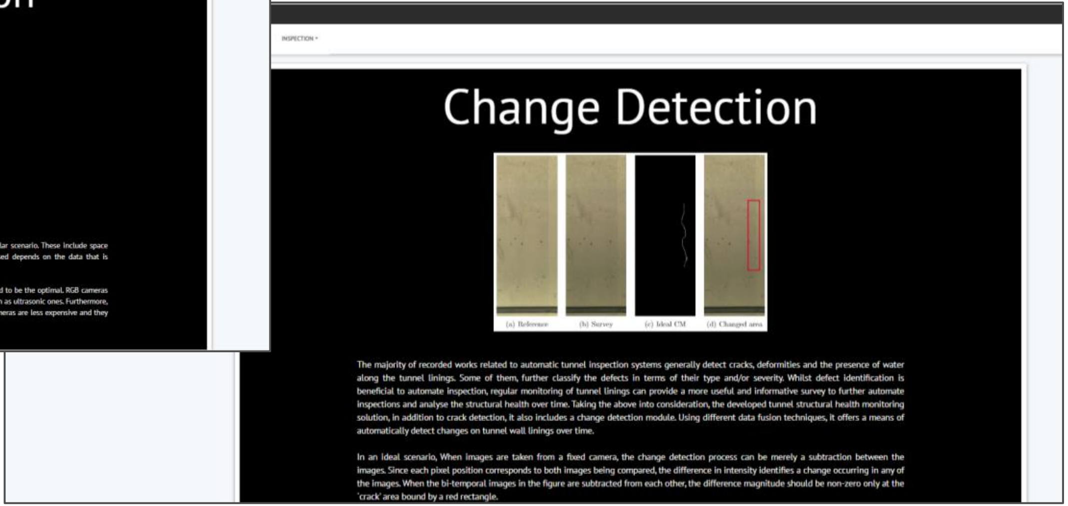
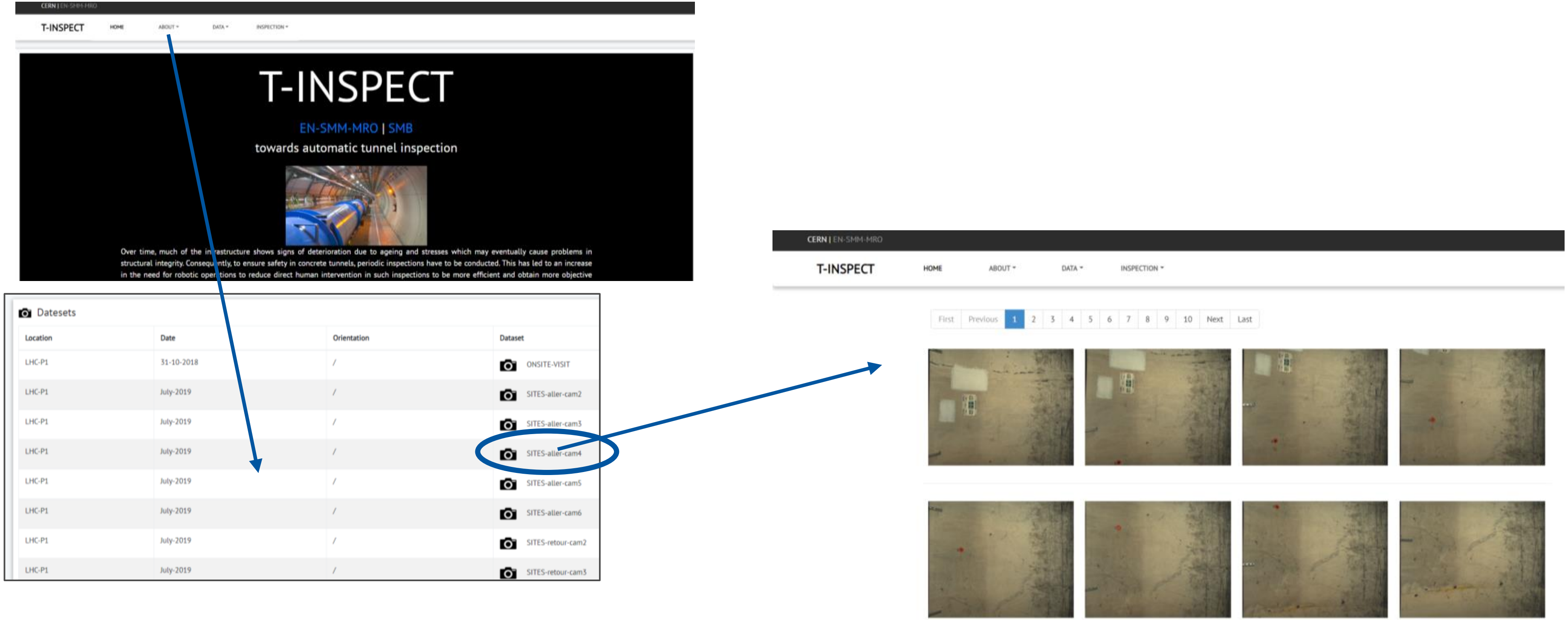
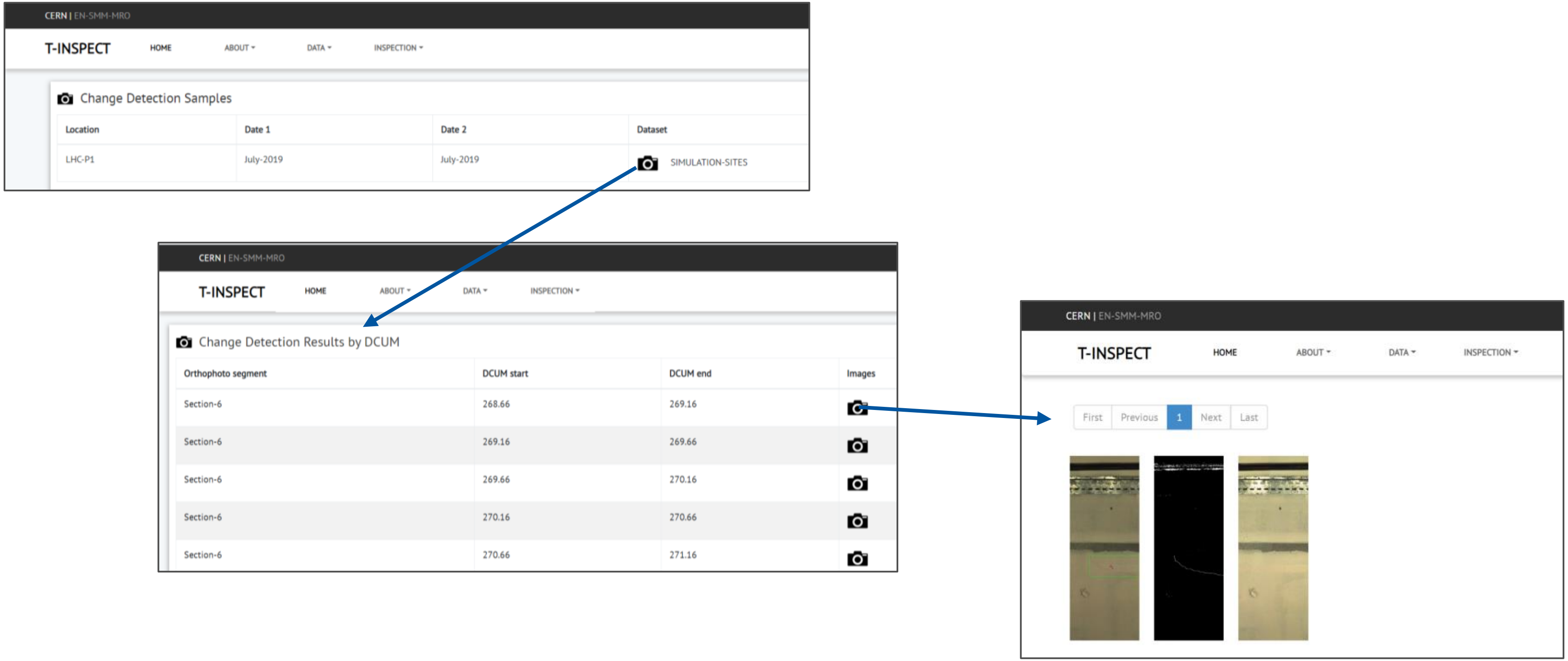


Image datasets

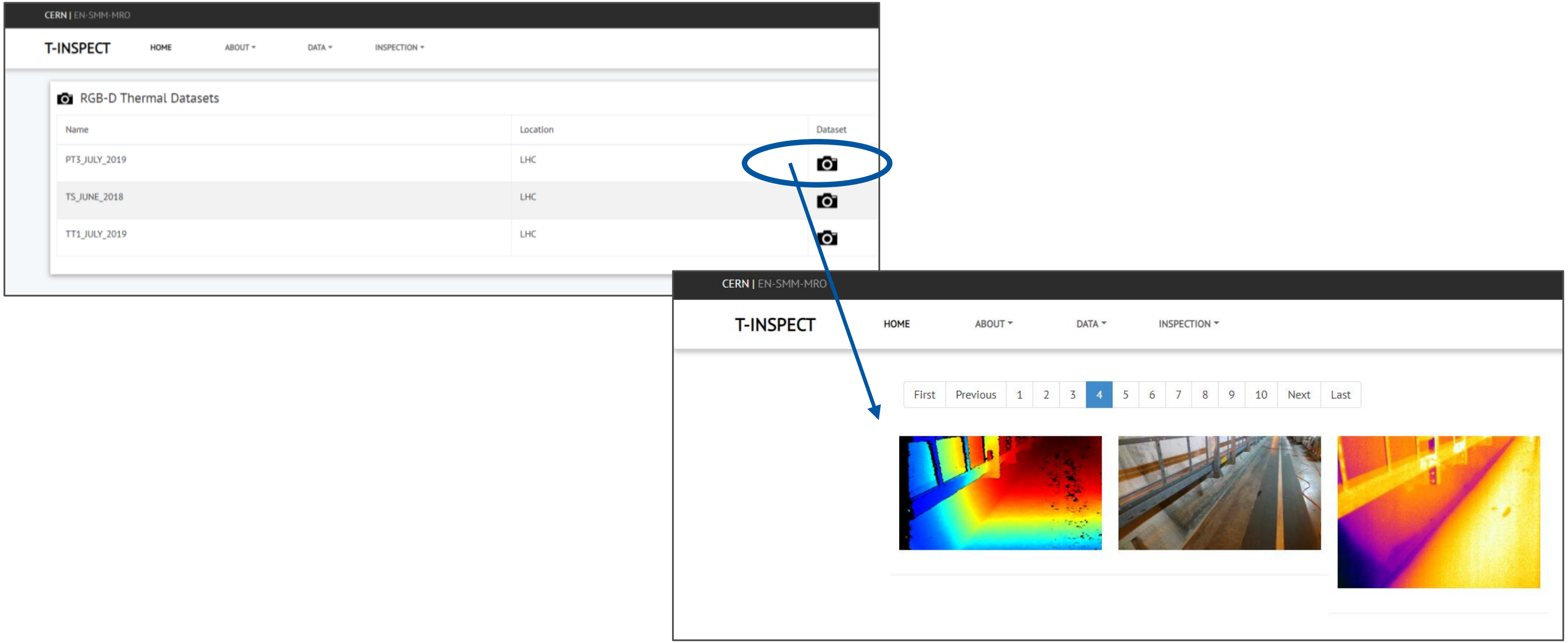


Location	Date	Orientation	Dataset
LHC-P1	31-10-2018	/	ONSITE-VISIT
LHC-P1	July-2019	/	SITES-aller-cam2
LHC-P1	July-2019	/	SITES-aller-cam3
LHC-P1	July-2019	/	SITES-aller-cam4
LHC-P1	July-2019	/	SITES-aller-cam5
LHC-P1	July-2019	/	SITES-aller-cam6
LHC-P1	July-2019	/	SITES-retour-cam2
LHC-P1	July-2019	/	SITES-retour-cam3

Change Detection results

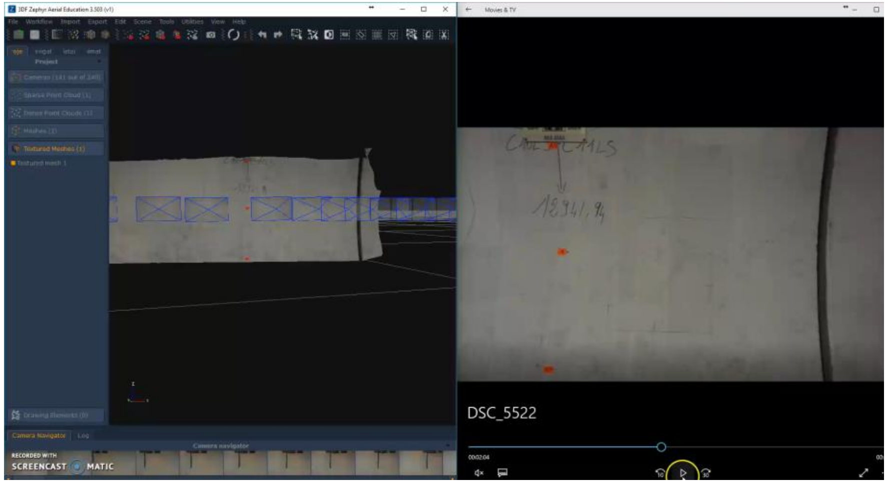


Thermal and RDGB-D images

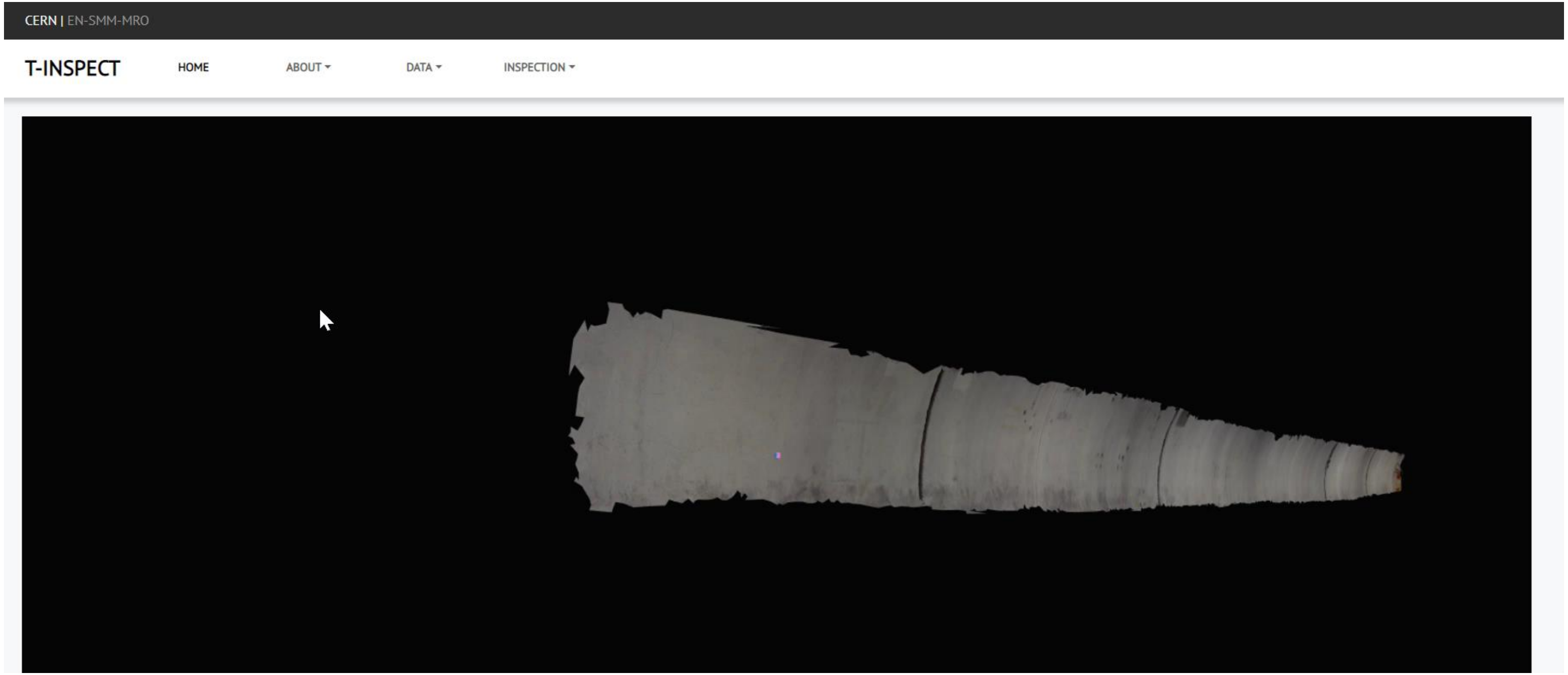


3D and VR

3D and VR models for better contextualization



3D models on the web-page



Publication contributions

[published]

1. Tunnel inspection using photogrammetric techniques and image processing: A review, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 144, 2018.
2. A comprehensive virtual reality system for tunnel surface documentation and structural health monitoring, 2018 IEEE International Conference on Imaging Systems and Techniques (IST), Krakow, 2018.
3. Automatic Crack Detection using Mask R-CNN, 11th International Symposium on Image and Signal Processing and Analysis (ISPA), Dubrovnik, Croatia, 2019.
4. VR-SHM - A structural health monitoring tool to assist crack detection using deep learning and virtual reality, Sustainable Built Environment conference, Malta, 2019

[under review]

1. Specular highlights detection using a U-Net based deep learning architecture, 2020 IEEE International Conference on Image Processing (ICIP)
2. Automatic crack detection using deep learning models - a comparative analysis, Automation in Construction
3. Tunnel structural health monitoring using a computer vision and data fusion change detection solution, Image and Vision Computing Journal

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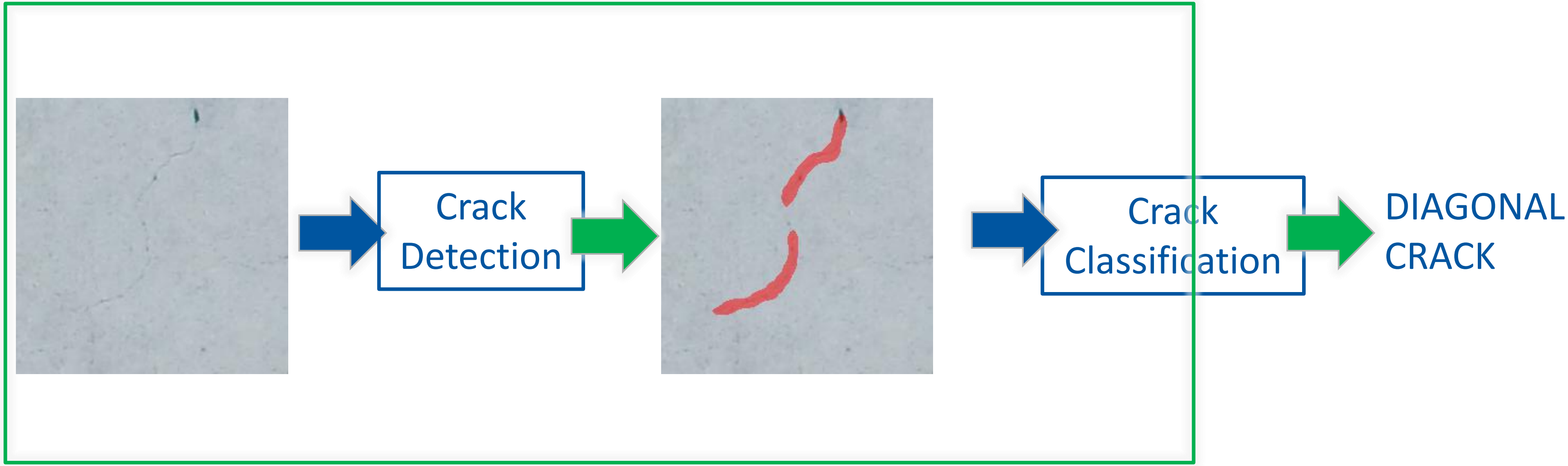
Crack classification

From crack detection to crack classification…..

- crack detection can be used as a pre-processing stage to crack classification
- once crack's bounding boxes are identified, properties such as, width/length/moments of the contours can be extracted to get the directionality
- these can then be used:
  - via rule-based conditions such as if length > width by a certain amount then it is a vertical crack (just as an example)
  - to implement a more accurate and generalised way of classification by using these properties as a feature vector and then use pattern recognition techniques or machine learning, through classification networks such as SVMs
- deep learning principle can also be used for classification

From crack detection to crack classification…..



DONE ✓

ONGOING

Thermal imagery
Data Fusion

Thermal Imagery for in-depth inspection

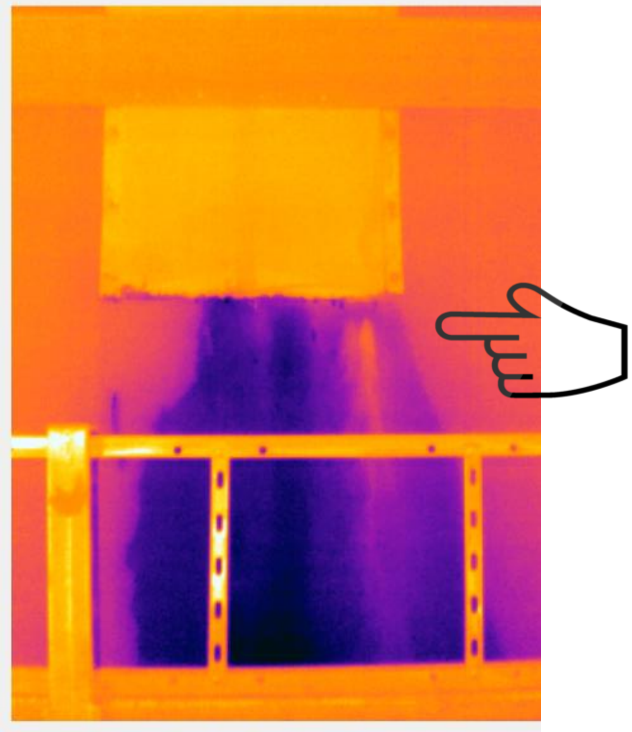
non-contact technology which measures infrared wavelengths emitted from objects

Work done

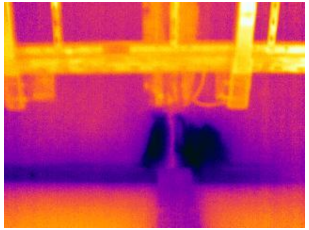
✔ developed an interface that:

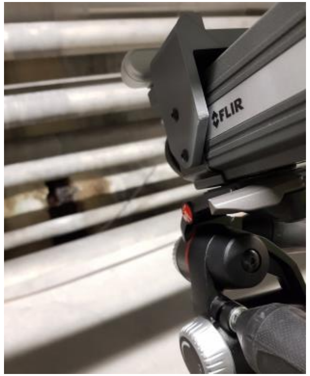
- ➢ captures images / videos
- ➢ saves the temperatures in °C

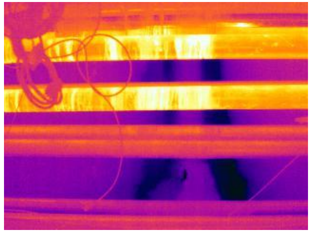
✔ data acquisition in TT1, LHC PT3

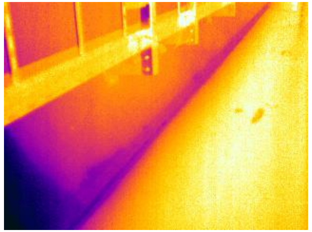


Thermal Imagery for in-depth inspection



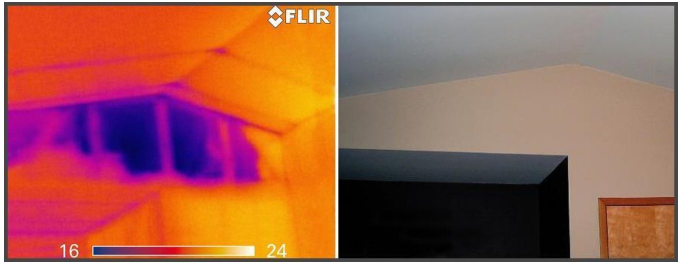






Thermal – Visible image fusion

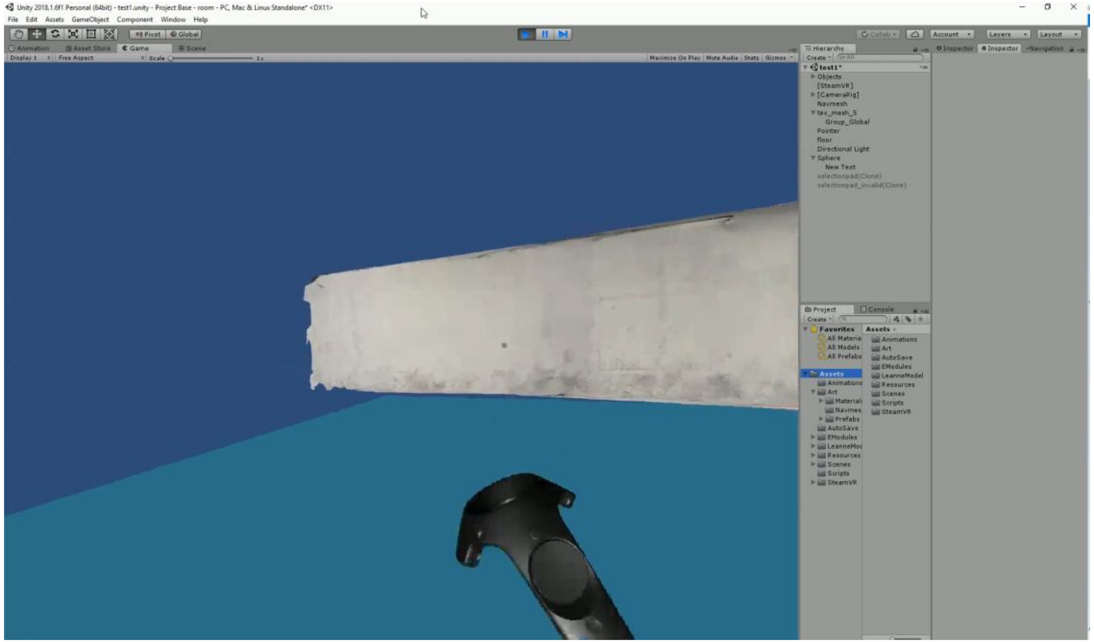
- **TIR images** distinguish targets from their backgrounds based on the radiation difference, which works well in all-weather and all-day/night conditions
- **Visible images** provide texture details with high spatial resolution and definition in a manner consistent with the human visual system



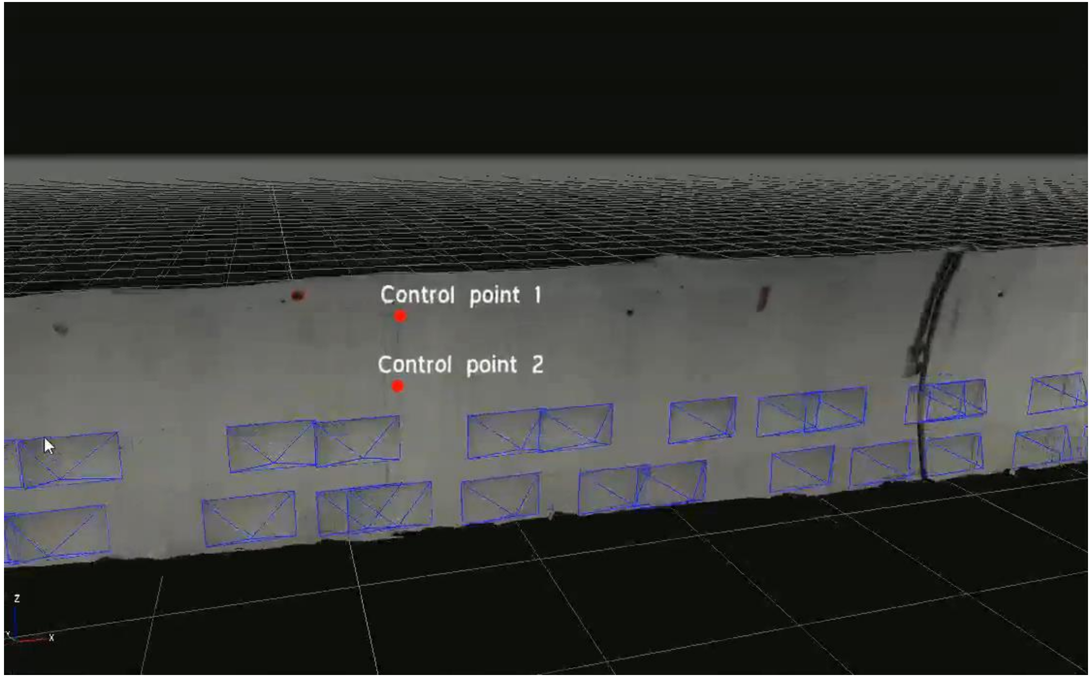
- Fusion of these two types of images combines their individual properties and can be beneficial for in-depth inspection to detect water leakages, deposition etc.

VR

Augment information to the VR models



Remote measuring from VR



to monitor the **full tunnel lining** cross-section

- additional hardware which is currently in procurement stages

to ensure **monitoring speed and personnel safety**

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What has been done so far

- ❑ Reduce inspection time
- ✓ Image capture in real-time using **on-board processors** during technical stops, inspection process **executed offline on powerful computers**, to flag issues within a few hours

- ❑ Reduce personnel presence in tunnels
- ✓ Implementation of remote image capturing **on moving robots**

- ❑ Objective inspection, to reduce report subjectivity
- ✓ Anomaly defect (cracks) detection using **deep learning**

What has been done so far

- ❑ Change monitoring
- ✓ **Reliable** change detection using **image processing** and **data fusion**
- ✓ Pre-processing and post-processing stages **to reduce false alarms** using image processing and deep learning techniques

- ❑ Visualization to aid tunnel surface documentation and analysis
- ✓ Experimentation with the use of **3D and VR models** for their use in **tunnel surface documentation, inspection and analysis**
- ❑ Experimentation with the use of **thermal imagery** for in-depth inspection

Man Power needed for the possible future work

- ❑ Future manpower needed to have a fully operational device: mainly hardware integration tasks on existing robotic platforms + testing and commissioning of the novel 360 deg camera system under procurement.
  - ✓ 2 FTE (Robotics/Integration Engineer) + 1 TECH

Thanks a lot