

ABOUT: Evaluation procedure for automated BIM-capable object detection in tunnel constructions

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Introduction

- Every year, 4700 km of new tunnels are built in the world.
- Germany has:
 - more than 700 km tunnels,
 - more than 200 tunnels,
 - Road tunnels
 - Railway tunnels
 - Underground tunnels
- Requirements:
 - Safety managements
 - Proper maintenance and renovation
 - Regular inspection
 - Tunnel inventory



Tunnel Inspection

- Conventional tunnel inspection techniques:
 - On-site inspections using adapted cars
 - Laser scanners
 - Manual data collection
- **Issues:**
 - Focusing on certain areas of interest or certain features
 - Time-consuming and tiresome (> several hours or days)
 - Quite expensive (> 100,000 €)
 - Well experienced operator
 - Tunnel blocking for several hours
 - Risk areas for operators
 - Special vehicles for high-lift work
 - Visual inspection of anomalies



Local, Manual, Expensive !



Tunnel Inspection

- State-of-the arts tunnel inspection techniques:
 - Vision-based systems on the normal vehicles
 - Cameras and LED lights
- **Features:**
 - Dynamic and high speed surveying systems
 - Improved efficiency
 - Reduced inspection time
 - Enhanced safety
 - Automatic data collecting and processing



Global, Automatic, Low-cost !



@Dibit



@Dibit



@Chapman, 2016



@Ricoh



@Huang, 2017



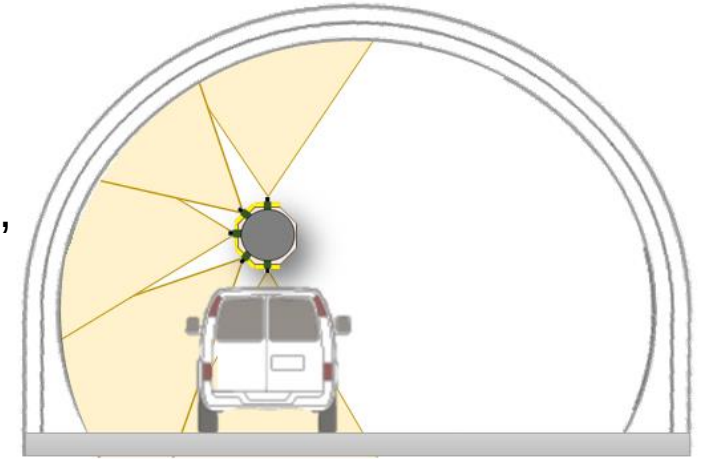
@Jiang, 2019



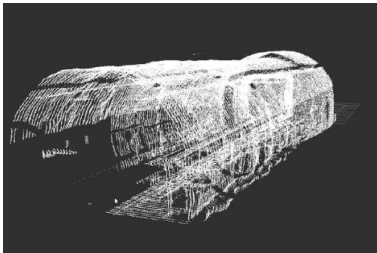
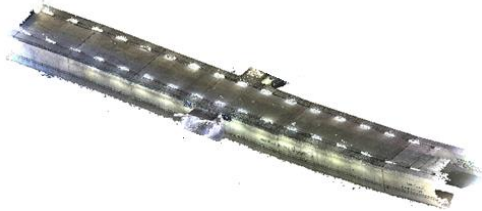
@Terra

Project ABOUT

- Cooperation project between companies and research facilities
- Partners: Viscan Solutions GmbH - Stuttgart University of Applied Sciences, Department of Surveying
- **Goal:** develop a multi-cameras tunnel inspection system for:

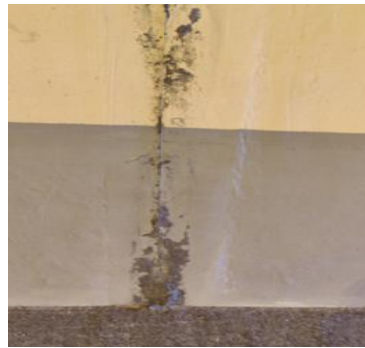


3D reconstruction

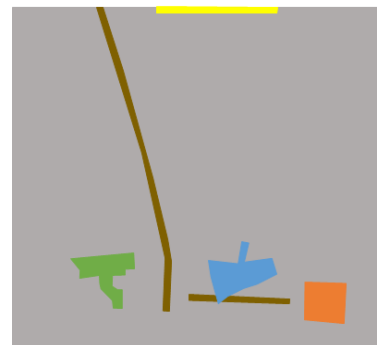


using Pix4D Cloud

Damage detection



Object recognition



based on Deep Learning

○ Main Features:

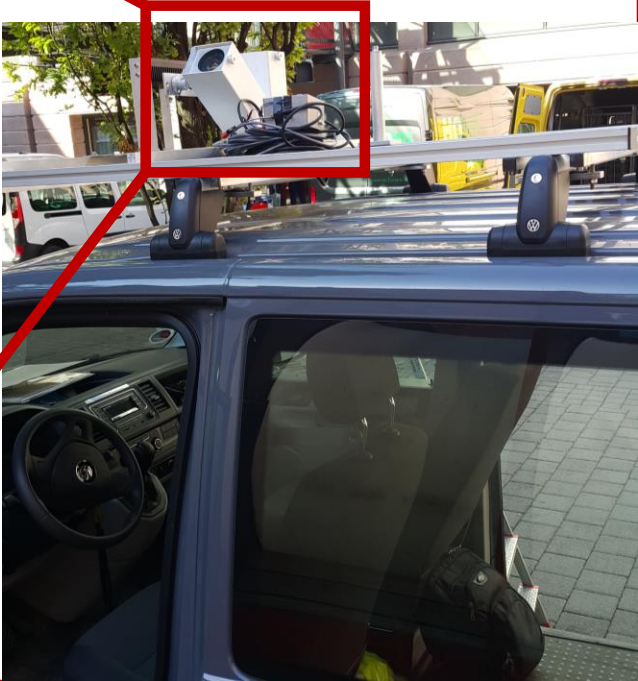
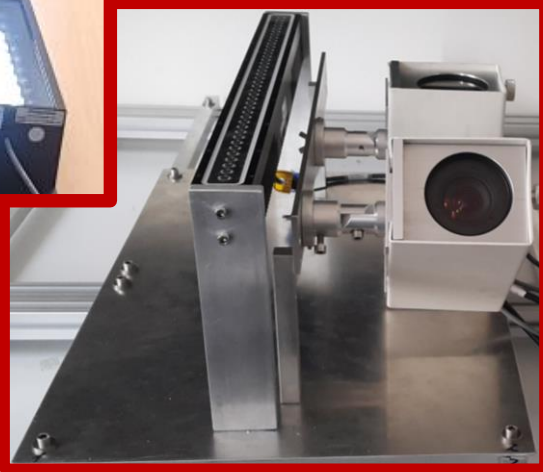
- Low cost (MV cameras and Flash LEDs)
- No GPS/IMU, No laser scanners
- Synchronized image capturing
- Operating speed: 60-65 km/h
- Recording range: 3-8 m
- 3D model accuracy: 2-5 mm
- Crack detection accuracy: 1-3 mm
- Object detection rate: > 90%

Main Components

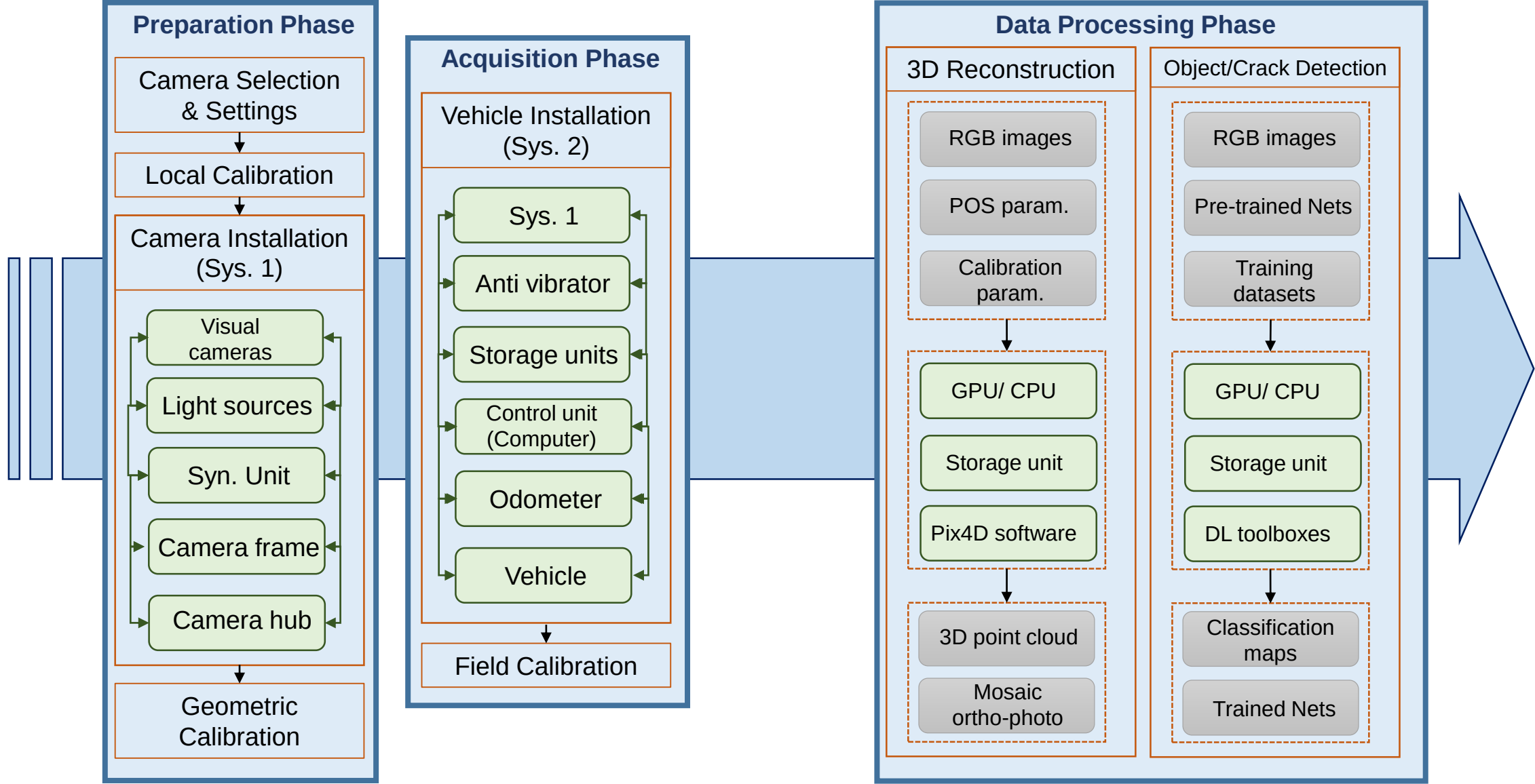
- Area scan machine vision (high speed) cameras
- High power flash LEDs
- Synchronization unit
- LED controller
- Modular Platform

Factor	Value
Sensor	CMOS, Area Scan
Resolution	5 - 12 MP
Sensor format	1.1"
Pixel size [µm]	3.45
Focal length (lens)	6 -12 mm
FPS	5 - 20
Shutter	Global
Interface	USB 3.0

Factor	Value
Sensor	LED, Area baesd
Operation mode	Flash
Wavelength	White
Flash time	250 µs
Flash rate	5 - 20 Hz
Working distance	3-8 m
Controller	Non-integrated
Thermal management	Yes
Interface	GPIO



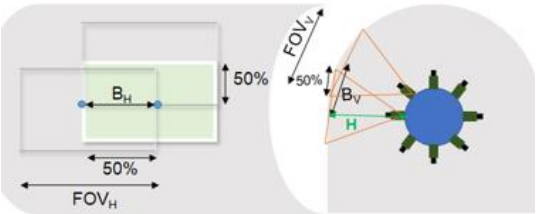
Main Working Packages



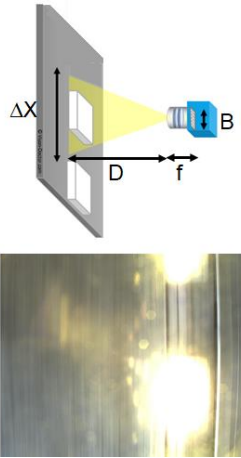
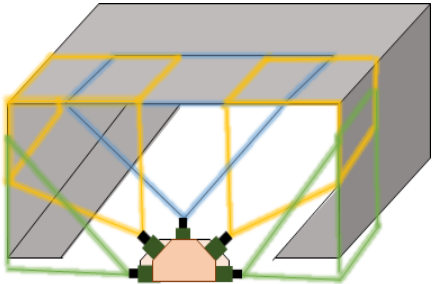
Challenges related to data collection

Camera Selection:

- Line scan or Area-scan camera?
- Rolling shutter or Global shutter?
- Small format or Large format?
- CCD or CMOS?
- Small buffer or Large buffer?
- GigE or USB 3.0 interface?
- Number of cameras? 10, 8, 5?
- Angle between cameras? 36°, 45°, 56°?
- Required lens? 6mm, 12mm, 20mm?
- Required radiometric resolution? 8, 10, 12, 24, 32 bit?
- Required shutter speed? Microseconds, milliseconds, seconds?
- Cost?
- ...



Company	Origin	Brand	Name	MP	Res.	Sensor format	pixel size	Lens (S 200-S 400)	FPS	Shutter	Buffer	Exposure range	Price	Mass (without lens) gram	Picture	Link
FLIR		BLACKFLY USB3	BFS-U3-12054C-CS	12	4000 x 3000	1/1.7"	1.85 µm	TAMRON 8-12-16-25 mm	31	Rolling shutter with global reset	240 MB	10 µs to 30 s	\$575.00	36		https://www.flir.com/products/blackfly-u3-usb3/model-BFS-U3-12054C-CS
			BFS-U3-12356C-C	12.3	4096 x 3000	1.1"	3.45 µm	TAMRON 8-12-16-25 mm	30	Global shutter	240 MB	10 µs to 30 s	\$2,935.00	36		https://www.flir.com/products/blackfly-u3-usb3/model-BFS-U3-12356C-C
			BFS-U3-20056C-C	20	5472 x 3648	1"	2.4 µm	TAMRON 8-12-16-25 mm	18	Rolling shutter with global reset	240 MB	...	\$729.00	36		https://www.flir.com/products/blackfly-u3-usb3/model-BFS-U3-20056C-C
		GRASSHOPPER3 USB3	GS3-U3-12054C-C	12	4240 x 2824	1"	3.1 µm	TAMRON 8-12-16-25 mm	7	Global shutter	128 MB	0.040 ms to 32 s	\$3,695.00	90		https://www.flir.com/products/grasshopper3-usb3/model-GS3-U3-12054C-C
			GS3-U3-12356C-C	12.3	4096 x 3000	1.1"	3.45 µm	TAMRON 8-12-16-25 mm	30	Global shutter	128 MB	0.01 ms to 32 s	\$3,249.00	90		https://www.flir.com/products/grasshopper3-usb3/model-GS3-U3-12356C-C
		FLK A3 USB3	FL3-U3-12053C-C	12	4000 x 3000	1/2.3"	1.55 µm	no recommended	15	Rolling shutter with global reset	32 MB	0.162 ms to .99 s	\$595.00	41		https://www.flir.com/products/flk3-usb3/
Basler	Germany	Basler ace USB3	acA600-10uc	14	4608 x 3288	1/2.3"	1.4 µm	Basler 8-16 mm	10	Rolling Shutter	-	-	\$695.00	80		https://www.baslerweb.com/de/produkte/cameras/cameras-ace-usb3-ace600-10uc/
			acA6024-20uc	12.3	4024 x 3036	1/1.7"	1.85 µm	Basler 8-16-25 mm	31	Rolling Shutter	-	-	\$595.00	80		https://www.baslerweb.com/de/produkte/cameras/cameras-ace-usb3-ace6024-20uc/
			acA5472-17uc	20	5472 x 3648	1"	2.4 µm	Kowa 8-25 mm	17	Rolling Shutter	-	-	\$795.00	80		https://www.baslerweb.com/de/produkte/cameras/cameras-ace-usb3-ace5472-17uc/
			acA1112-30uc	12.3	4096 x 3000	1.1"	3.45 µm	Kowa 8-25 mm	30	Global shutter	-	-	\$1,195.00	80		https://www.baslerweb.com/de/produkte/cameras/cameras-ace-usb3-ace1112-30uc/
			acA6000-10uc	14	4608 x 3288	1/2.3"	1.4 µm	Basler 8-16 mm	10	Rolling Shutter	-	-	\$695.00	80		https://www.baslerweb.com/de/produkte/cameras/cameras-ace-usb3-ace6000-10uc/
stemmer imaging	United Kingdom	Optocirc CamPerform Cyclone	CP-CYCLONE-16-204-C	16	4672 x 3416	4/3"	3.9 µm	-	294	Global shutter	-	-	-	400		https://www.stemmer-imaging.com/en/produkte/cameras/cameras-ace-usb3-ace6000-10uc/
		Allied Vision BumbleBee PRO	B 1250C	12.5	4096 x 3072	-	4.3 µm	-	142	Global shutter	-	-	-	500		https://www.alliedvision.com/en/produkte/cameras/cameras-ace-usb3-ace6000-10uc/
IDS	Germany	USB 3.1 Gen. 1	UI-3-3000SE	12.29	4096 x 3000	1.1"	3.45 µm	-	32	Global shutter	128 MB	0.032 ms - 2000 ms	-	109.5		https://en.idc.de/produkte/cameras/cameras-ace-usb3-ace6000-10uc/
SVS Vizek	Germany	EXO	exo253CU3	12.3	4096 x 3000	1.1"	3.45 µm	-	30	Global shutter	256 MB	28 µs - 1 s	-	138		https://www.svs.com/de/produkte/cameras/cameras-ace-usb3-ace6000-10uc/
			exo387CU3	16.8	5456 x 3076	2/3"	3.45 µm	-	22	Global shutter	256 MB	29 µs - 1 s	-	320		https://www.svs.com/de/produkte/cameras/cameras-ace-usb3-ace6000-10uc/



$$\Delta X = V_e \times T_e$$
$$\Delta X = (D \times B \times PS) / f$$

$$V_e = 16 \text{ m/s}$$

$$T_e = ?$$

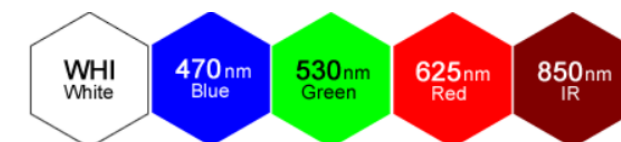
f [mm]	D [m]	T _e [µm]
6	3	21
	4	29
	5	36

Challenges related to data collection

LED Selection:

- Linear, spot, or **Area-based** led?
- Constant, switch, **flash** light?
- NIR or **White** light?
- Integrated or **external** controller?
- Size (FOV) of the LED? 15°, 30°, **50°**?
- Working distance? <1m, **>3m**?
- Number of LEDs? 10, 8, **5**?
- Max. flash rate? 1000, 100, **30**, 1 Hz?
- Required pulse width? **Microseconds**, milliseconds, seconds?
- Cost?
- ...

1	Company	Country	Price	Type	Name	Controller	Light	Flash time (pulse width)	Flash frequency	Working Distance	Size [mm]	Illumination	Lens	Photo	link
2	LUMIMAX	DE	1.190,00 €	Area Flood	LQ100FL-49-W-220	Integrated	Flash	20-220 µs	35 Hz	2	65 x 65	268 w/m2 @ 0.5m	49°		https://www.lim-ax.com/en/lumimax/products/art-area-flood-lights/lq100fl-49-w-220-7365.html
3	LUMIMAX	DE	525,00 €	Mini Bar	LSB200FL-48x19-W	External (335,00 €)	Flash/Const.	100 µs	10-35-100 Hz	2	195 x 15	140 w/m2 @ 0.5m	48x19°		https://www.lim-ax.com/en/lumimax/products/art-led-bar-lights-1/lsb200fl-48x19-7792.html
4	LUMIMAX	DE	2.050,00 €	Bar	LB500FL-48x19-W-220	Integrated	Flash	20-220 µs	35 Hz	2	490 x 22	359 w/m2 @ 0.5m	48x19°		https://www.lim-ax.com/en/lumimax/products/art-led-bar-lights-1/lb500fl-48x19-220-7553.html
5	Metaphase	USA	890,00 € 1.400,00 €	Area Flood	MB-FLD	External (540,00 €)	Flash/Const.	2µs – 60ms	up to 50kHz	5.5	210 x 90 380 x 90	600,000 Lux	11° - 30°		https://www.metaphase-tech.com/wp-content/uploads/2018/04/MB-FLD_PDS-v20190528.pdf
6	Metaphase	USA		Area Front	MB-FL	Integrated	Constant	Need external controller for flash	?	?	200 x 100		11° - 30° - 34°		https://www.metaphase-tech.com/wp-content/uploads/2018/03/MB-FL_PDS-v20190611.pdf
7	Metaphase	USA		Line	MB-CCL	Integrated	Constant	Need external controller for flash	?	?	140 - 3100	1.5 million Lux	no		https://www.metaphase-tech.com/wp-content/uploads/2018/03/MB-CCL_PDS-v20191014.pdf
8	Metaphase	USA		Long Range Strobe	LRS608	Integrated	Flash	2-250 µs	up to 50kHz	30	160 x 160		12° - 28°		https://www.metaphase-tech.com/wp-content/uploads/2018/03/LRS608_PDS-v20190605-.pdf
9	Gardasoft	USA	1,600.00 € *	High-speed LED controllers	FP200	2 channels	Flash	1 µs - 5 s	10kHz	-	-	-	-		http://www.gardasoft.com/LEI-Controllers/FP/
10	Gardasoft (Stemmer Imaging)	DE	400.00 € *	Entry-Level Controllers	RC120	1 channels	Flash	100 µs - 100 ms	100 Hz	-	-	-	-		https://www.stemmer-imaging.com/en/products/gardasoft-rc120/
11	Gardasoft (Stemmer Imaging)	DE	1,800.00 € *	High Speed and High-Power Controllers	TR-HT220	2 channels	Flash	20 µs - 5 s	30kHz	-	-	-	-		http://www.gardasoft.com/LEI-Controllers/TR-HT/
12	BASLER	DE	349.00 €	SLP Strobe Controller	121040	?	Flash/Const.	50µs - 5ms	200 Hz	-	-	-	-		https://www.baslerweb.com/en/ducts/vision-components/basler-lighting/basler-slp-strobe-control-121040/



Challenges related to data collection

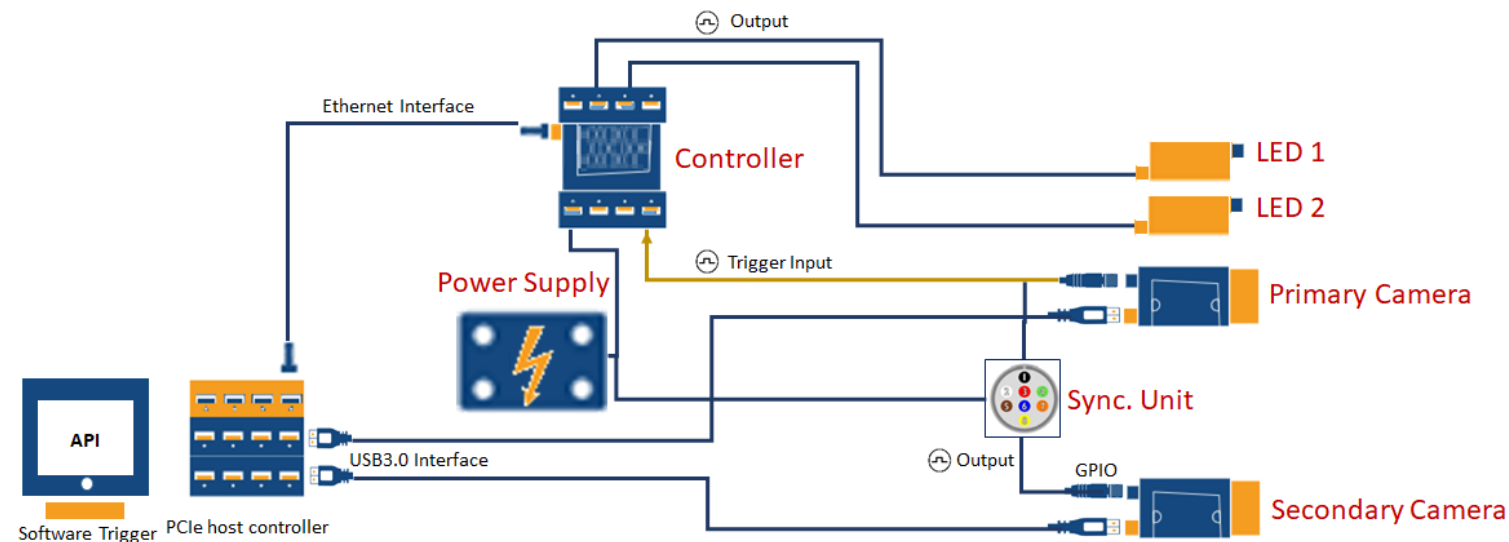
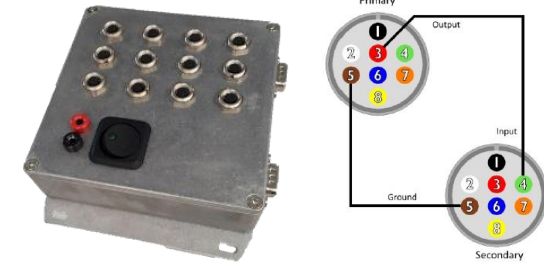
○ Synchronization:

- Between cameras? **Hand-made sync. unit**
- Between the cameras and LEDs? **LED controller**
- Trigger input? **Primary camera**
- Pulse width? **200-250 μ s** $\Rightarrow$ **To avoid Motion blur (in speed of 60-65 km/h)**
- Triger rate? **5-10 Hz** $\Rightarrow$ **Limit of USB band width and storage unit**

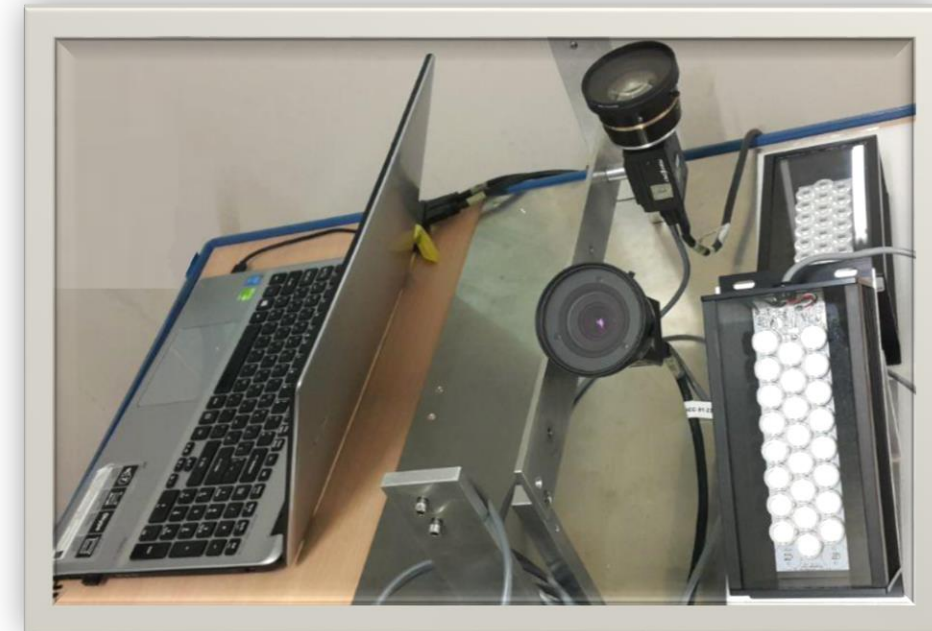
LED Controller



Synchronization unit

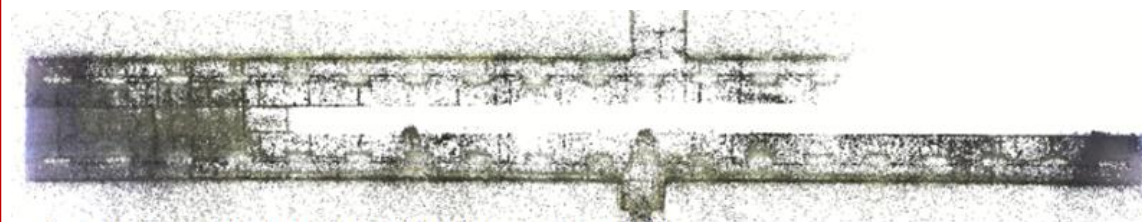
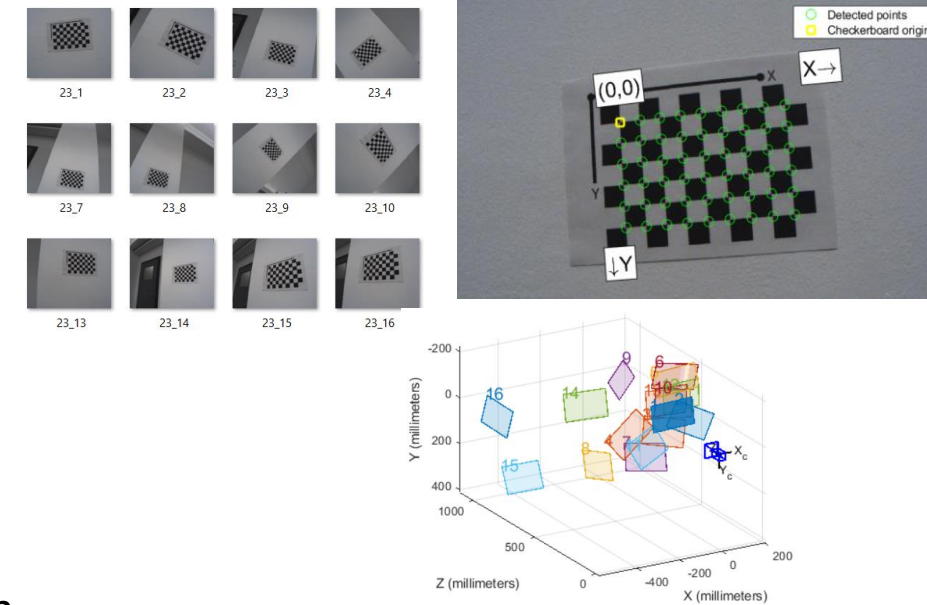


Computer and Storage Units

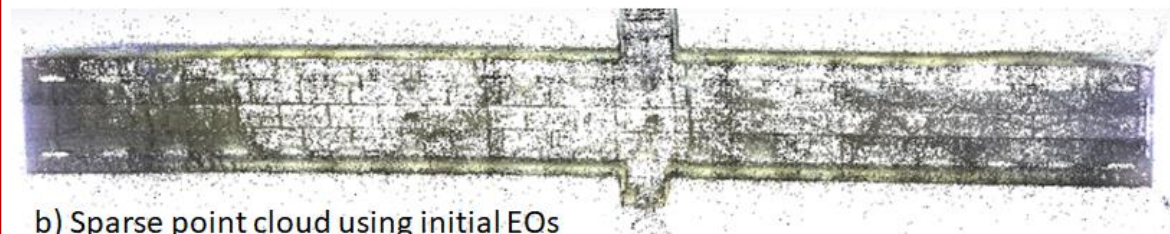


Challenges related to data processing

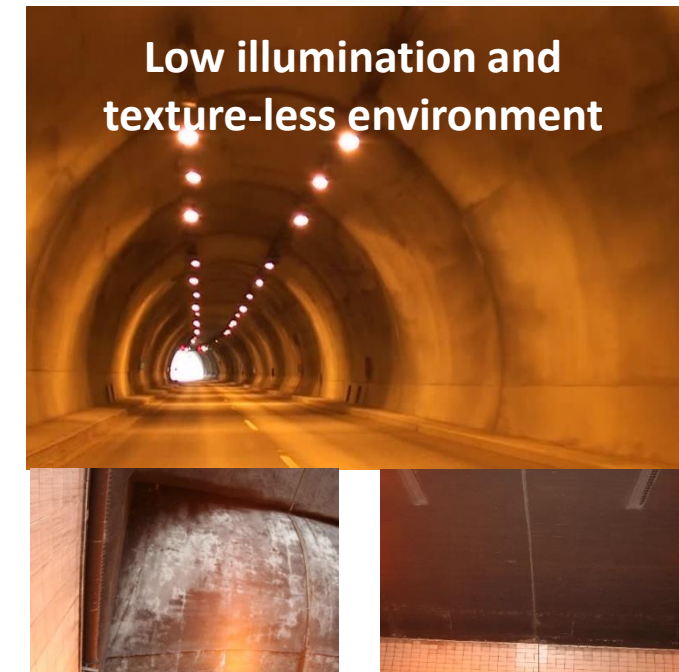
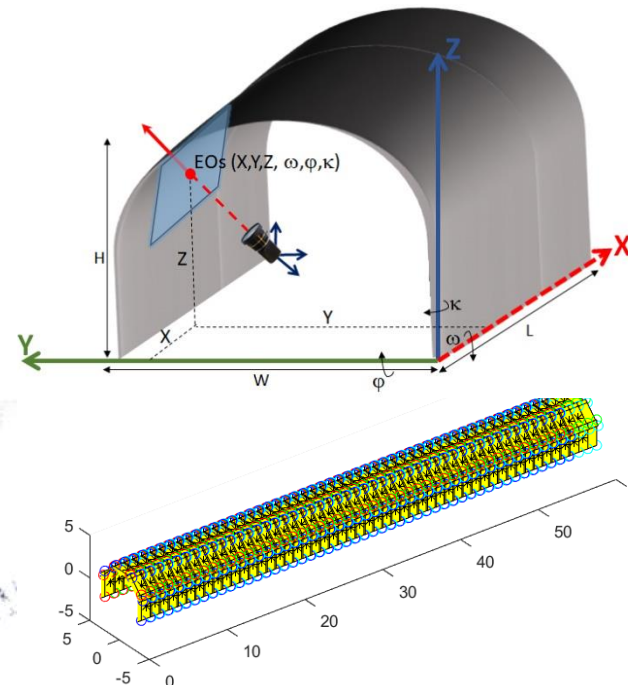
- **Required Calibration:**
 - Single calibration for interior orientations
 - Geometric calibration for exterior orientations (EOs)
- **Low illumination and texture-less environment make the image alignment difficult for Pix4D and Agisoft Metashape.**
 - Solution: Estimate Eos based on the tunnel's coordinate system.



a) Sparse point cloud without using initial EOs



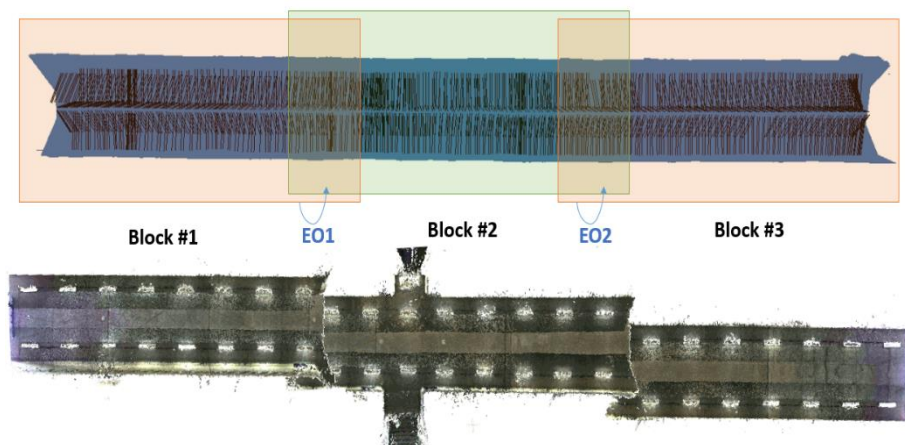
b) Sparse point cloud using initial EOs



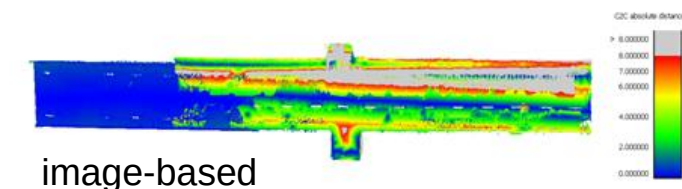
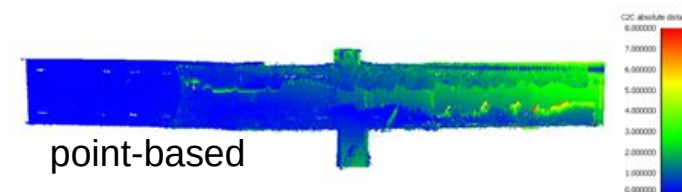
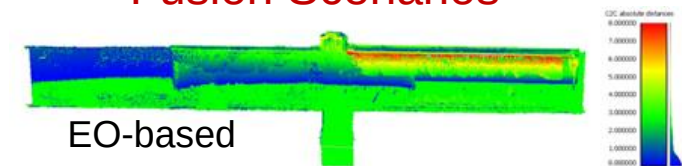
Challenges related to data processing

Point Cloud Fusion:

- Processing scenarios: ring-wise, strip-wise, or **block-wise**?
- Fusion: image-based, EO-based, or **point-based**?



Fusion Scenarios



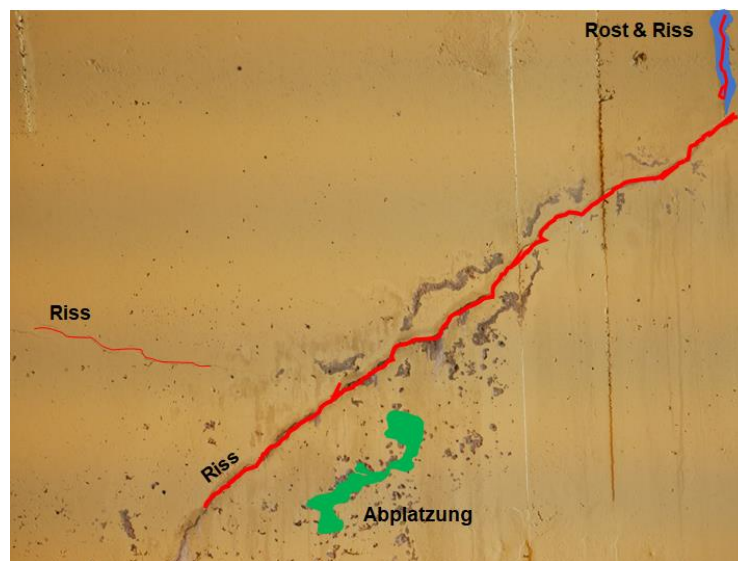
Challenges related to data processing

- **Generate datasets for training the DeepLab:**

1. Data collecting manually
2. Image labeling manually
3. Data augmentation automatically

- **Damage classes:**

- crack
- spalling
- rust

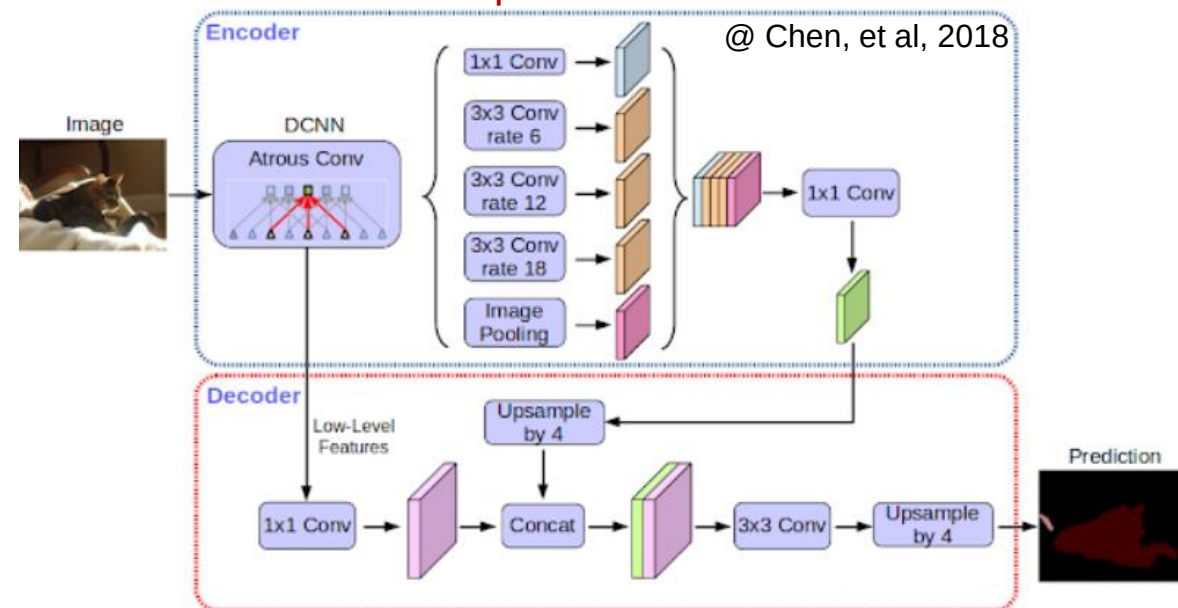


- **Object classes:**

- traffic signs
- lamp, lights
- camera
- axial fan
- traffic light
- cable
- alarm speaker
- air vent
- electronic box

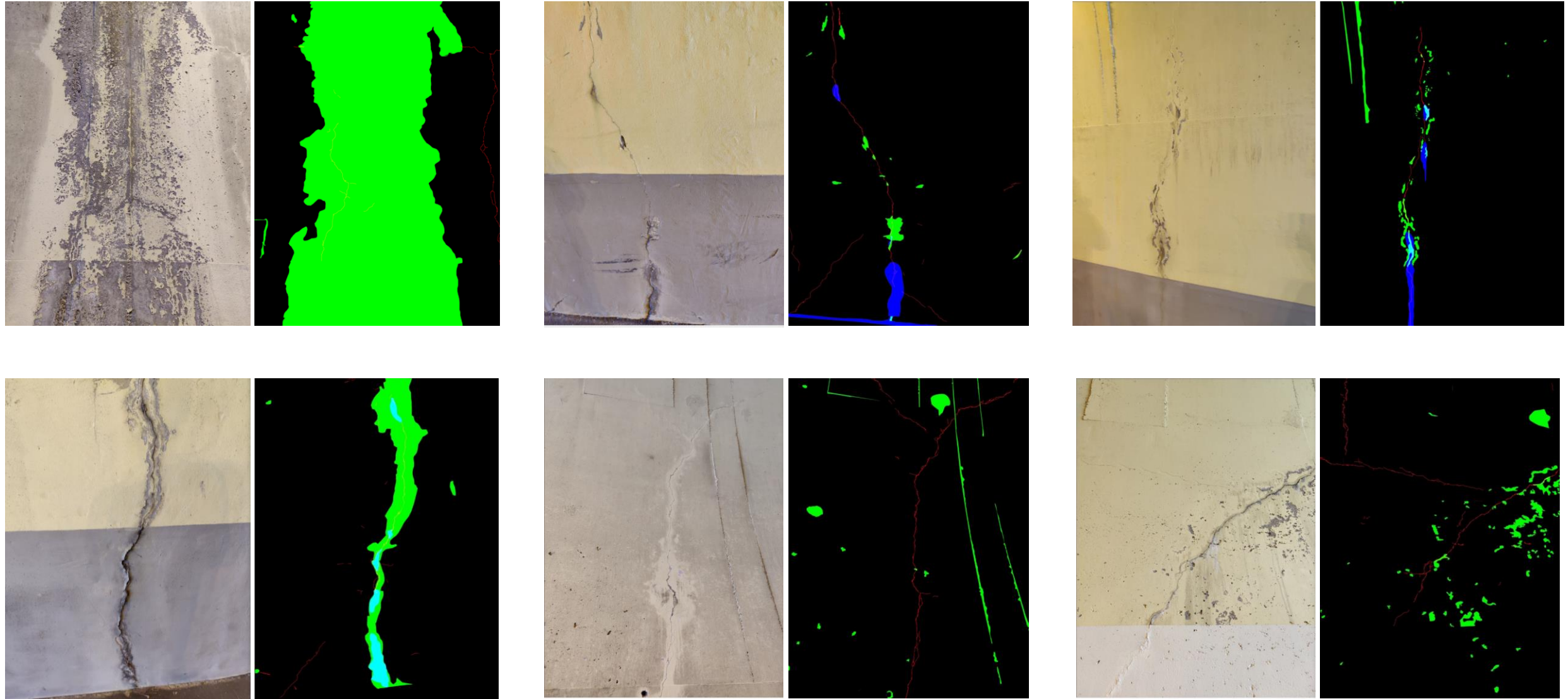


DeepLab-v3+ model

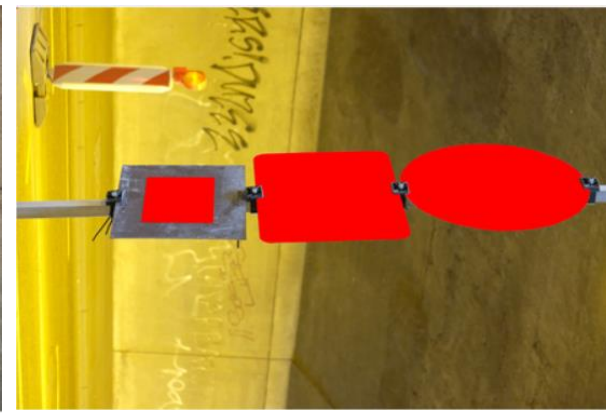
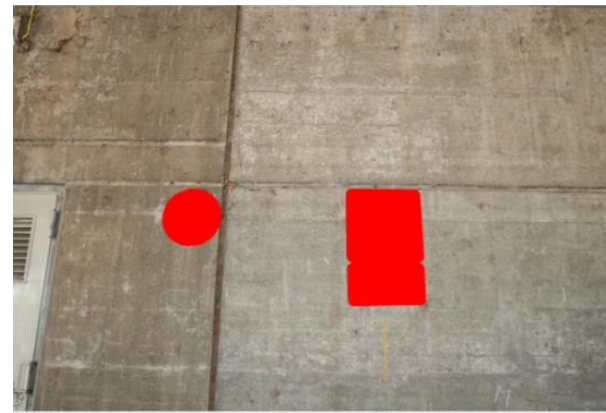
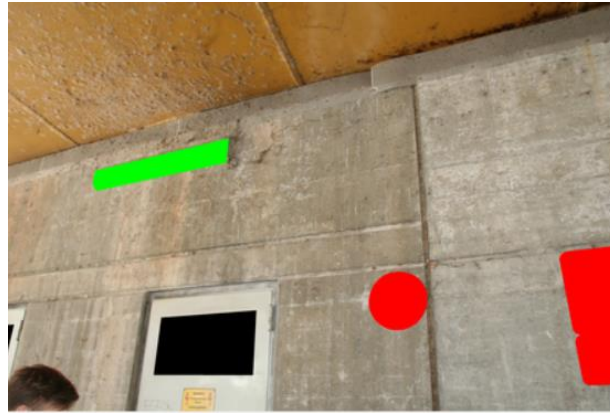
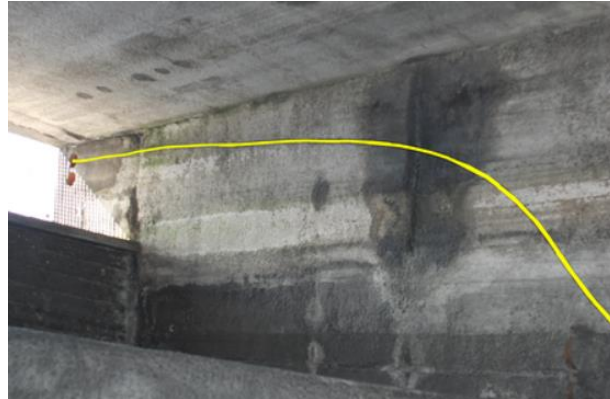


<https://ai.googleblog.com/2018/03/semantic-image-segmentation-with.html>

Training datasets for damage detection



Training datasets for object recognition



Primary results of crack detection

Image



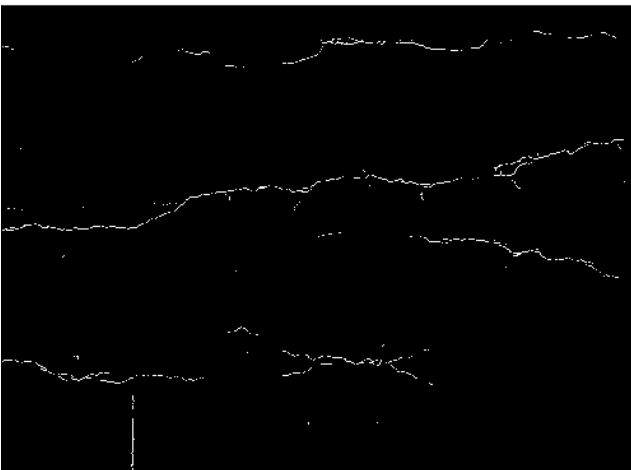
Prediction



Image

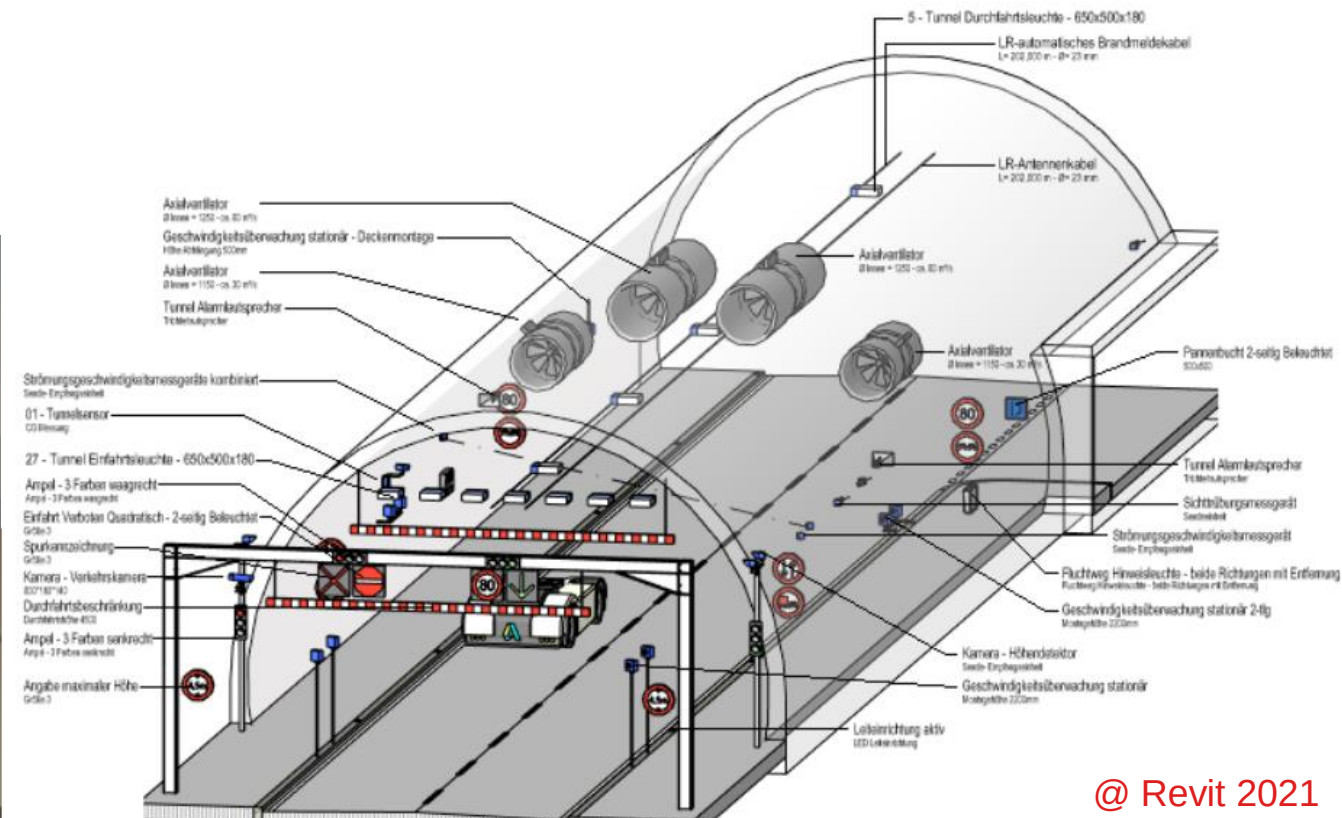


Prediction



Future Works

- System construction for real tunnels
- Performance evaluation of the system
- Deeplab training and evaluation for object recognition
- Transfer the results to CAD models (BIM)



Thanks for your attention