



A non-contact optical technique for vehicle tracking along bounded trajectories



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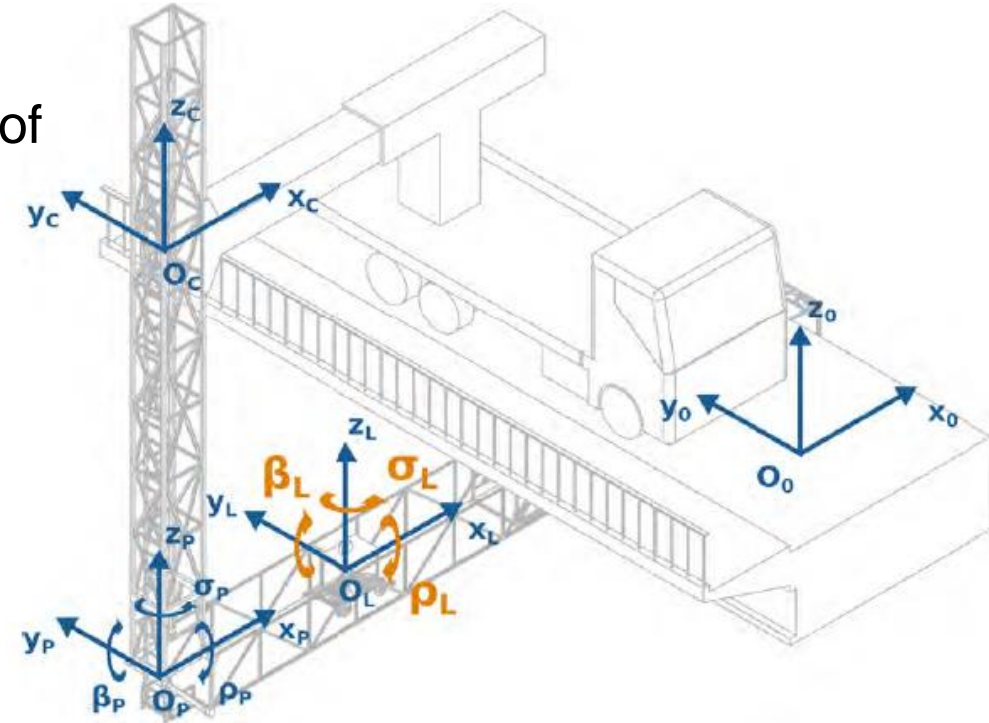


SUMMARY

- Introduction
- State of the art
- Solution proposed
- By-bridge application
- Metrologic analysis
- Conclusion

Introduction

- Measure of a non-controlled trajectory of a vehicle along a bounded rectilinear course
- Purposes:
 - 3D reconstruction of concrete bridge (Giberti and al. [1])
 - Tracking of a laser scanner on a carrying system,
 - The carrying system is in movement along the walkable section of a by-bridge camion
 - From (O_P, X_P, Y_P, Z_P) to (O_L, X_L, Y_L, Z_L) :
3 (small) rotations + 3 translations



[1] H. Giberti, A. Zanoni, M. Mauri, and M. Gammino, "Preliminary study on automated concrete bridge inspection," in ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis. American Society of Mechanical Engineers, 2014, pp. V003T15A011– V003T15A011.

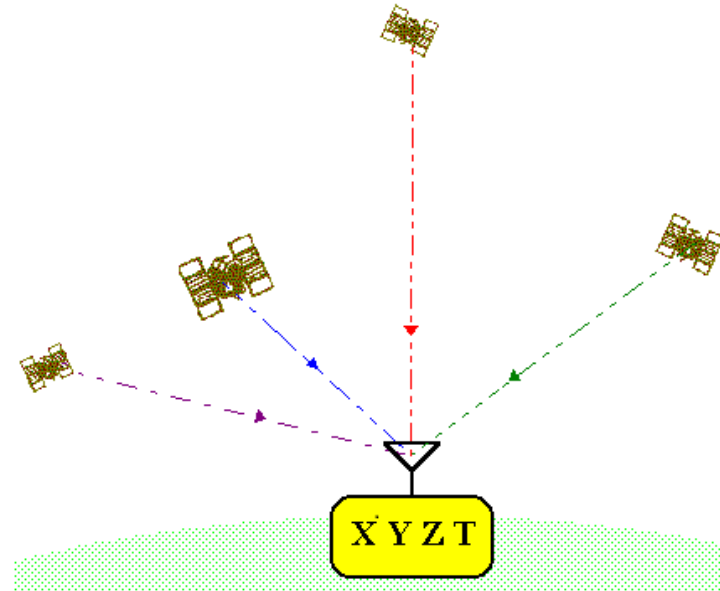


State of the art

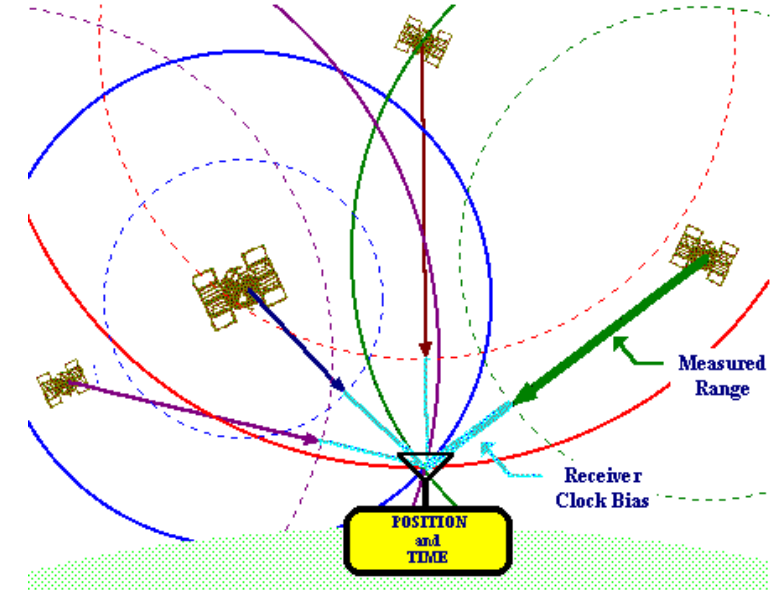
- Global Positioning System (GPS)
 - Triangulation through multiple satellites in known positions

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Distance measurement



Position estimation

- Accuracy from the dozen of centimetres to one meter
- Sensibility to occlusions



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State of the art

- Inertial Measurement Units (IMUs)
 - Accelerometers + gyroscopes + magnetometers
 - Position → Double integration of the acceleration



- **Previously tried, but without success**
 - **Problems in drifting**
 - **Problems with vibration**

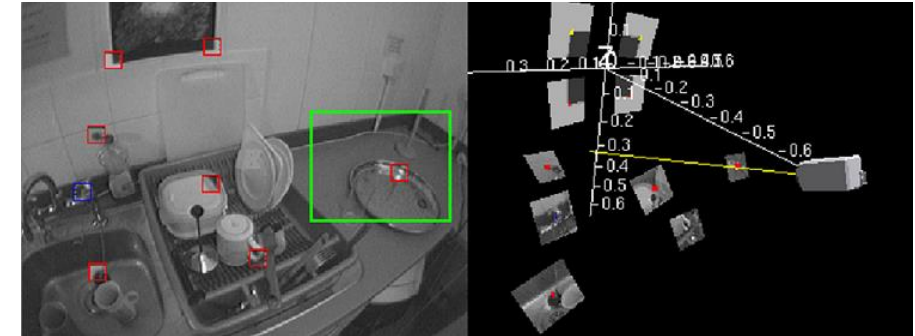
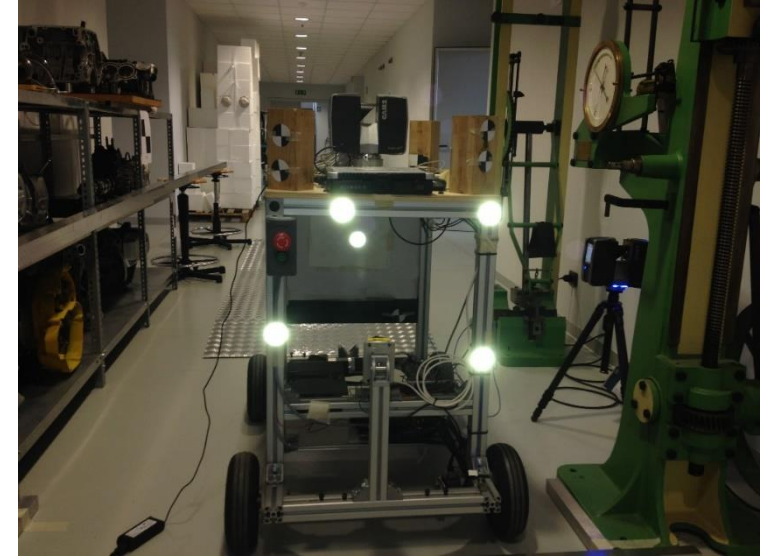


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State of the art

- Computer Vision Techniques (Object Motion / EgoMotion)
 - Tracking techniques: Stereoscopy
 - Based on previous study for object tracking
 - Problems in accuracy for long depth
 - Simultaneous Localization And Mapping Techniques (SLAM)
 - May not be enough accurate
 - But can be adapted, limited to a few degree of freedom





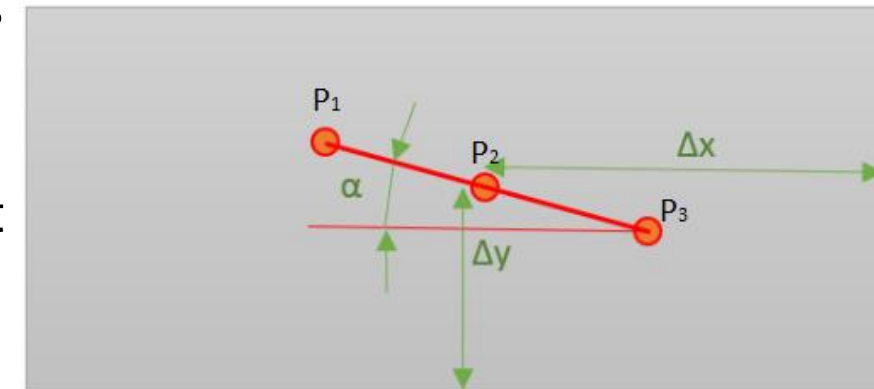
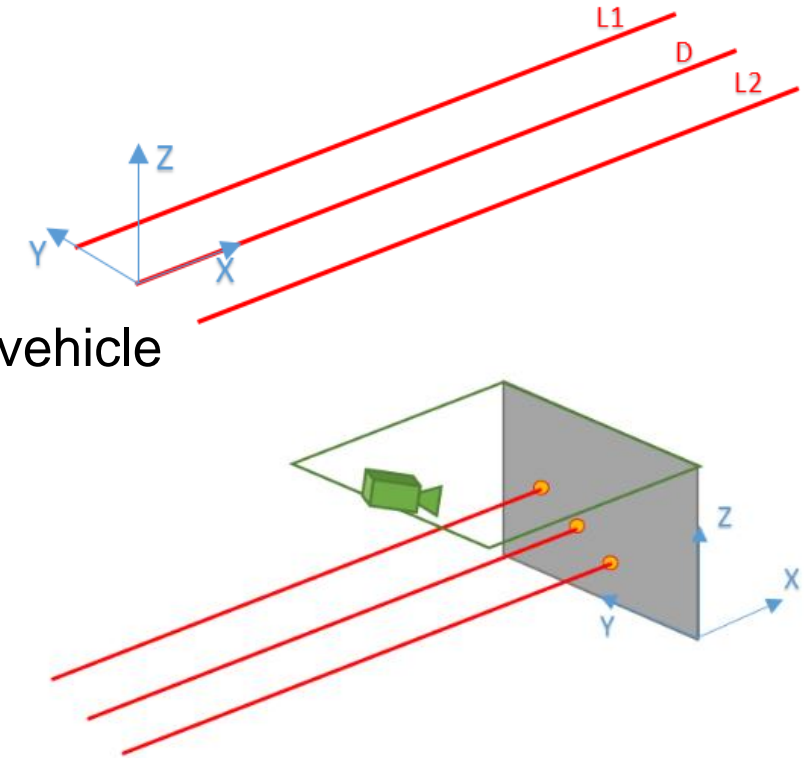
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Solution proposed

- System {Lasers + Rangefinder + Camera}
 - 3 red lasers aligned, 1 being a rangefinder
 - Placed on a support
 - Aligned and pointing in direction of the vehicle
 - Defining the reference system
 - Measure the X-displacement of vehicle
 - 1 Camera
 - Placed on the vehicle
 - Captures the projection of the lasers beams on a planar surface of the vehicle.
 - Measures the Y and Z-displacement and the roll rotation of the vehicle

➤ **Total of 4 degrees of freedom**



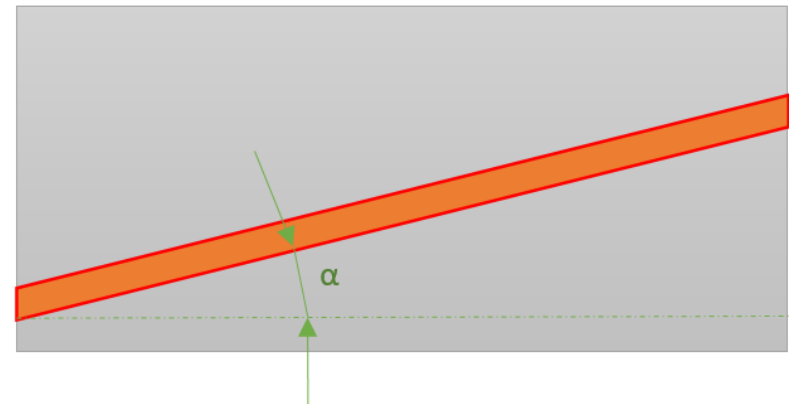
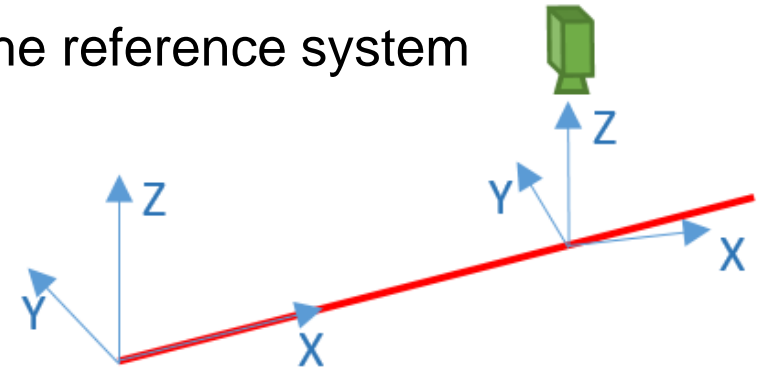


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Solution proposed

- System {Camera + Features}
 - 1 Camera, capturing images in a plane of the reference system
 - Placed on the vehicle
 - Pointing in the direction of a plane where we want to measure the angle
 - Features to reference the measure
 - A straight line placed along the path
 - Line detection algorithm in order to measure the rotation



➤ **Measures 1 degree of freedom (rotation)**

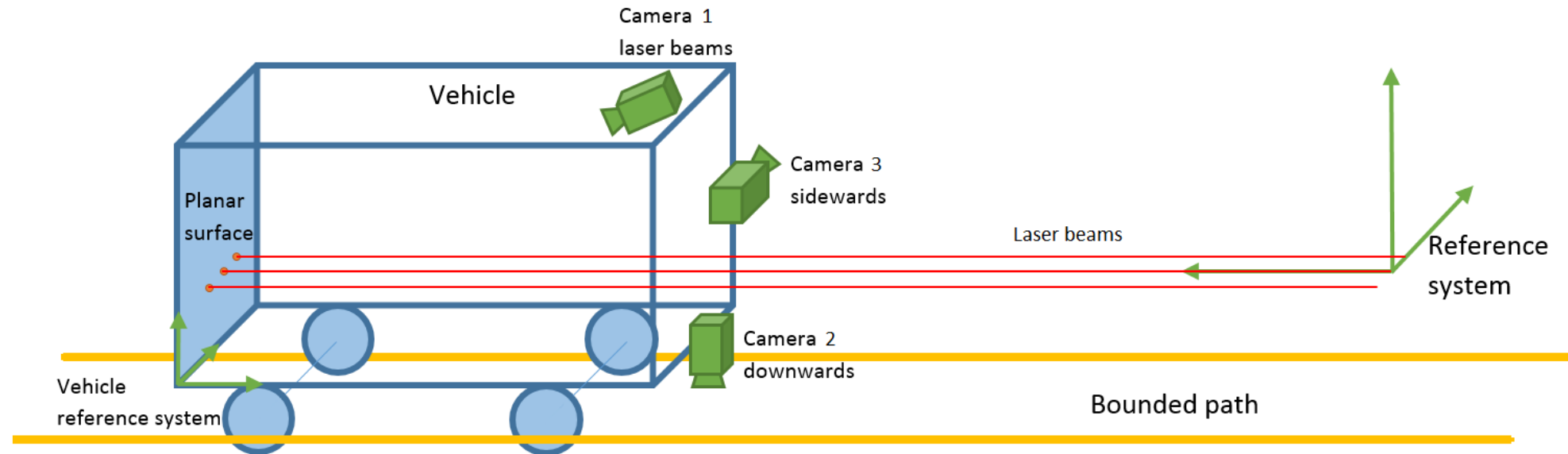


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Solution proposed

- Complete system:
 - (x1) System {Lasers + Rangefinder + Camera}
 - Measures 4 degrees of freedom (3 translations + Roll rotation)
 - (x2) System {Camera + Line}
 - Measures Yaw and Pitch rotations





By-bridge application

- {Lasers + Rangefinder + Camera}
 - 3 lasers one being a rangefinder placed on a mechanical support
 - Projection of laser beams on a vehicle planar surface, captured an IDS camera (*uEye UI-5240CP-M-GC, 1280x1024, 25Hz*)
 - Image acquisition through a Labview software

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Plane Settings

Objects	Threshold
Bright Objects	30

Ignore Objects touching Image Borders
 Fill Holes within Objects
 Minimum Object Size 10 (pixels)
 Maximum Object Size 1000 (pixels)
 Show Search Area
 Show Center
 Show Bounding Box

ROI Plane

Left	Top	Right	Bottom
300	0	1000	500

1280x1024 0.25X 8-bit image 17 (0,0)

Object centers (real world)

	Nb Detected Object	time
76,7484	3	9043
123,985		
-11,2015		
134,165		
188,551	2	239
130,344		
0		
0		
	Loop timer 3	0
	5	
	ROI offset	
	30	



By-bridge application

- {Yaw Camera + Line}
 - Decametre as reference line for the measurement of yaw angle
 - Camera with IR lightning system and filters
 - Image acquisition through a Labview software



Edge Options Down

Search Direction: Bottom to Top

Edge Options: Show Search Area, Show Search Lines, Show Edges Found, Show Result

Edge Polarity: Rising Edges

Kernel Size: 5

Width: 15

Minimum Edge Strength: 10,00

Interpolation Type: Zero Order

Data Processing Method: Average

Line Options Down

Number of Lines: 1, Step Size: 5

Type: 1, Min. SNR (db): 10

First Edge Rake: 10, Min. Score: 10, Min. Points (%): 30

Max. Score: 1024, Hough Iterations: 2

Orientation: 1, Angle Range: 3, Angle Tolerance: 0,01

Search Margin Down

Left	Top	Right	Bottom
200	300	930	750

ROI offset: 20

Timer Down: 15

t Elab Down: 14

time 3: 6880

i 3: 182

errori 3: 0

1280x1024 0.33X 8-bit image 20 (170,26)

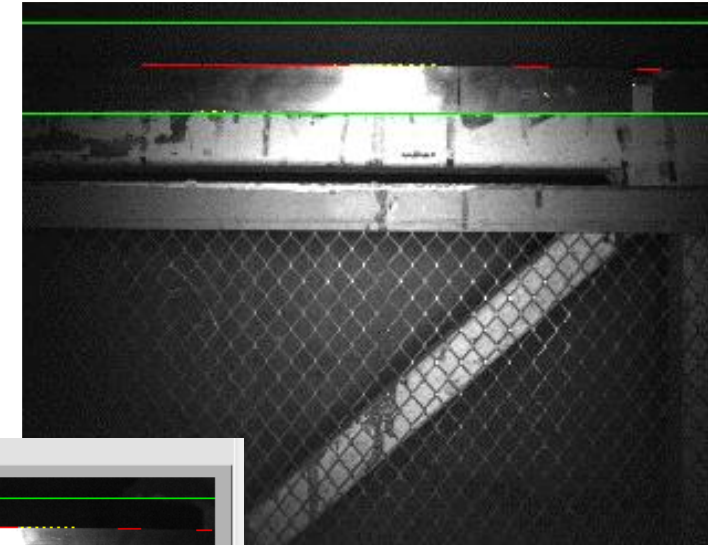
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By-bridge application

- {Pitch Camera + Line}
 - Handrail as reference line for the measurement of pitch angle
 - Camera with IR lightning system and filters
 - Image acquisition through a Labview software



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The screenshot shows a LabVIEW control panel with several sections:

- Edge Options Side:** Search Direction (Top to Bottom), Edge Options (Show Search Area, Show Search Lines, Show Edges Found, Show Result), Edge Polarity (Rising Edges), Kernel Size (3), Width (5), Minimum Edge Strength (20,00), Interpolation Type (Zero Order), Data Processing Method (Average).
- Line Options Side:** Number of Lines (1), Step Size (5), Type (First Edge Rake), Min. SNR (db) (20), Min. Score (10), Min. Points (%) (25), Max. Score (1024), Hough Iterations (2), Orientation (-2), Angle Range (7), Angle Tolerance (0,01).
- Search Margin Side:** Left (0), Top (0), Right (1280), Bottom (500).
- ROI offset:** 80
- Timer Side:** 20
- t Elab Side:** 32
- time 2:** 49095
- i 2:** 1292
- errori 2:** 330

The main image area shows a grayscale image of a handrail with green and red lines overlaid. The status bar at the bottom indicates: 1280x1024 0.25X 8-bit image 19 (4,652).



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By-bridge application

- Complete Solution
 - Mathematical model

$$X_c = \delta,$$

$$Y_c = -Y_2,$$

$$Z_c = -Z_2,$$

$$Roll = \arctan\left(\frac{Z_1 - Z_3}{Y_1 - Y_3}\right)$$

$$Pitch = \alpha$$

$$Yaw = \beta$$

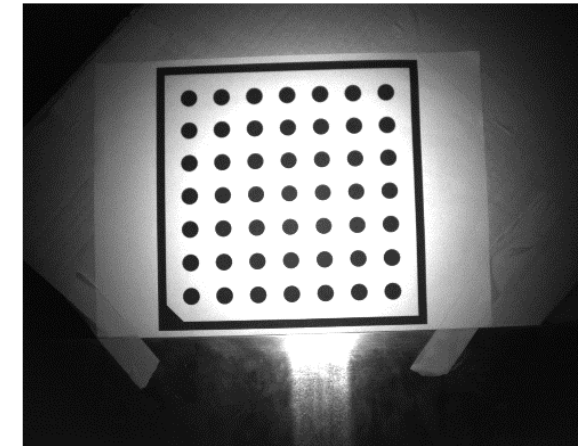
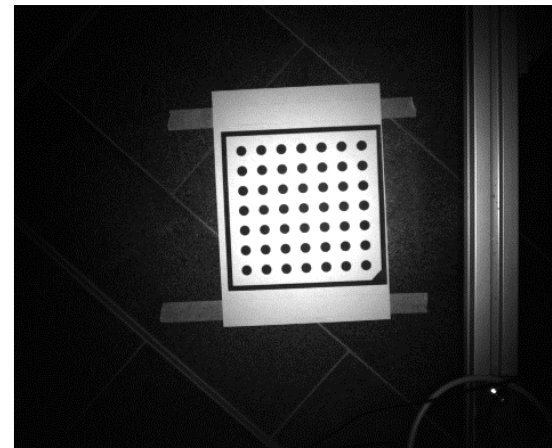
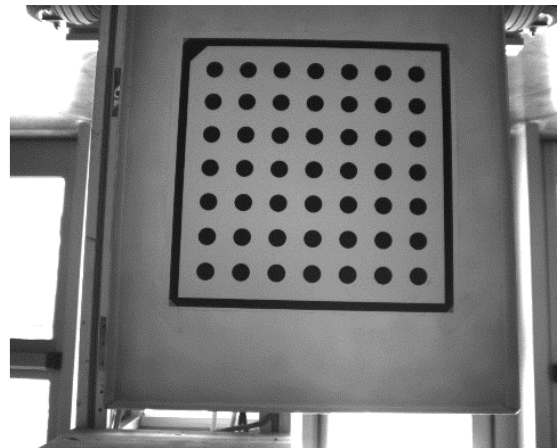


- $X_c, Y_c, Z_c, Roll, Pitch, Yaw$ the components of position and orientation of the carrier
- δ the distance measured by the rangefinder
- $Y_1, Z_1, Y_2, Z_2, Y_3, Z_3$ the position of the dots in the camera frame
- α, β the angles measured by the cameras respectively sideways and downwards



By-bridge application

- Calibration
 - Camera internal parameters calibration



- Calibration in the measurement plane
- Optical distortions correction
- Remap image in camera reference system (pixel ↔ mm)

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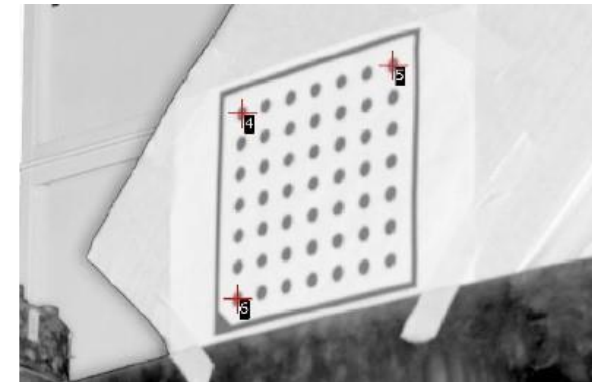
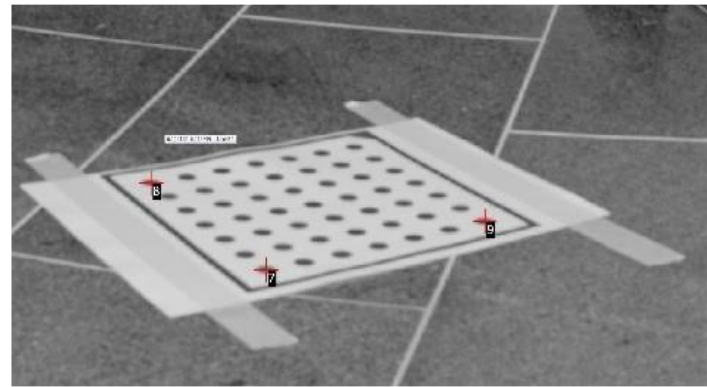
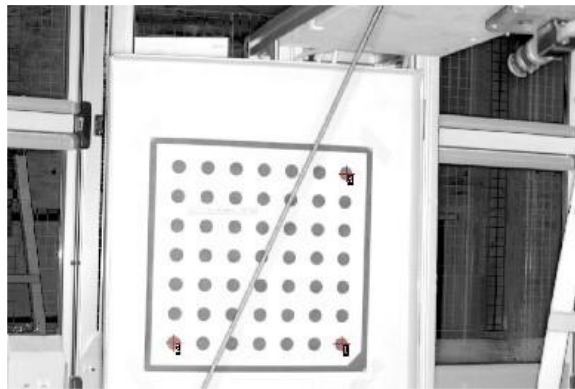


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By-bridge application

- Calibration
 - Camera internal parameters calibration
 - Camera external parameters calibration



- Registration of cameras reference system into global reference system
- Transformation matrix for different reference systems

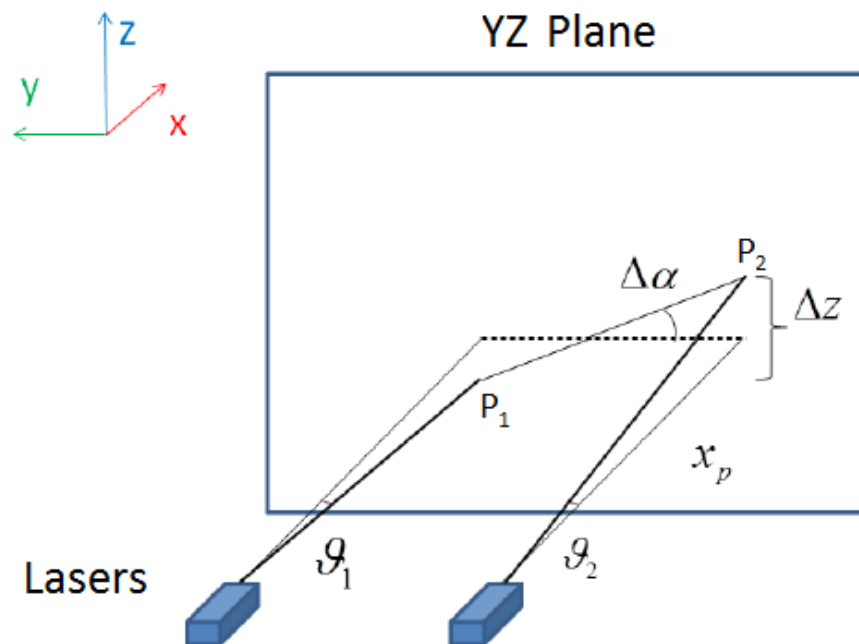


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By-bridge application

- Calibration
 - Camera internal parameters calibration
 - Camera external parameters calibration
 - Misalignment of laser beams



$$\begin{aligned} \Delta\alpha &= -\arctan\left(\frac{z_{P_2} - z_{P_1}}{y_{P_2} - y_{P_1}}\right) \\ &= -\arctan\left(\frac{x_p \tan\theta_2 - x_p \tan\theta_1}{y_{P_2} - y_{P_1}}\right) \\ &\approx -\frac{x_p (\tan\theta_2 - \tan\theta_1)}{\text{distance}(P_1 - P_2)} \end{aligned}$$

- Residual roll angle linear with the progression distance
- Possibility to identify it if not corrected

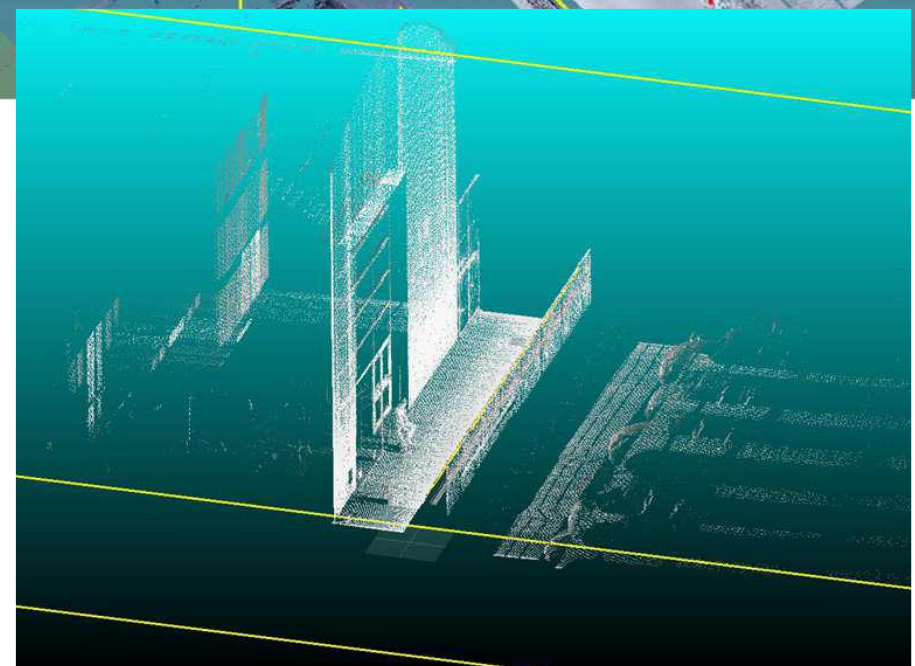
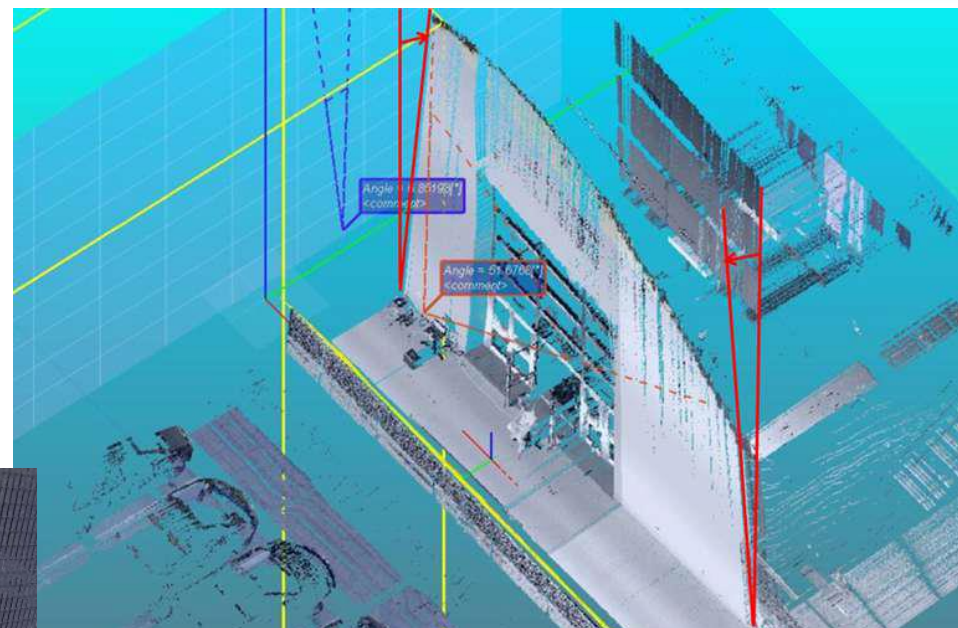


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By-bridge application

- 3D Reconstruction:
 - Politecnico di Milano building
 - Without roll compensation
 - With roll compensation (0.5deg/m)





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Metrologic analysis

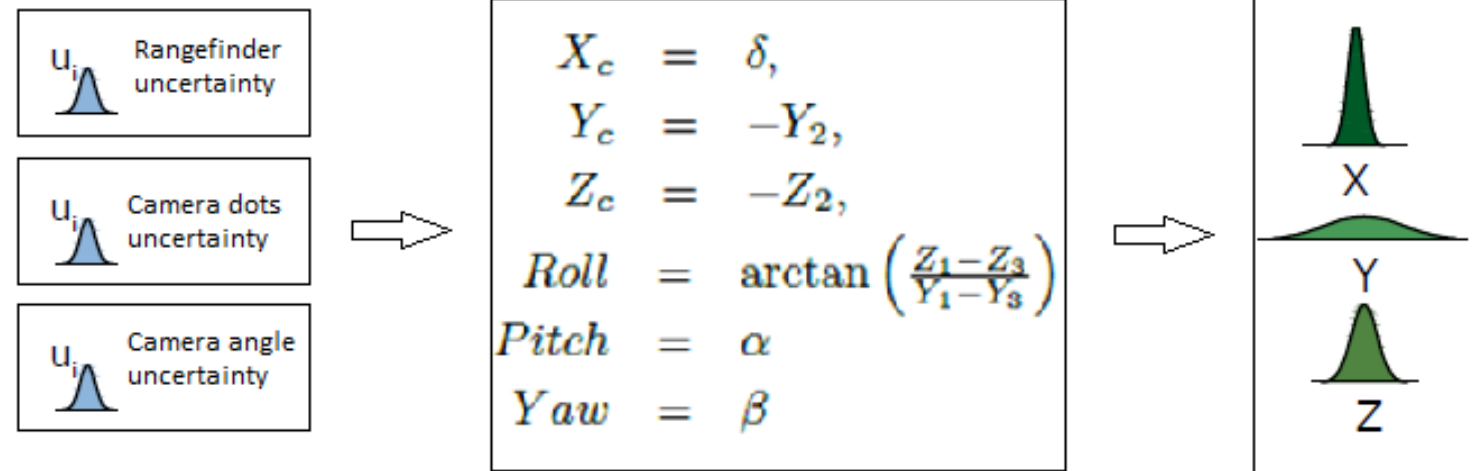
- Instrument error estimation with 1000 measurements:
 - Rangefinder: Resolution of 1mm in distance measurement:
 - $U_{Rangefinder} = \frac{1}{2\sqrt{3}} \approx 0,29 \text{ mm}$
 - Camera Blob: Pixel resolution of 0,5 mm in the planar surface:
 - $U_{Dots} \approx 0,06 \text{ mm}$ thanks to subpixel calculus of dots barycentre
 - Camera Angle: Resolution of $0,01^\circ$ in line angle estimation:
 - $U_{Angle} \approx 0,04^\circ$

Instrument	Theoretical Uncertainty	Experimental Uncertainty
Rangefinder	1,00mm	0,29mm
Camera blob	0,50mm	0,06mm
Camera angle	$0,01^\circ$	$0,04^\circ$



Metrologic analysis

- Monte Carlo model



Component	Translation Uncertainty	Rotation Uncertainty
X	0,29mm	0,03°
Y	0,06mm	0,04°
Z	0,06mm	0,04°

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Conclusion

- Design of a custom tracking system
- Metrological analysis of the system
 - More accurate than the state of the art
 - Constant uncertainty along the trajectory
- Application in a concrete project
 - **Have to be tried in real situation, system tuning may be necessary and accuracy worse**
 - **Can be adapted to other projects that require position tracking along rectilinear trajectory**
 - **Some improvement can be test with SLAM technique with TOF Camera**



THANK YOU FOR THE ATTENTION