POLITECNICO DI MILANO

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

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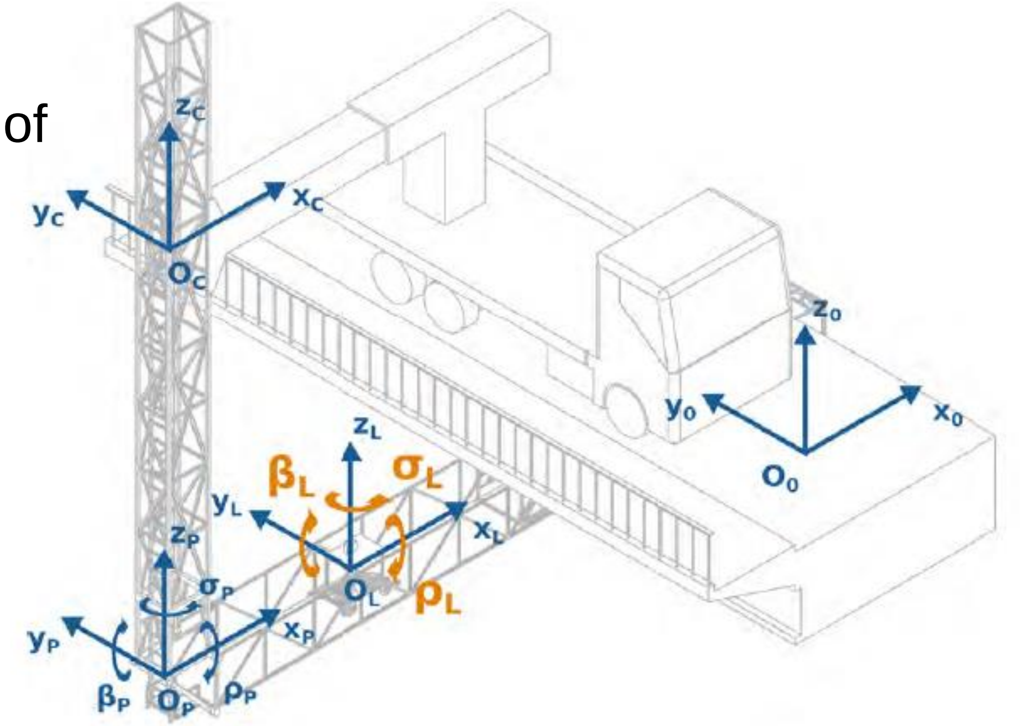
SINECO

Introduction

- Measure of a non-controlled trajectory of a vehicle along a bounded rectilinear course

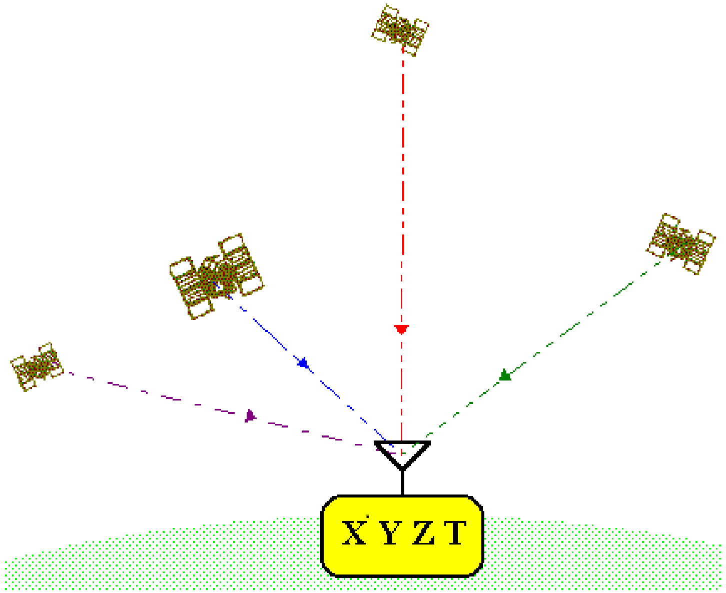


- Purposes:
  - 3D reconstruction of concrete bridge (Giberti and al. [1])
  - Tracking of a laser scanner on a carrying system,
    - The carrying system is in movement along the walkable section of a by-bridge camion
    - From (O_P, X_P, Y_P, Z_P) to (O_L, X_L, Y_L, Z_L):
      3 (small) rotations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

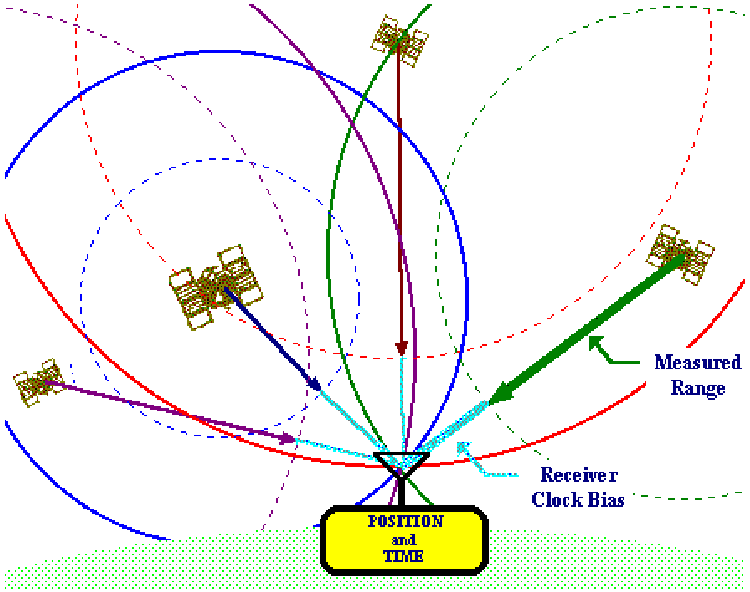
[1] H. Giberti, A. Zanoni, M. Mauri, and M. Gammino, *"Preliminary study on automated concrete bridge inspection,"* in ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis. American Society of Mechanical Engineers, 2014, pp. V003T15A011– V003T15A011.

State of the art

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



Distance measurement

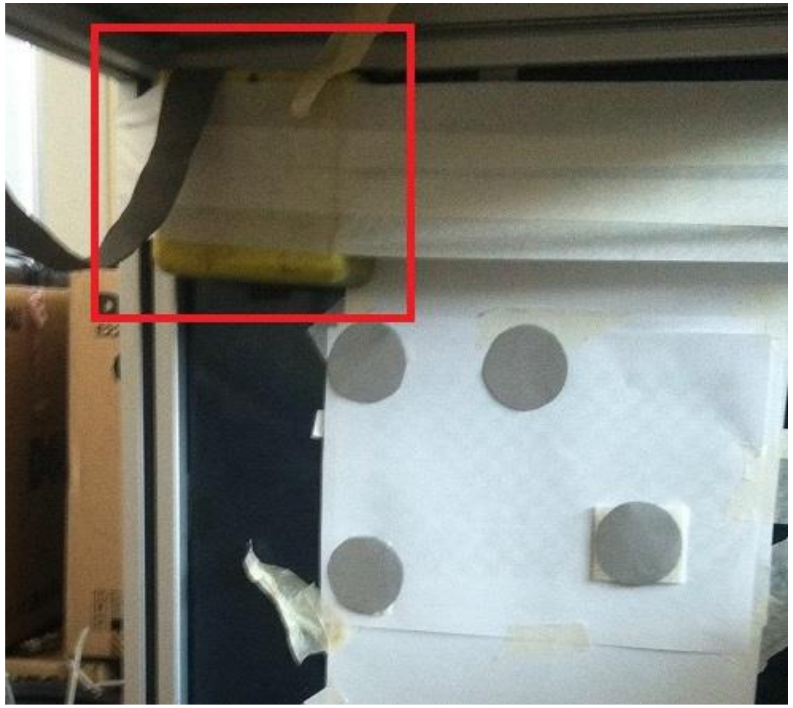


Position estimation

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

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

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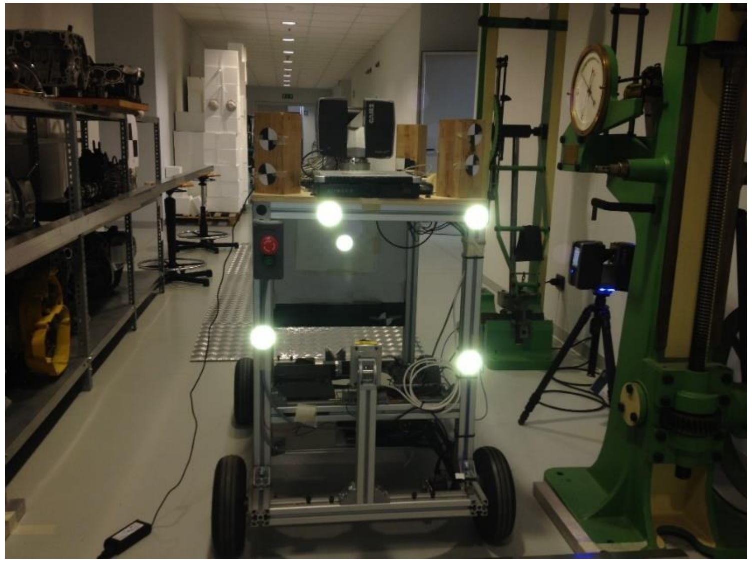
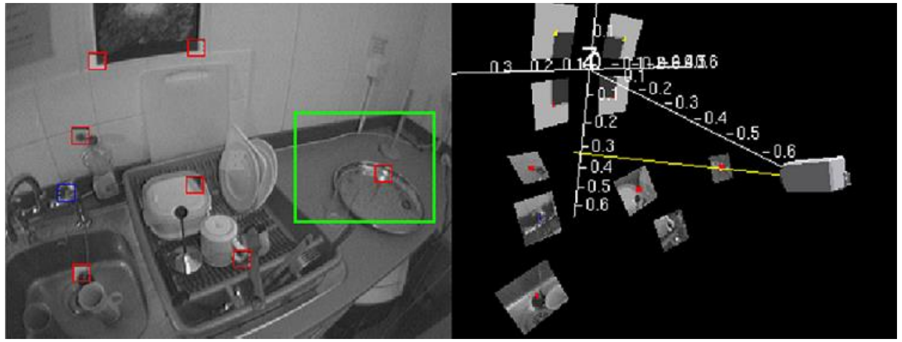
- Computer Vision Techniques (Object Motion / EgoMotion)
  - Tracking techniques: Stereoscopy
    - Based on previous study for object tracking
    - Problems in accuracy for long depth

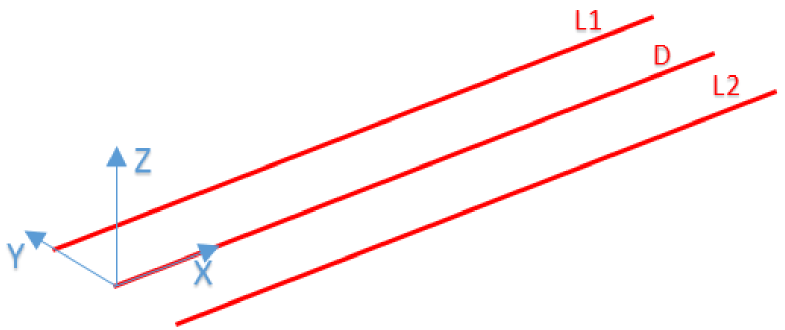


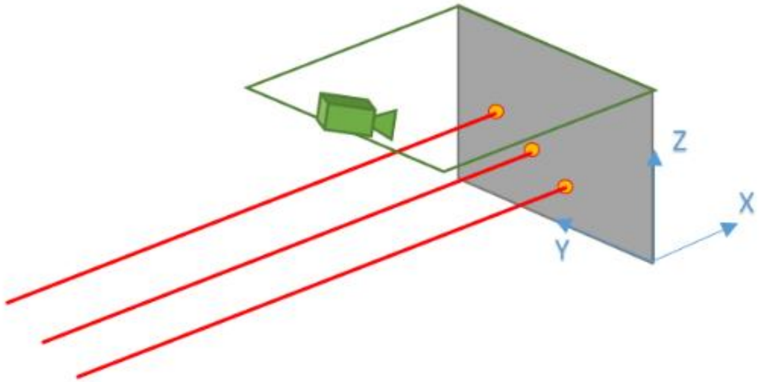
  - Simultaneous Localization And Mapping Techniques (SLAM)
    - May not be enough accurate
    - But can be adapted, limited to a few degree of freedom



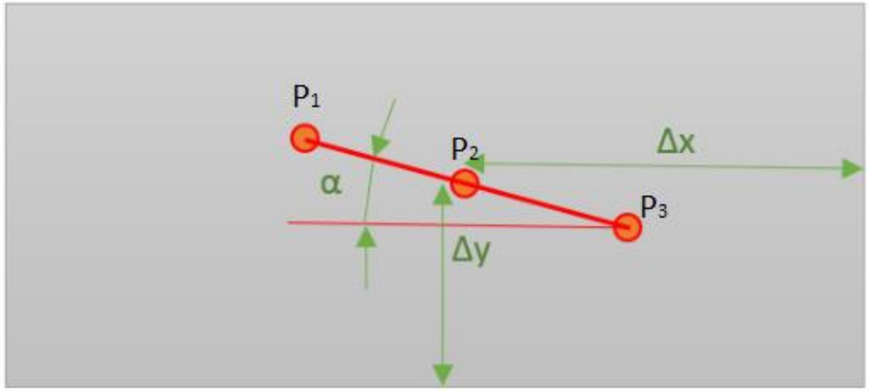
Solution proposed

- 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

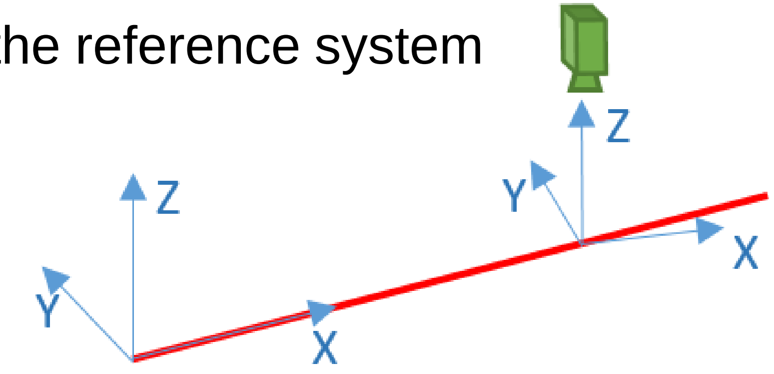


➢ Total of 4 degrees of freedom

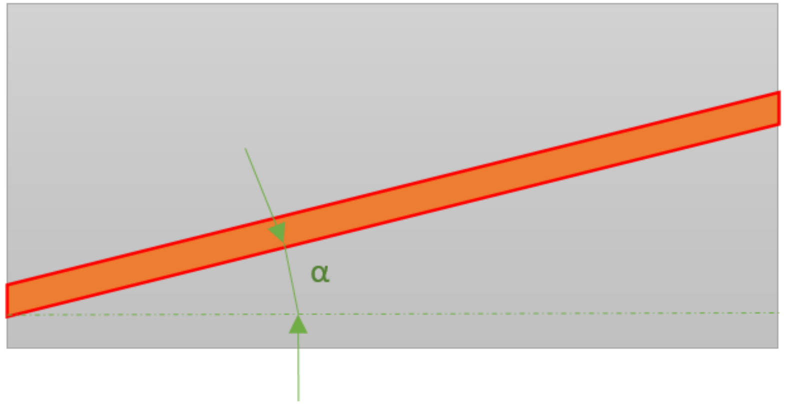
SUMMARY

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



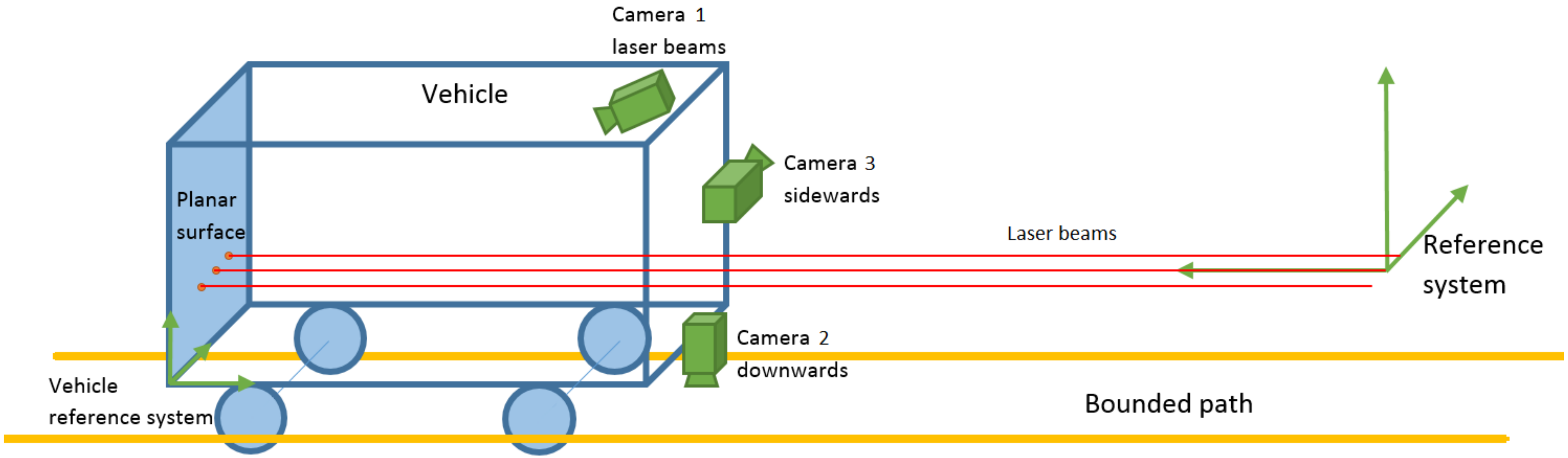
  - Features to reference the measure
    - A straight line placed along the path
    - Line detection algorithm in order to measure the rotation



➢ Measures 1 degree of freedom (rotation)

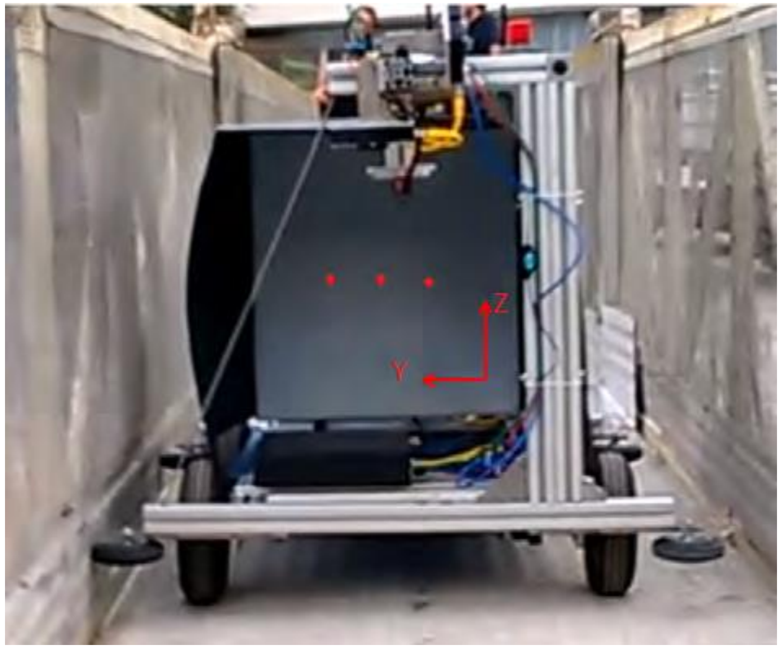
Solution proposed

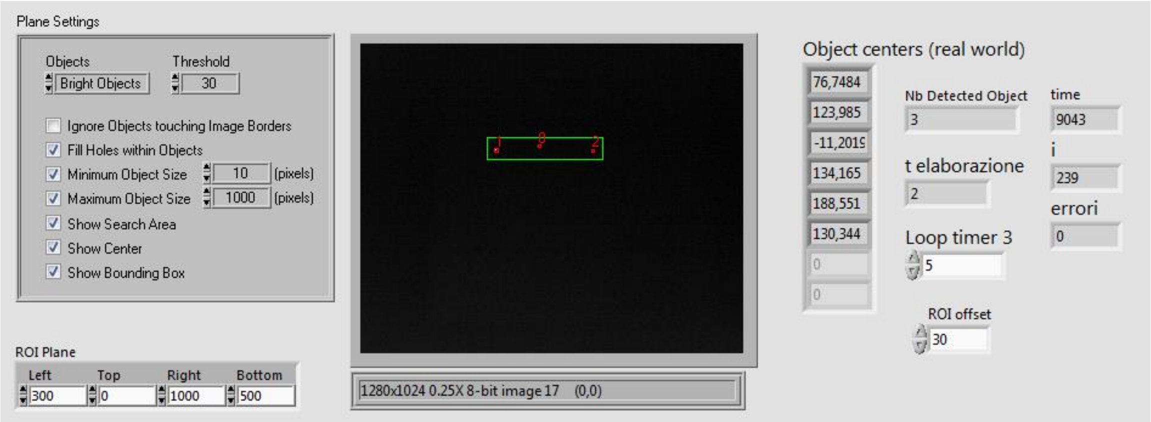
- Complete system:
  - (x1) System {Lasers + Rangefinder + Camera}
    - Measures 4 degrees of freedom (3 translations + Roll rotation)
  - (x2) System {Camera + Line}
    - Measures Yaw and Pitch rotations



By-bridge application

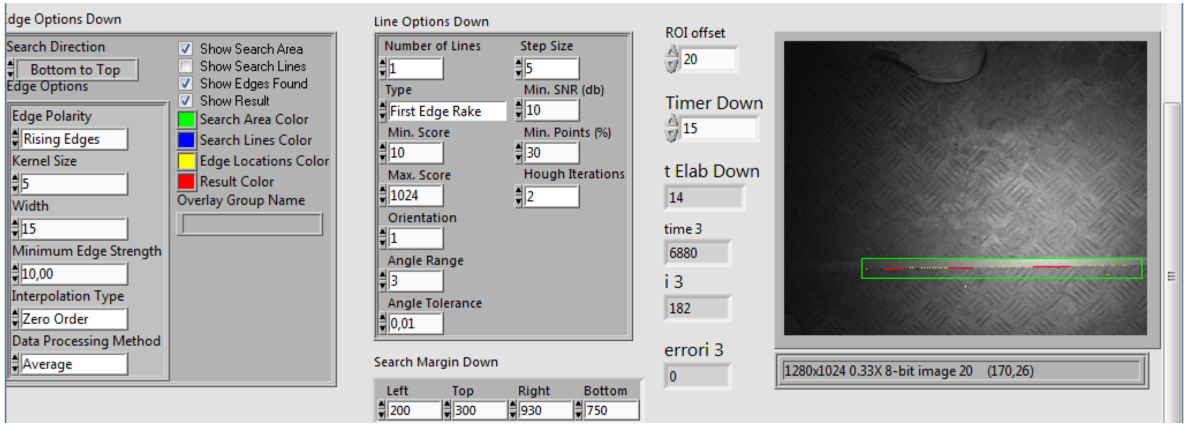
- {Lasers + Rangefinder + Camera}
  - 3 lasers one being a rangefinder placed on a mechanical support
  - Projection of laser beams on a vehicle planar surface, captured an IDS camera (*uEye UI-5240CP-M-GC, 1280x1024, 25Hz*)
  - Image acquisition through a Labview software





By-bridge application

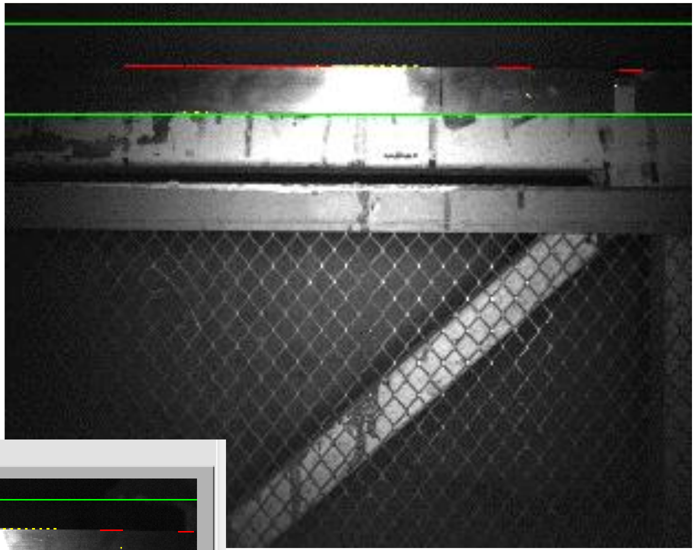
- {Yaw Camera + Line}
  - Decametre as reference line for the measurement of yaw angle
  - Camera with IR lightning system and filters
  - Image acquisition through a Labview software

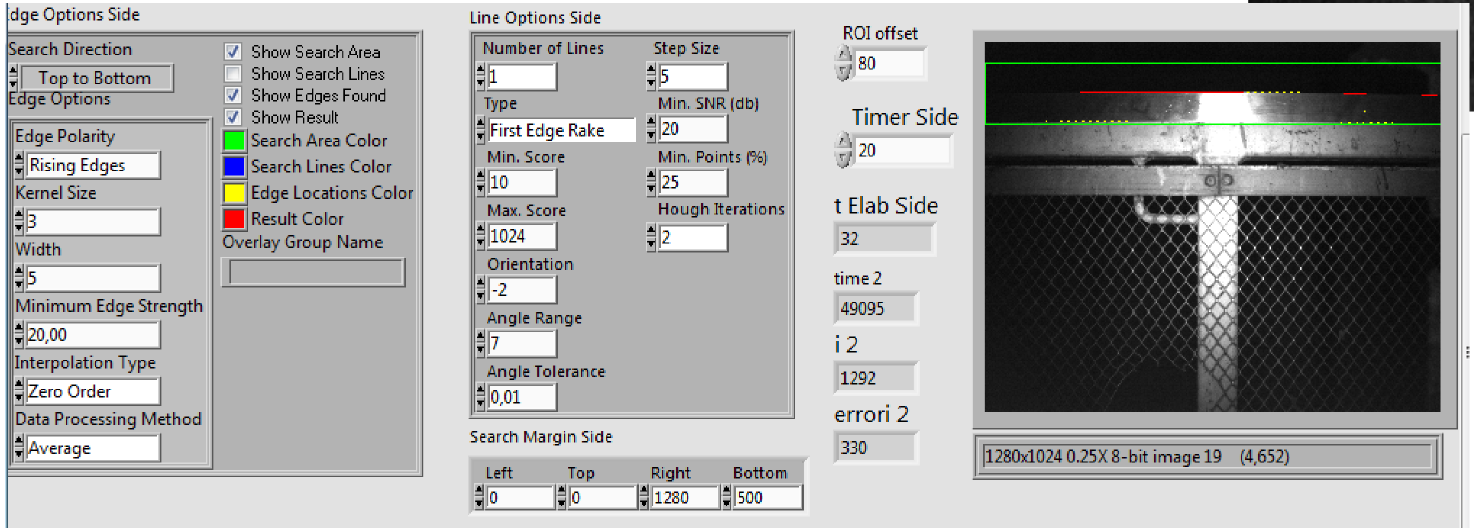


SUMMARY

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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By-bridge application

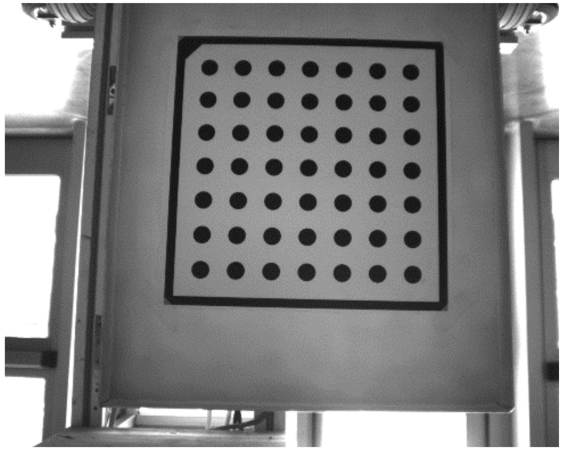
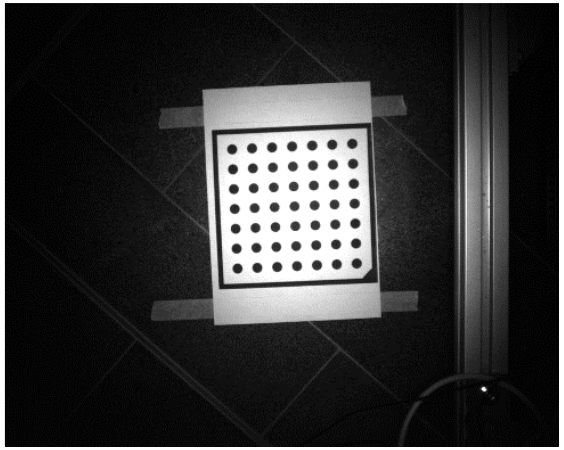
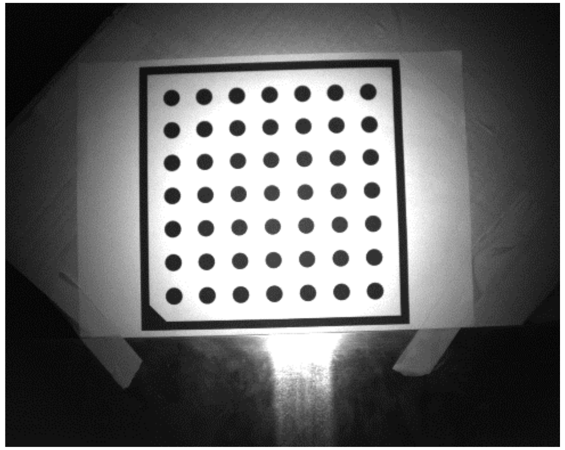
- Complete Solution
  - Mathematical model

$$
\begin{aligned}
X_c &= \delta, \\
Y_c &= -Y_2, \\
Z_c &= -Z_2, \\
Roll &= \arctan\left(\frac{Z_1 - Z_3}{Y_1 - Y_3}\right) \\
Pitch &= \alpha \\
Yaw &= \beta
\end{aligned}
$$

- $X_c, Y_c, Z_c, Roll, Pitch, Yaw$ 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 sidewards 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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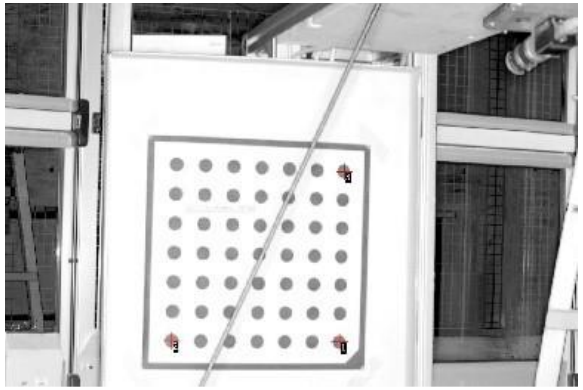
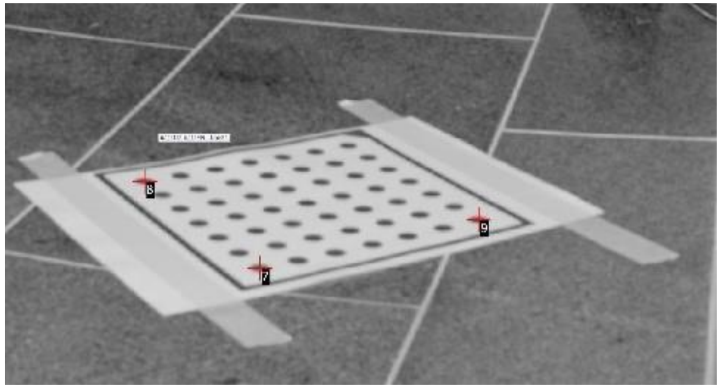
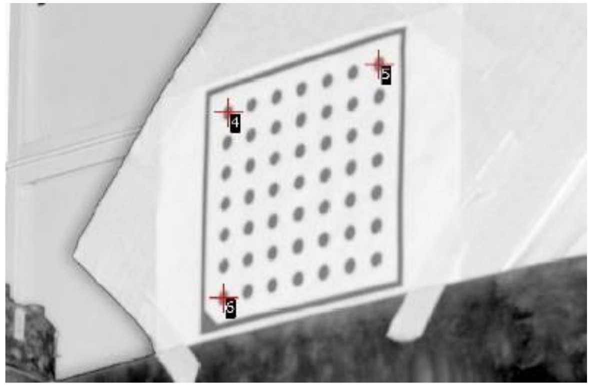
By-bridge application

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







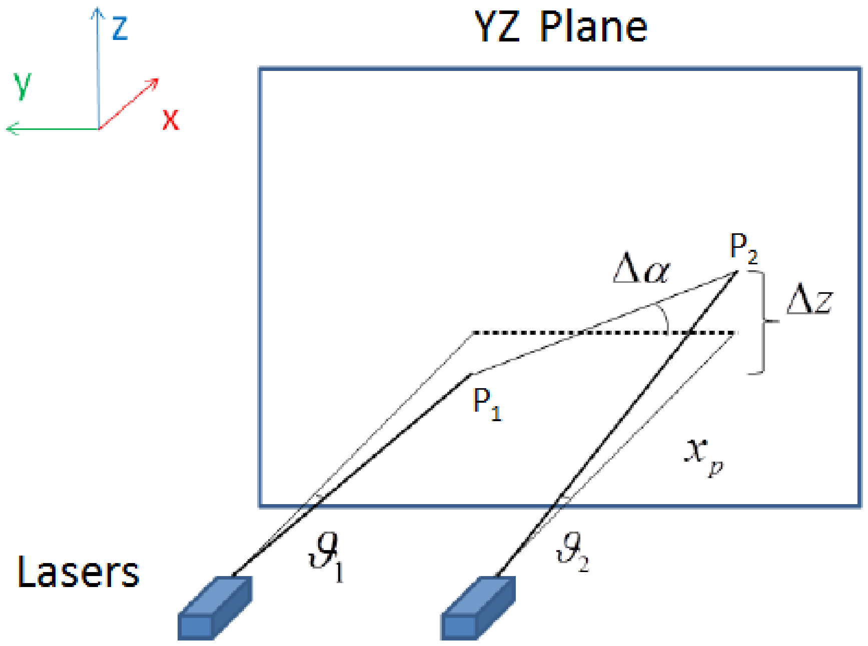
- ➢ Registration of cameras reference system into global reference system
- ➢ Transformation matrix for different reference systems

SUMMARY

By-bridge application

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

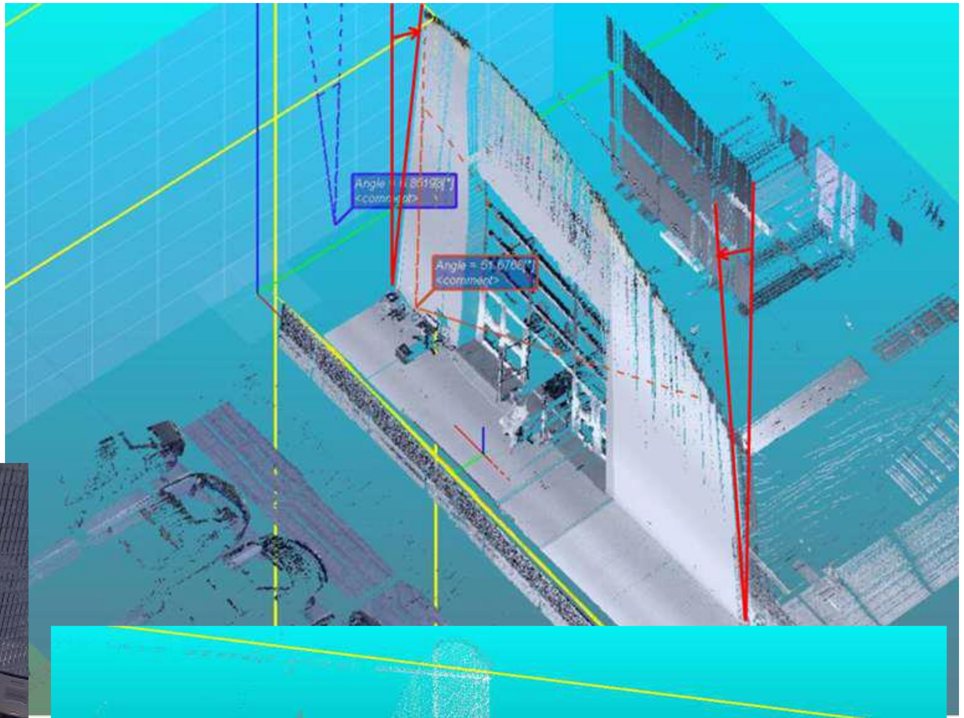
$$\Delta\alpha = -arctan\left(\frac{z_{P_2} - z_{P_1}}{y_{P_2} - y_{P_1}}\right) = -arctan\left(\frac{x_p \tan\theta_2 - x_p \tan\theta_1}{y_{P_2} - y_{P_1}}\right) \simeq -\frac{x_p(\tan\theta_2 - \tan\theta_1)}{distance(P_1 - P_2)}$$

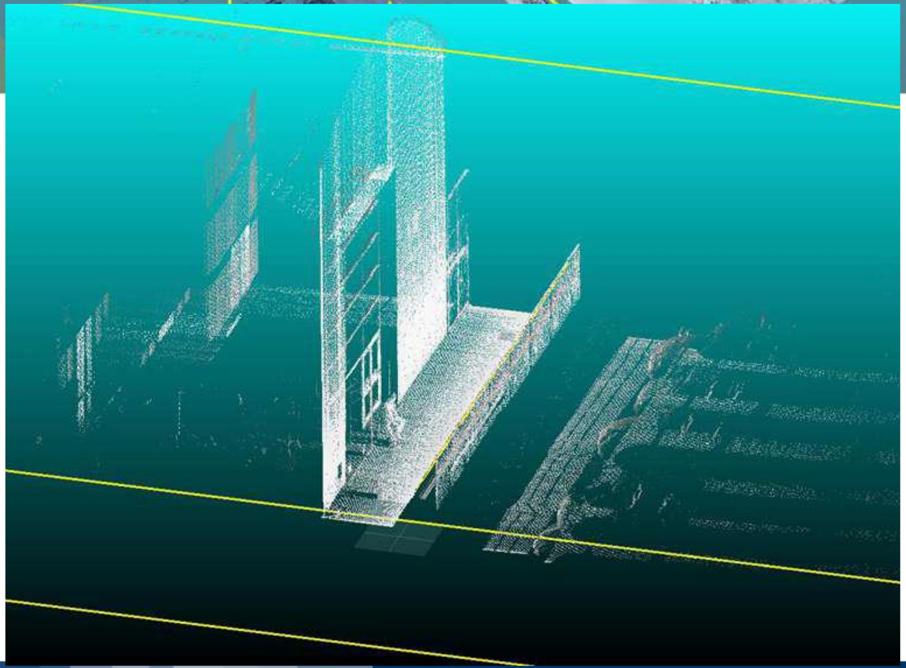


- ➢ Residual roll angle linear with the progression distance
- ➢ Possibility to identify it if not corrected

By-bridge application

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





Metrologic analysis

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

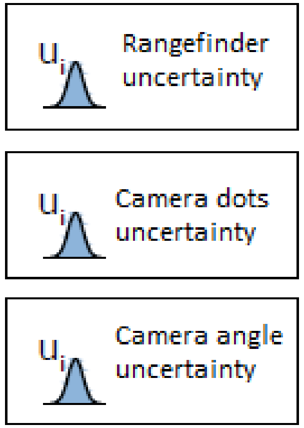
Instrument	Theoretical Uncertainty	Experimental Uncertainty
Rangefinder	1,00mm	0,29mm
Camera blob	0,50mm	0,06mm
Camera angle	0,01°	0,04°

SUMMARY

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

Metrologic analysis

- Monte Carlo model



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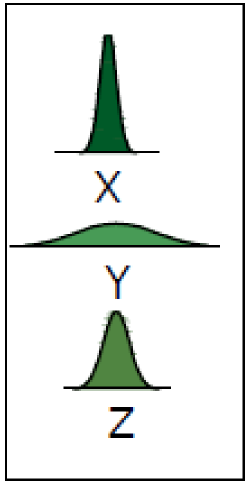

Component	Translation Uncertainty	Rotation Uncertainty
X	0,29mm	0,03°
Y	0,06mm	0,04°
Z	0,06mm	0,04°

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

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THANK YOU FOR THE ATTENTION