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

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

- **Position estimation**

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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
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
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
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
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
By-bridge application

- Complete Solution

  - Mathematical model

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

- \(X_c, Y_c, Z_c, Roll, Pitch, Yaw\) the components of position and orientation of the carrier
- \(\delta\) 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
- \(\alpha, \beta\) 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)
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
By-bridge application

• Calibration
  – Camera internal parameters calibration
  – Camera external parameters calibration
  – Misalignment of laser beams

\[ \Delta \alpha = -\arctan \left( \frac{z_{P_2} - z_{P_1}}{y_{P_2} - y_{P_1}} \right) \]

\[ = -\arctan \left( \frac{x_p \tan \theta_2 - x_p \tan \theta_1}{y_{P_2} - y_{P_1}} \right) \]

\[ \approx -\frac{x_p (\tan \theta_2 - \tan \theta_1)}{\text{distance}(P_1 - P_2)} \]

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

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