Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo

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Project Goals:

- Image processing techniques
- Time/cost reduction
- Fields of application:
  - Assembly process
Required Tasks:
• Fast and accurate measurements
• Handle ‘aeronautic surfaces’
• Applicable to ‘aeronautic volumes’
• Integration into automated processes (robot, …)

Mobile Surface Inspection
[Brandner et al., Sensor+Test 2007]
Structure of the Talk

• Introduction
• Active Stereo
• Sensor Geometry
• Sensor Calibration
• Experiments
• Conclusions
Introduction

• Surface Inspection
  – Geometric Parameters
    • Position, diameter, distance, thickness, …
  – Surface Quality
    • Roughness, colour, …
  – Areas of Application: Assembly, QC

• ‘Aeronautic Specialities’
  – Surface Properties
    • Materials, coatings, albedo, …
  – Working Volumes
  – Uncertainty Bounds
Inspection Systems

- Manual Gauges
  - Inspection time, repeatability, uncertainty

- Coordinate Measurement Machines
  - Working volume
  - Required infrastructure

- Optical Systems
  - Interferometric systems
    - Large volume
    - Laser radar / laser tracker

- ‘Indoor GPS’
  - Large volume
  - Optical/RF
Vision-Based Inspection

- **Non-Contacting**
  - Sensitive/non-rigid surfaces
- **Cameras as Sensors**
  - CCD/CMOS technology
  - 2D sensors
- **Difficulties/Limitations**
  - Surface properties
  - Line of sight condition
  - Geometric complexity / real-time processing
  - Environment: ambient light, reflections
- **Structured Light**
  - Triangulation sensors
  - Coherent/non-coherent illumination
  - Static/dynamic patterns
Active Stereo Setup

- **Stereo Setups (Greek: solid)**
  - Traditional: combination of cameras
  - Reconstruction of geometric entities in 3D
    - Calibrated cameras (Intrinsics+Extrinsics)
  - Structured light to aid correspondence search
    - but usually encoded (spatial, temporal)

- **Active Stereo Setups**
  - Combination of at least one camera and N>1 projectors
  - Reconstruction of geometric entities in 3D
  - Structured light to perform
    - Projector
Active Stereo Setup (II)

- Stereo Reconstruction
  - Intersection of rays
- Required Calibration
  - Camera intrinsics/extrinsics
  - Projector intrinsics/extrinsics
Active Stereo (III)

- **Projector Choice**
  - Size/weight considerations
  - Calibration strategy
  - Energy consumption, illumination intensity
  - Harsh environments (shop floor)

- **Laser Sources**

  → No straight lines!
  → Calibration of the Projector?
Laser Fan Model

- **Geometric Model**
  - Laser centre
  - Approximation of the laser beam for each plane

- **Assumptions**
  - Single centre
  - Virtual plane
  - Polynomial distortion

\[ s_i(t) = (p_{i,x}(t), p_{i,y}(t))^T \]

\[ S_i(t) = c_L + \alpha(t, a_2 t^2 + a_1, 1)^T \]
Sensor Geometry

- Application: close range measurements
  - Two cameras
  - Two projectors
- 4 Active Stereo Setups
- 1 ‘Passive’ Stereo Setup
Sensor Calibration

• Camera Calibration
  – Intrinsics + Extrinsics (camera stereo pair)

• Calibration Steps
  – Planar calibration grid (ARToolKit Targets)
  – Multiple (known) views (CMM)
  – Non-linear optimisation
Sensor Calibration (II)

- **Laser Calibration**
  - Intrinsics + Extrinsic

- **Calibration Steps**
  - Multiple views, planar target
  - Line intersections are projections of laser centre
  - Virtual plane → “fan of lines” model

![Diagram showing laser calibration steps](image)
Experiments

• Sensor Prototype
  – 2 CCD cameras 1280x960, 30fps
  – 2 Lasers 635nm, 0-30mW, parallel lines
  – Control unit (power, sync)

• Prior Knowledge
  – CAD model
  – Hand-eye calibration
  – Field of view

• Measurement Process
  – Pre-calculated robot trajectory
  – On-line/real-time estimation
Experiments (II)

- **Test Target**
  - Precisely known geometry

- **Measurements**
  - Angle between adjacent planes
  - Distance between parallel planes
    - “Step” measurement
    - Wall thickness
"Step" - Parallel Planes

Measurement Result (Exp. Uncertainty, k=3)

Step: 0.024 +/- 0.016 mm

Angle: 0.03 +/- 0.06 deg
Angle between Planes

Measurement Result (Exp. Uncertainty, k=3)

Angle: 91.29 +/- 0.18 deg
Conclusions

- **Active stereo** triangulation sensor for vision-based surface inspection for aeronautic applications
- Application of robust **laser projectors**
- Geometric “**fan of lines**” model of the laser projector
- **Calibration strategy** based on simple targets
- Measurement results using reference part
- Future work
  - Extension to more complex projector patterns
  - Extension of the range of target geometries
  - Improved calibration strategy
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