Comparison of Cross Correlation and Optical Flow Methods for Processing Retroreflective and Natural Background BOS data

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Introduction

• Motivation

• Processing methods
  • Normalized cross-correlation
  • Optical flow

• Data sets
  • **Wind tunnel data**: retroreflective BOS NASA plume/shock interaction
  • **Flight data**: natural background AirBOS T-38

• Schlieren image results

• Conclusions
Motivation

• Cakebos/BOSCO early initial oflow?
BOS Processing Methods

• Displacement calculation between wind-on and reference
• Normalized cross-correlation
  • Well established technique in BOS, PIV
  • “Window matching” displacement
  • Subpixel localization via correlation peak finding
• Optical flow
  • Technique from computer vision community to detect motion, segmentation, and identification in video
  • Directly solve for the “brightness velocities”
• Registration, map to grayscale, and sequence averaging
Optical Flow I

- Horn Schunck: global regularization method
  - Dense solution method
  - Intuitive formulation
- Brightness constancy: \( I_x u + I_y v = -I_t, \)
- Smoothness constraint: \( \| \nabla u \|^2 + \| \nabla v \|^2 \)
- Minimize the functional:

\[
\int \left( (I_x u + I_y v + I_t)^2 + \alpha^2 (\| \nabla u \|^2 + \| \nabla v \|^2) \right) \, dx \, dy
\]
Optical Flow II

• Euler-Lagrange yields simple iterative method
  • Jacobi vs. Gauss-Seidel
  • Converge to 10E-6

\[
\begin{align*}
  u &= \bar{u} - I_x \frac{I_x \bar{u} + I_y \bar{v} + I_t}{\alpha^2 + I_x^2 + I_y^2} \\
  v &= \bar{v} - I_y \frac{I_x \bar{u} + I_y \bar{v} + I_t}{\alpha^2 + I_x^2 + I_y^2}
\end{align*}
\]

• Numerical considerations
  • \( u, \bar{u} \) separated via 9-pt Laplacian stencil (window)
  • 8\textsuperscript{th} order spatial derivatives
  • Image spatial derivatives from 2 frames
• **Shock Interaction studies with nominal Mach 2 jet exit**
  - Freestream Mach 1.6 and 2
  - Multiple shock generating geometries
• **RBOS speckle pattern below pressure rail**

**Diamond airfoil**

**Aft-swept deck**
RBOS Raw data
• Desert used as natural background speckle pattern
• Observer plane photographs target from above
• Pass 1 – 5000ft separation, Pass 2 – 2000ft separation
Use of multiple reference images

- Multiple AirBOS reference images available
  - Reduce freestream noise, Moiré patterns
  - Potentially clarify additional structure
- Standard deviation of freestream ROI
  - Significant reduction after 5 images
  - Tradeoff between cost and noise
- Difficult to used in RBOS images
  - Backgrounds must be distinct
  - Out of plane model rotation
Shock-plume interaction I: double-wedge airfoil
Shock-plume interaction II: aft-swept deck
AirBOS pass 1: single instance
AirBOS pass 1: full sequence average
AirBOS pass 2: single instance
AirBOS pass 2: full sequence average
Conclusions

• Optical Flow
  • Improved flow feature detail over cross-correlation, for both flight and wind tunnel data
  • Regularization method appears robust to data sets
  • Easily parallelized

• Use of multiple reference images
  • Decrease solution noise
  • Significant improvement with five distinct reference images

• Provided most detailed AirBOS schlieren images to date

• First use of optical flow for production test at NASA Ames Research Center

• Caveats
  • More sensitive to hard shadows than cross-correlation
  • Additional lighting considerations for wind tunnel applications
  • “Brightness constancy” violations: no solution in shadowed region
Questions?