The Common Adjustment of GPS and Photogrammetric Measurements

Cameron Ellum and Prof. Naser El-Shemy
19 April 2005

mobile multi-sensor systems research group

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Background:
GPS controlled photogrammetry
- First envisioned in the mid-eighties
- Heavily researched throughout the mid-to-late eighties
- Commercially operational since the early nineties

Background:
Datum definition
- Traditional photogrammetry
- GPS controlled Photogrammetry

Background:
Including GPS data in the adjustment
- GPS data is included in the photogrammetric adjustment as processed positions, using parameter observation equations:
  \[ r_{GPS}^2 = r_{GPS}^2 + r_{image}^2 + \left( b_{GPS}^2 + d_{GPS}^2 \right) \]
- Shift (b) and drift (d) terms are intended to account for incorrect ambiguity resolution; may also account for datum translation

Background:
GPS controlled photogrammetry
- Advantages:
  - Allows for a reduced number of ground control points – potentially none, if ties to an existing datum are not required
  - Reduces cost and turn-around time
  - Can increase accuracy, and resulting networks may have more homogenous accuracy
Background:

Limitations of current technique:
- The sharing of information between the photogrammetric and navigation processors is strictly one-way. The navigation processing stream does not benefit from the photogrammetric data.
- Current integration strategies have always presupposed differential GPS. The possibilities of undifferenced GPS have not been examined.
- The traditional "shift-and-drift" approach for including GPS data assumes that incorrect ambiguity resolution manifests itself as a linear error. In reality, this is not the case.

Research Objectives:

Combined adjustment:
- Combine the raw GPS measurements and photogrammetric measurements in a single adjustment
- Enables GPS data to be used even when less than four satellites are visible
- Simplified, single-step processing
- Ultimate goal: utilise photogrammetric network to aid GPS ambiguity resolution
- Hopefully, will improve accuracy and, more importantly, reliability

Implementation:

Combined adjustment overview:
- Undifferenced or double-difference ranges
- Code ranges or carrier phase ranges

Implementation:

GPS Observation Equations:
- Undifferenced code range observation equation:
  \[ p = |r_{GPS}| + c\Delta \Delta \]
  - Receiver clock offsets are added to the adjustment as additional parameters
- Double-difference code range observation equation:
  \[ \Delta p = (|r_{GPS}| - |r_{GPS}|) - (|r_{GPS}| - |r_{GPS}|) \]
  - No additional parameters
- Double-difference carrier-phase observation equation:
  \[ \Delta \Delta = (|r_{GPS}| - |r_{GPS}|) - (|r_{GPS}| - |r_{GPS}|) + \Delta \Delta \]
  - Double-difference amplitudes are added to the adjustment as additional parameters

Implementation:

Combined adjustment framework
Testing: Data set description

- Aerial photogrammetric block
  - 42 images, 7 flight lines
  - 4096 × 4069 pixels
  - Field of view ≈ 37°
  - Flying height ≈ 900m
  - Side lap ≈ 30%
  - End lap ≈ 60%
  - 53 control/check points

Testing: Nominal scenarios

- Ground controlled network
  - Mean: 0.20 m, -0.04 m
  - Std. dev.: 0.13 m, 0.35 m

- Double-difference carrier phase exposure station positions
  - Noise level of ≈15 cm horizontal, ≈35 cm vertical

Testing: Nominal scenarios

- Noise level of ≈15 cm horizontal, ≈35 cm vertical

Testing: Smoothed, undifferenced code ranges

- Combined adjustment
  - Horiz.: mean 4.11 m, std. dev. 0.40 m
  - Vert.: mean -53.65 m, std. dev. 1.34 m

- Position observations
  - Horiz.: mean 4.11 m, std. dev. 0.78 m
  - Vert.: mean -53.18 m, std. dev. 1.42 m

  - Same data, slightly improved results

Testing: Smoothed, double-difference code-ranges

- Position observations
  - Horiz.: mean 0.36 m, std. dev. 0.17 m
  - Vert.: mean -40.78 m, std. dev. 0.38 m

- Combined adjustment
  - Horiz.: mean 0.31 m, std. dev. 0.15 m
  - Vert.: mean -40.73 m, std. dev. 0.36 m

  - Virtually the same
  - Close to best results possible from the network

Conclusions

- Optimist
  - With undifferenced observations, accuracy improves

- Pessimist
  - With double-differences, no change

- Realist
  - Inconclusive, more testing required

  - Results are sensitive to relative weights on image measurements and GPS ranges

Outlook:

- Combined adjustment

  - Ultimate goals:
    - Improve reliability
    - GPS ambiguity resolution

  - A negligible or non-existent accuracy increase is okay, if the above two goals can be met
Outlook: Information sharing between processors

- Two-way sharing of information between a photogrammetric adjustment and a kinematic GPS processor
  - Kalman-filter-based kinematic GPS processor will provide positions to the photogrammetric adjustment
  - Photogrammetric adjustment will, in turn, provide position updates (and covariance) to the Kalman filter

Outlook: Information sharing between processors

- Navigation filter is aided by the photogrammetric adjustment
  - GPS Kalman Filter
  - GPS measurements
  - Image Measurements
  - bundle adjustment
  - Kinematic model is retained
  - Adjustment operates sequentially

Acknowledgements

- Test data provided by Applanix Corporation

- Financial support from:
  - Killam Trusts
  - NSERC

Implementation: Combined adjustment software

- Some statistics:
  - Lines of code > 83,000
  - Existing GPS/INS processor < 33,000
- Goal: maintainability and extensibility
- Adjustment program has been divided into individual adjustment modules connected in a hierarchical fashion
  - Photogrammetric adjustment
  - GPS adjustment
  - Terrestrial network adjustment

Implementation: Combined adjustment framework

- Each sub-adjustment makes a few generic routines available to the parent adjustment
- The parent adjustment then only has to call the routines in the appropriate order
- The adjustments inherit a generic behaviour from a common base, or, when necessary, implement their own custom behaviour.
- Program is more maintainable:
  - Individual adjustments can be tested and debugged in isolation.
  - Inheritance and polymorphism results in less code

Implementation: Atmospheric error mitigation

- Troposphere
  - UN83 zenith delay model
  - Neil mapping function
- Ionosphere
  - Not mitigated because of resulting increase in noise.
  - Orbit and clock
  - Not mitigated because it primarily introduces a bias, and because it differences out in the double-difference observations
The GPS processor used in the combined adjustment has a number of idiosyncrasies:

- The exposure events likely don’t coincide with GPS measurements, so the processor can interpolate GPS measurements between actual measurement epochs.
- None of the GPS stations need to have fixed coordinates. The datum for the entire network can be controlled by information coming from another child adjustment.