Mobile Stereo-Mapper: A Portable Kit for Unmanned Vehicles

J. Li-Chee-Ming[1], C. Armenakis[1], R. Lee[2]

[1]GEOMATICS ENGINEERING, [2]SPACE ENGINEERING
DEPARTMENT OF EARTH AND SPACE SCIENCE AND ENGINEERING
SCHOOL OF ENGINEERING

Zurich, September 14-16, 2011

YORK UNIVERSITÉ UNIVERSITY redefine THE POSSIBLE.

UAV-g

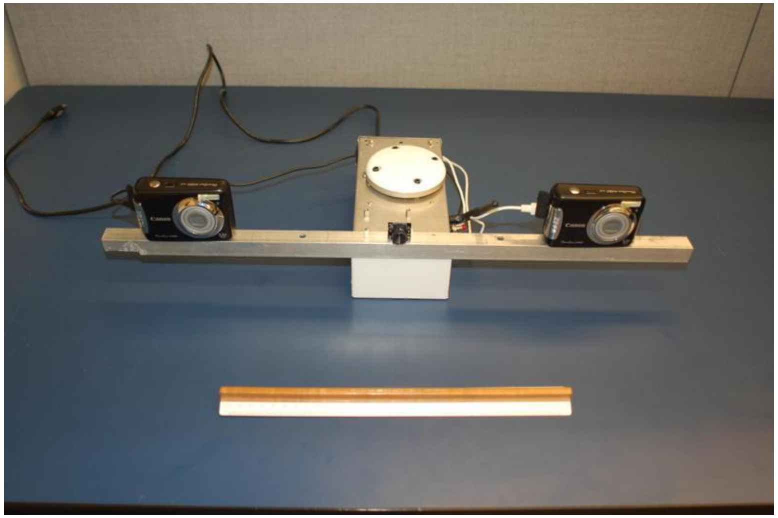
GeoICT

Motivation

- **Tracking Moving Objects**
  - People, vehicles, etc.
  - Unknown/Dangerous environments (no GCPs)
  - Provide object positions in near-real time
  - RMS positioning accuracy of 1/100
  - i.e. Emergency response to time-critical events
- **Data collection: Safe, fast, cost-effective**
  - Unmanned platforms (UAV/UGV)
  - Direct georeferencing

UAV

Mars Rover (UGV)



Mobile Stereo Mapping System

Outline of Presentation

1. Mobile Stereo Mapping System: Description
2. System Components
   - GPS, IMU, magnetometer, camera
3. Sensor Performance
4. Direct Georeferencing
   - System Calibration: Camera, leverarm, and boresight
5. First Field Test
6. Direct Georeferencing Accuracy Assessment
7. Concluding Remarks

Mobile Stereo Mapping System: Description

Acquire 3D data from UVS (UAV,UGV) platforms

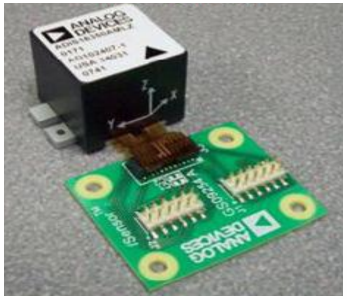
- Direct georeferencing
- Stereo imagery
- Portable
- Remote operation
- Low cost (MEMS technology)
- Light weight (about 1 kg)

MSMS undergoing system calibration

System Components

Novatel OEMStar GPS (L1 carrier phase)

ADIS16364 IMU (MEMS)



LinuxStamp 2 Processor

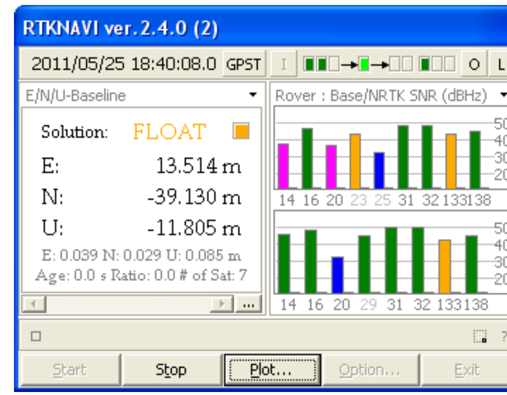
HMC5843 Magnetometer

Canon A480 Camera

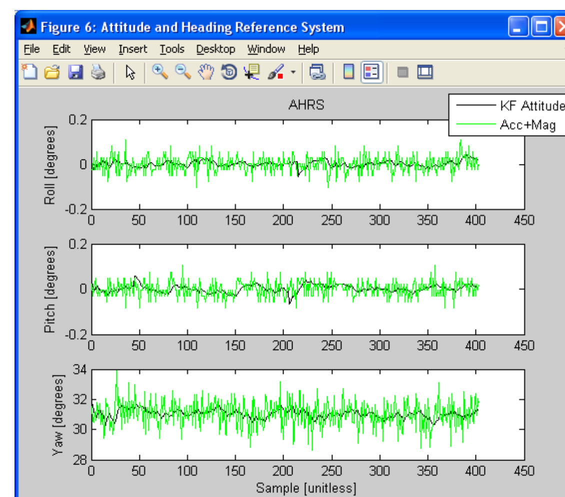
Xbee RF Module

Sensor Performance

	±σ	freq
Positioning		
Single frequency RTK-GPS	0.2m	10Hz
Single frequency static GPS	0.01m	10Hz
Atttitude and Heading		
IMU roll and pitch	0.12°	100Hz
IMU/magnetometer heading	0.26°	10Hz
Sensor Synchronization		
GPS time-tag and camera sync	0.1ms	10Hz



RTKlib positioning



Paparazzi Attitude and Heading

Left Image

Right Image

Camera Sync (CHDK)

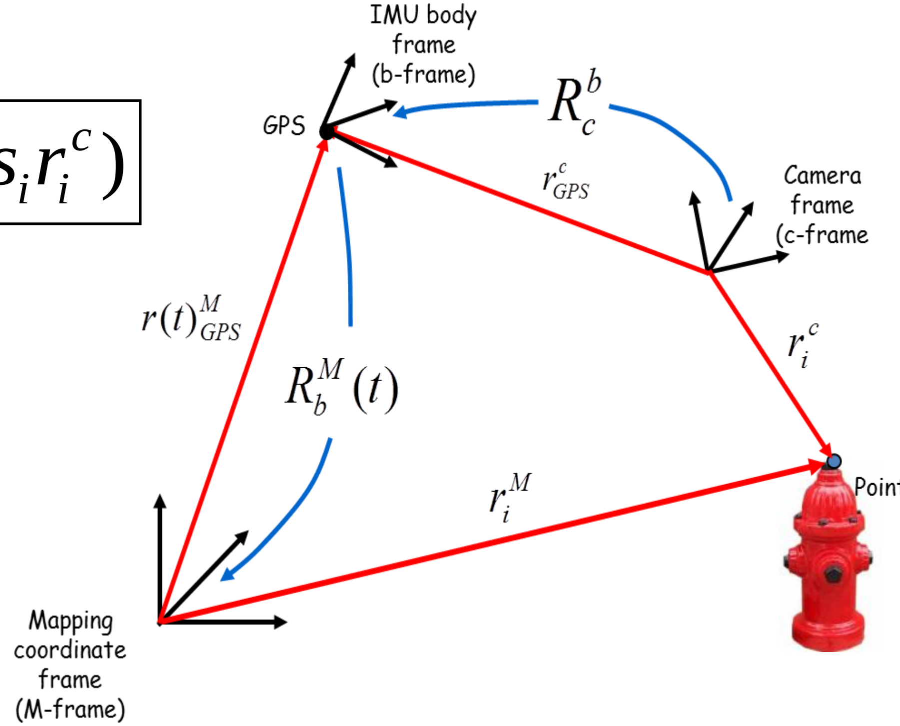
Direct Georeferencing

- Model transforms the position of the point of interest r_i^c, measured in the camera coordinate system, to the position vector in the mapping frame r_i^M.
- Requires camera, leverarm, and boresight calibrations.

$$r_i^M = r(t)_{GPS}^M - R_b^M(t) R_c^b (r_{GPS}^c - s_i r_i^c)$$

boresight

leverarm



Field Test #1

Initial calibration and testing is performed in a static position.

- Static GPS (L1) for 15 minutes (<100m baseline)
- IMU/magnetometer for 15 minutes
- Capture stereo-pair images
- Control points from a geo-referenced Lidar point cloud

Static MSMS

Petrie stereo-pair

Geo-referenced Lidar point cloud

Field Test #1

Process two different datasets to check consistency:

- Cameras' relative position and orientation
- Leverarms and boresights

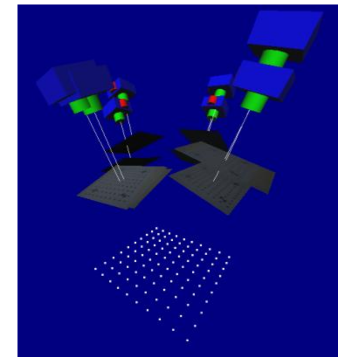
Dataset 1: Petrie Building

Dataset 2: William Small

Camera Calibration Results

Field vs Laboratory Calibration

- Focal length and principal point are consistent.
- Lab calibration reliably solves lens distortions.
- In field calibrations, lens distortions were not stable.



Petrie Camera Calibration

	Field Calibration		Laboratory Calibration			
IO parameters	**Left Camera**	**Right Camera**	**Left Camera**	**Right Camera**	σ_{Left} **(±)**	σ_{Right} **(±)**
f [mm]	6.8742	6.8339	6.848	6.8125	**0.001**	**0.008**
x_P [mm]	3.0607	3.0607	3.1181	3.1277	**0.005**	**0.005**
y_P [mm]	2.2987	2.2987	2.3233	2.3804	**0.006**	**0.006**
k1	0	0	1.66e-3	1.66e-3	**2.7e-4**	**2.7e-4**
k2	0	0	3.19e-5	0	**2.1e-5**	**2.1e-5**
p1	0	0	-3.26e-4	-3.60e-4	**3.5e-5**	**3.5e-5**

Bundle Adjustment Results

Evaluate camera position:

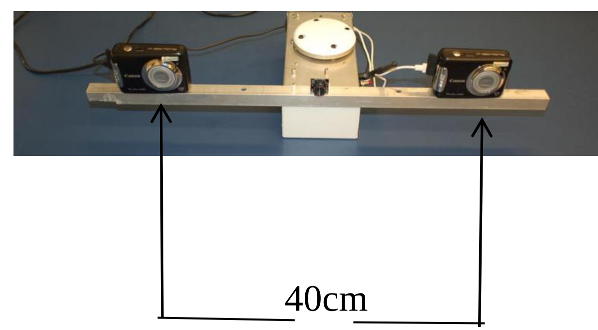
•Camera separation was surveyed to be 40cm.

•The large error from Petrie dataset.

•The error is much smaller for William Small, suggesting bundle adjustment can be trusted.

	Petrie		**Will Small**	
m-frame	**Left Cam**	**Right Cam**	**Left Cam**	**Right Cam**
N [m]	0.0287	0.2087	-0.2581	0.0502
E [m]	-0.1971	0.1358	0.0398	-0.2217
D [m]	-1.5225	-1.5244	-1.5115	-1.5192
Base [m]	**0.375**		**0.402**	

Camera positions from bundle adjustment



Bundle Adjustment Results

Evaluate camera orientation:

- Cannot physically measure camera’s orientation
- Camera relative orientation should be consistent among data sets

	Rel. Orientation	
c-frame	**Petrie**	**Will Small**
Δω [°]	**-1.194**	**-0.701**
Δφ [°]	**-1.181**	**-1.060**
Δκ [°]	**-1.262**	**0.247**

- Relative orientations are not consistent
- Future work: Determine relative orientation via lab calibration

Leverarm Calibration Results

Evaluate leverarms:

- Difficult to physically measure lever arm components
- Lever arms (in the camera frame) should be consistent among datasets
- GPS solution is good, so majority of the error is from the X-coordinate of the camera's position
- Camera separation is along the x-axis in the camera frame
- Fixing the camera separation to 40cm should reduce this error.

c-frame	Petrie	Will Small
X [m]	-0.179	-0.258
Y [m]	-0.028	-0.025
Z [m]	-0.096	-0.116

Left leverarm

c-frame	Petrie	Will Small
X [m]	0.195	0.144
Y [m]	-0.030	-0.020
Z [m]	-0.143	-0.125

Right leverarm

Boresight Calibration Results

Evaluate boresights:

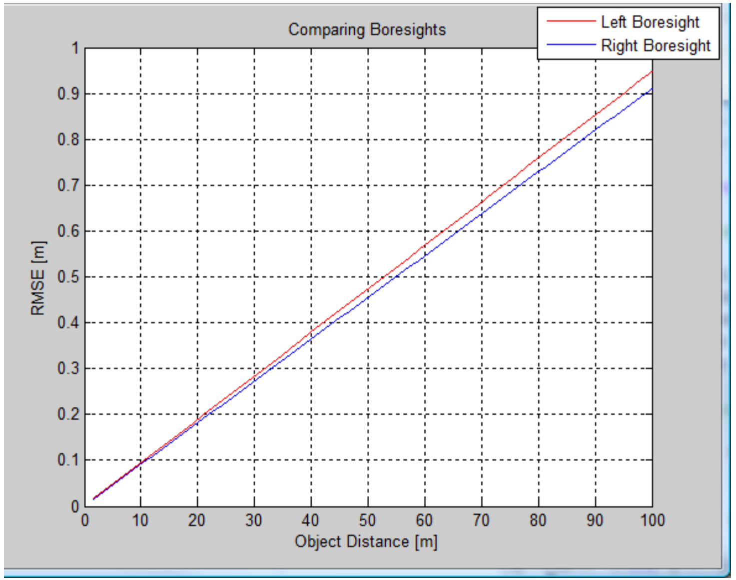
- Boresights should be consistent among dataset
- Difficult to extract euler angles from boresight rotation matrix
- Transform a vector from the camera frame to the body frame
- Compare vectors in the body frame
- 3D error is less than 1/100 of the object distance

$$r^b_{Petrie_{left}} = R^b_c(Petrie_{left}) * r^c$$

$$r^b_{WillSmall_{left}} = R^b_c(WillSmall_{left}) * r^c$$

$$Error_{Left} = RMSE(r^b_{Petrie_{left}} - r^b_{WillSmall_{left}})$$

$$Error_{Right} = RMSE(r^b_{Petrie_{left}} - r^b_{WillSmall_{left}})$$



Direct Georeferencing Accuracy Assessment

Evaluate accuracy of extracted 3D points:

- Directly georeference William Small stereo pair using parameters from Petrie calibration.

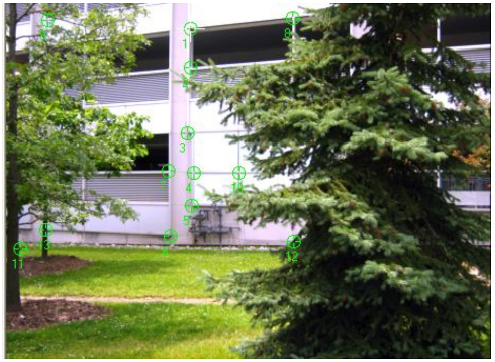
- Extract features from William Small stereo-pair via space intersection.

- Evaluate the posterior standard deviations

- To increase the accuracy of the Petrie bundle adjustment:
    1. Constrain the camera separation to 40cm, and/or
    2. Constrain the relative orientation of the cameras.
        - Problem: Do not have known relative orientation

Direct Georeferencing Accuracy Assessment

- Average posterior standard deviation among 11 points
- Constraining the camera base significantly increased the accuracy
- Object distance is approximately 20m, thus accuracy requirements (1/100) are not met.




Extracted features

1. No constraints		
$\sigma_{N\,(\pm\,m)}$	$\sigma_{E\,(\pm\,m)}$	$\sigma_{D\,(\pm\,m)}$
2.978	1.444	0.409

2. Constrain camera base		
$\sigma_{N\,(\pm\,m)}$	$\sigma_{E\,(\pm\,m)}$	$\sigma_{D\,(\pm\,m)}$
0.295	**0.275**	**0.068**

3. Constrain camera base and relative orientation		
$\sigma_{N\,(\pm\,m)}$	$\sigma_{E\,(\pm\,m)}$	$\sigma_{D\,(\pm\,m)}$
2.527	1.879	1.049

General Concluding Remarks

• A low-cost, light weight mobile stereo-mapping system has been developed to be used onboard unmanned mobile platforms (UAV, UGV)

• Position and orientation estimations are based on low cost MEMS sensors

• Camera, leverarm and boresight calibrations were performed to determine systematic errors and biases of the MEMS sensors and the sensors relative geometry.

• Accuracy assessment of the system was performed

Specific Concluding Remarks

•Camera (excluding lens distortion), leverarm and boresight were calibrated in the field.

•An increase in accuracy was found in constraining the camera base in the bundle adjustment.

•The relative orientation of the cameras could not be reliably constrained via field calibration.

•Future work:

- •Estimate the cameras’ relative orientation in laboratory calibration.
- •Use for frames to estimate calibration parameters in the least-squares BA
- •Perform kinematic testing.
- •Integrate the MSMS with a UVS (UAV, UGV).
- •Using directly-georeferenced imagery, generate orthoimages
- •Integrate these data in 3D model environments.

Thank you

External Support

•Ontario Graduate Scholarship (OGS)
•Natural Sciences and Engineering Research Council of Canada (NSERC)

redefine THE POSSIBLE.