Mobile Mapping Systems – The New Trend in Mapping and GIS applications

GEOMATICS ENGINEERING

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Topics

- Background on mobile mapping systems (MMS)
  - Motivation for their development
- Components of MMS
  - Kinematic Modeling
  - Direct Georefercning
- New developments

Mobile Mapping Systems (MMS)

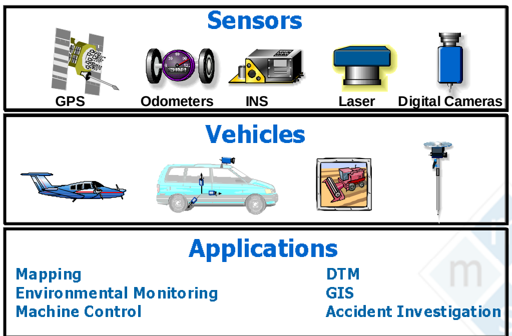
- The idea of mobile mapping, i.e. mapping from moving vehicles, has been around for at least as long as photogrammetry has been practiced.
- About 15 years ago, advances in satellite positioning and inertial technology made it possible to think about mobile mapping in a different way. Instead of using ground control as reference for orienting the images in space, trajectory and attitude of the imager platform could now be determined directly.
- Hand in hand with this development went the change from analog to digital imaging techniques – a change that has considerably accelerated over the past few years.

Characteristics of MMS

- They are typically used in kinematic mode.
- Integrates a set of sensors (Navigation and Digital Imaging) mounted on a common platform and synchronized to a common time bas
- Generally use direct georeferencing modules to transform the time-dependent measurement process into a sequence of georeferenced remotely sensed data which can be considered

> They can be immediately **deployed everywhere** on the globe **without the need** for identifying existing **ground control**.

Components of MMS



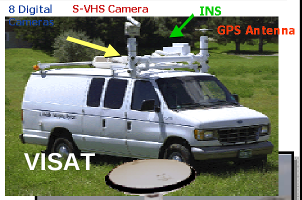
MMS – Important Dates

1980	Digital inertial technology (Strapdown INS) becomes available
1985	Differential GPS used for precise kinematic positioning
1988	Industrial analog video cameras
1993	Consumer digital cameras
1994	Commercial - land MMS
1998	High-resolution digital cameras and scanners
2000	Commercial - airborne MMS
2002	MEMS technology used in MMS prototypes

MMS – Early Land Systems

- Mostly Stereo-based systems
- B/W low resolution analog cameras
- GPS and dead-reckoning is the standard (VISAT – GPS/INS)
- Accuracy: 0.3 – 3 m
- Limited production and image interval
- Limited Speed of the vehicle

Land DMM – State of the Art



- Mostly panoramic view
- Color medium/high resolution digital camera
- GPS/INS integrated systems Accuracy: 0.1 – 1 m
- High production and small image interval

Airborne MMS – State of the Art

Full Frame Single Digital Camera	3-line Pushbroom Scanner	Multiple Full Frame Digital Camera

Applanix - Digital Sensor System (DSS)	Leica - Airborne Digital Sensor (ADS40)	ZI - Digital Mapping Camera (DMC)

Image Georeferencing

- It defines the transformation of a point in the image frame (i-frame) to the mapping frame (m-frame)
- Two piece of information are required
  - Camera's lens perspective centre in the m-frame
  - Rotation matrix between the i and m-frame

$$r_p^m = r_{pc}^m(t) + s R_i^m(t) r_p^i$$

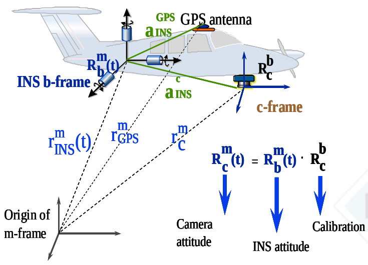
Photo Scale

Georeferencing

- Two basic approaches to determine the EO parameters
  - *Indirectly* by extracting from a block of images using Aerial Triangulation with sufficient number of well-distributed ground control points and measured tie points
  - *Directly* using suitable position and orientation sensor – also known as *Direct Georeferencing*
    - Global Positioning System (GPS)
    - Inertial Navigation System (INS)

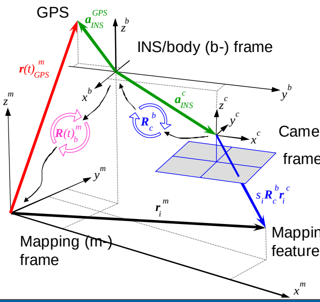
Georeferencing Model

$$r_i^m = r_{nav}^m(t) + R_b^m(t)[s_i \cdot R_c^b \cdot r^c + a_{INS}^c - a_{INS}^{GPS}]$$



Georeferencing – Coordinate Frames

$$r_i^m = r(t)^m_{GPS} + R(t)^m_b \left(s_i R^b_c r^c_i + a^c_{INS} - a^{GPS}_{INS} \right)$$

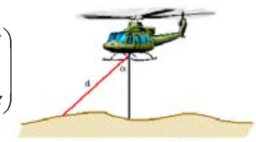


Georeferencing – Remote Sensor Measurements

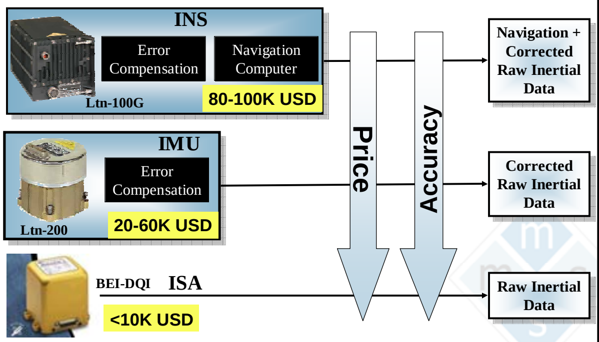
The Imaging Vector r^c = $\textit{Full Frame Scanners} = \begin{pmatrix} x - x_p \\ y - y_p \\ -f \end{pmatrix}$

$$\textit{Pushbroom Scanners} = \begin{pmatrix} 0 \\ y - y_p \\ -f \end{pmatrix}$$

LiDAR = $\begin{pmatrix} -d \cdot \sin\alpha \\ 0 \\ -d \cdot \cos\alpha \end{pmatrix}$

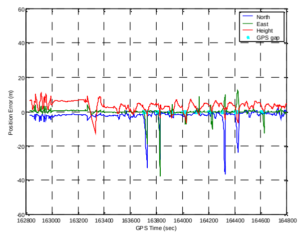


Inertial Technology



The Potential of MEMS

- University of Calgary MEMS-based IMU
- Developed by employing off-the-shelve MEMS sensors with an average cost 20$ per sensor



- Integrated with single point positioning GPS output (accurate to 10 -30 m) and processed through the INS Tool Box (Shin and El-Sheimy, 2003) Kalman filter software
- IMU stand-alone results during 30sec GPS outages are within 5-10 m (RMS)

Examples of MMS

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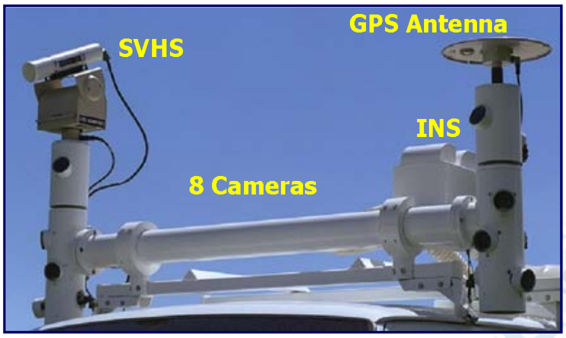
Land Based : The VISAT Van

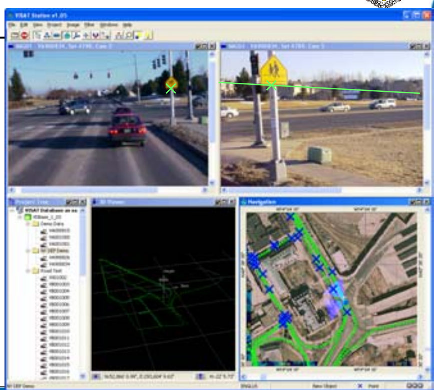
The VISAT Van



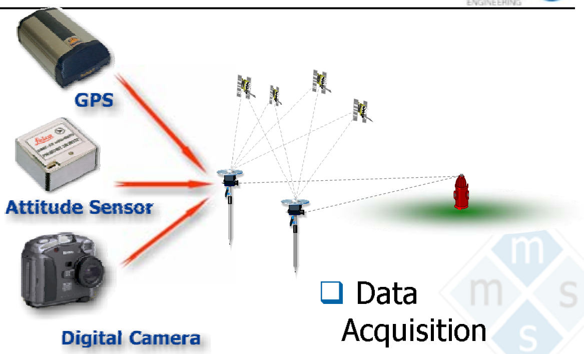
VISAT Van - Beta

Each camera enclosure is hermetically sealed and contain 3 cameras in front of windows of photogrammetric glasses to limit the distortion.

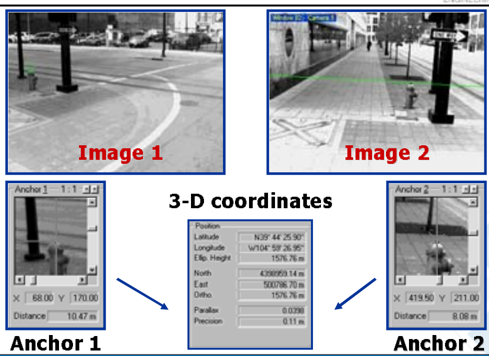
VISAT Station



Portable MMS System Overview



Portable MMS – System Overview

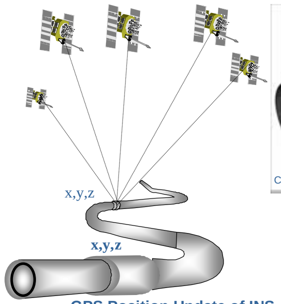


Mapping Accuracy

- Again, absolute accuracies similar to L1 RTK GPS
- Much of the error – particularly in height – is a bias
- Relative error is smaller

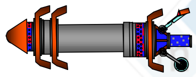
3 Images, 10-12 image point measurements	Easting	Northing	Height
RMSE (m)	0.07	0.10	0.04
Mean (m)	0.01	-0.08	-0.03
σ (m)	0.07	0.06	0.03
RMSE (m)	0.14	0.14	0.09
Mean (m)	0.10	0.05	-0.08
σ (m)	0.10	0.13	0.03

MMS in Pipelines Mapping - GeoPig Systems



GPS Position Update of INS

Courtesy of BJ Pipeline Inspection Services



Inertial Survey GEOPIG

GeoPig Systems

Courtesy of BJ Pipeline Inspection Services

Improving the Accuracy of GeoPig Systems

Section	Travel Time (min)	Length (km)
#1	21.7	4.004
#2	13.1	2.310
#3	24.3	4.336
#4	16.0	2.872
#5	21.7	3.866

Tactical Grade 1 deg/h	RMSE (m)
Case 1: INS+ Odometer + CUPT	*120*
Case 2: Case 1 + non-holonomic Constraints	*10*
Case 3: Case 2 + Backward Smoothing	*0.2 – 0.4*

Emerging Applications: Multi-sensors In Wildlife Management

The UofC - Collar

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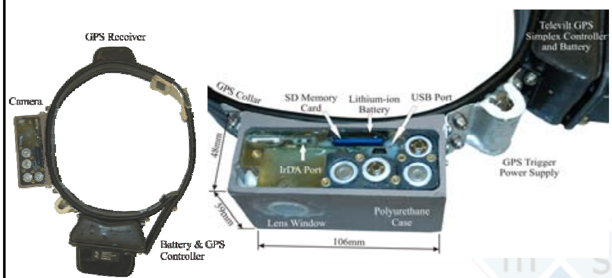
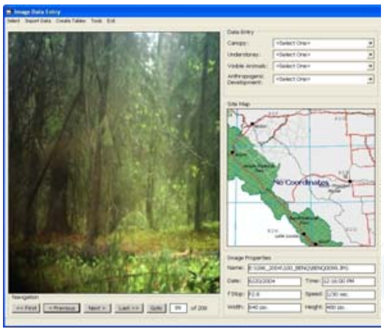
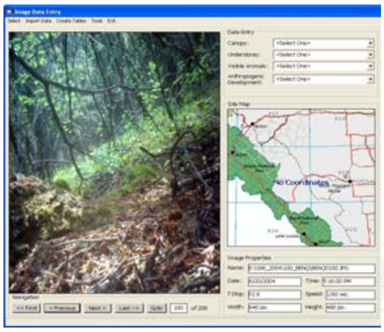


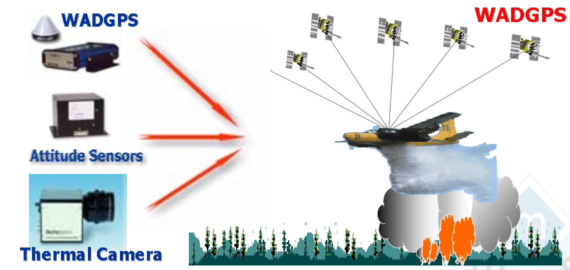
The UofC Collar



The UofC Collar

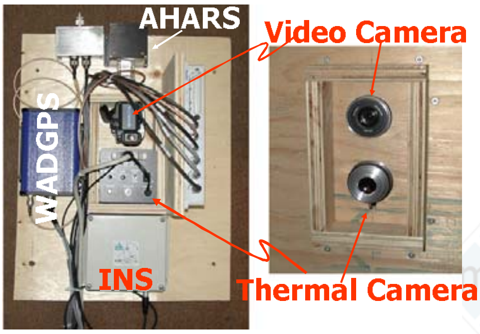


Emerging Applications: Real Time Identification and Location of Forest Fire Hotspots

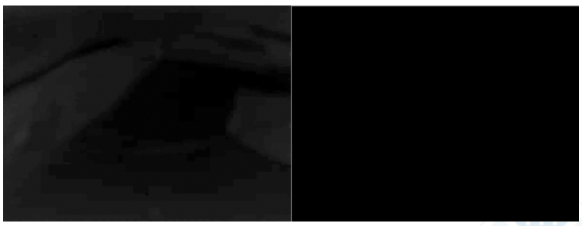


- Real-time reporting of the exact situation of fires
- Assisting the Forest Fire Information Centers in accurately assessing the fire
- Precisely directing water-bombers and fire-fighting crews

Hardware Components



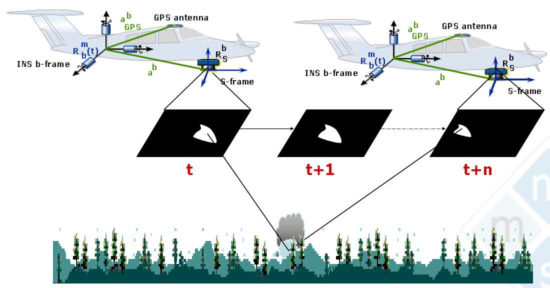
Real-time Detection of Forest Fires and Hotspots



Original Thermal Images Detected Fires and Hotspots

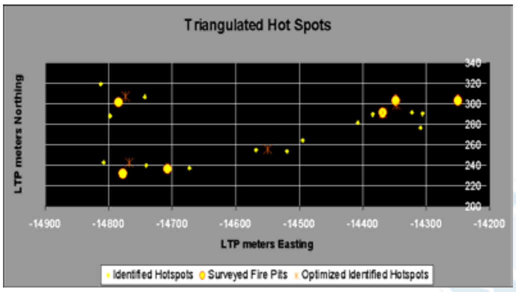
System Concept

$$r^m_{Point} = r^m_{INS}(t) + R^m_b(t)\,(S\,R^b_c\,r^c - a^b)$$



F3 System Accuracy

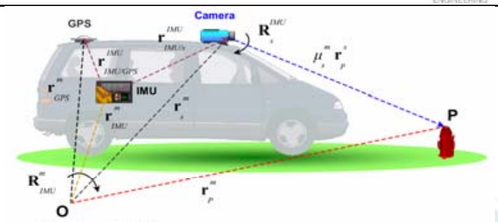
Horizontal RMS of 8 m



Summary

1. **MMS are becoming an emerging trend for mapping applications because of :**
   - Market demands for efficient ways of data collection and
   - A technology push due to new imaging and navigation hardware.
2. **Multi-sensor systems are characterized by :**
   - Tight sensor integration during the measurement process (synchronization on common platform).
   - A total solution approach (no external control needed).
   - Georeferencing by INS/GPS as the core mathematical technique.
3. **Other Important aspects of MMS are :**
   - Data fusion with the goal of minimizing the total error budget.
   - Implementation of MMS for real-time applications.
   - Efficient manipulation of large data sets.

Georeferencing Model (cont.)



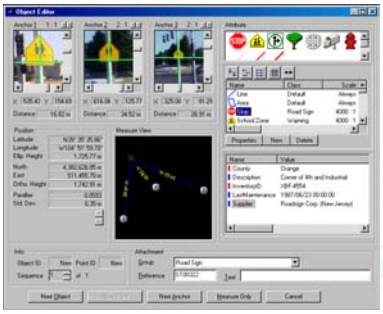
$$\mathbf{r}_P^m = \mathbf{r}_s^m + \mu_s^m \mathbf{R}_s^m \mathbf{r}_P^s$$

$$\mathbf{r}_P^m = \left(\mathbf{r}_{GPS}^m - \mathbf{r}_{IMU/GPS}^m + \mathbf{r}_{IMU/s'}^m\right) + \mu \mathbf{R}_{IMU}^m \mathbf{R}_{s'}^{IMU} \mathbf{r}_p^{s'}$$

$$\mathbf{r}_P^m = \left(\mathbf{r}_{GPS}^m - \mathbf{R}_{IMU}^m \mathbf{r}_{IMU/GPS}^{IMU} + \mathbf{R}_{IMU}^m \mathbf{r}_{IMU/s'}^{IMU}\right) + \mu_s^m \mathbf{R}_{IMU}^m \mathbf{R}_{s'}^{IMU} \mathbf{r}_p^{s'}$$

$$\mathbf{r}_P^m = \mathbf{r}_{GPS}^m + \mathbf{R}_{IMU}^m \left(\mathbf{r}_{IMU/s'}^{IMU} - \mathbf{r}_{IMU/GPS}^{IMU} + \mu_s^m \mathbf{R}_{s'}^{IMU} \mathbf{r}_p^{s'}\right)$$

VISAT Station – Object Editor



Direct Georeferencing – State of the Art

Performance	Navigation-Grade (INS or IMU)	Tactical Grade (IMU or ISA)	Consumer Grade (sensory or ISA)
Price (USD)	150-250k	100-150K	30 – 100$/axis
Gyro Drift rate (deg/hr)	≅ 0.015 deg/hr	0.1- 10 deg/hr	100 – 3600 deg/hr
Accel bias	50 – 100 μg	200 – 1000 μg	0.1 – 0.5 g
Accuracy with DGPS	5-15 arcsec	0.1 - 10 arcmin	0.5-5 deg
Sensors/ applications	Film based aerial cameras & Land DMM systems	Digital aerial systems (including LIDAR and IfSar)	Portable DMM