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HIGH-PRECISION APPLICATIONS OF UAVS

Wednesday, February 24, 2016

WELCOME TO
High-Precision Applications of UAVs

Dr. Steven Waslander
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University of Waterloo

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Founder & Managing Director
delair tech

Francois Gervaix
Product Manager
Surveying
senseFly

Co-Moderator: Lori Dearman, Sr. Webinar Producer

Who's In the Audience?

A diverse audience of over 850 GNSS and unmanned professionals registered from 54 countries, 29 states and provinces representing the following categories:

25% Professional User

17% System Integrator

14% Product/Application Designer

14% GNSS Equipment Manufacturer

30% Other

Welcome from *Inside GNSS*

Richard Fischer
Publisher of Inside Unmanned Systems
Director of Business Development
Inside GNSS

Welcome from *u-blox*

Mårten Ström
Senior Principal,
Product Management
at u-blox

Demoz Gebre-Egziabher
Aerospace Engineer and Mechanics Faculty
University of Minnesota

Poll #1

For your small UAV operations the centimeter level precision afforded by Real Time Kinematic (RTK) GNSS is:
(Please select one)

- ***An absolute necessity.***
- ***An unnecessary luxury.***
- ***Too crude (Not good enough).***
- ***A myth.***

Robust and Precise Positioning for UAVs

Steven L. Waslander
Associate Professor
University of Waterloo

UAV Inspection and Mapping Markets

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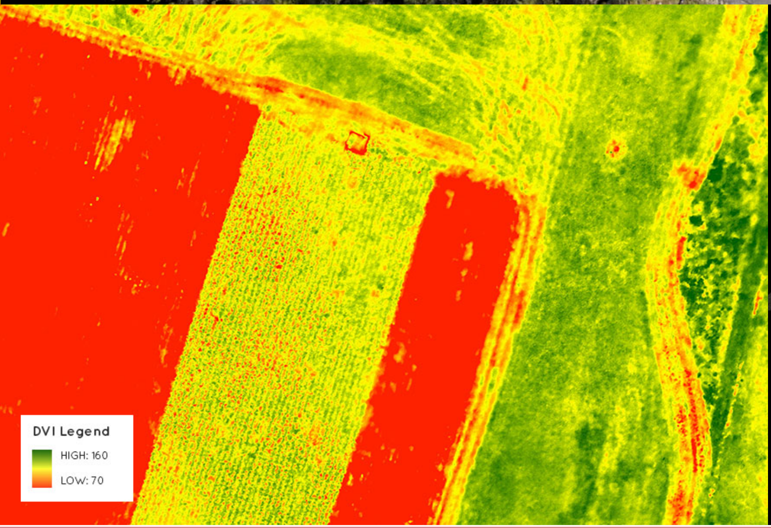
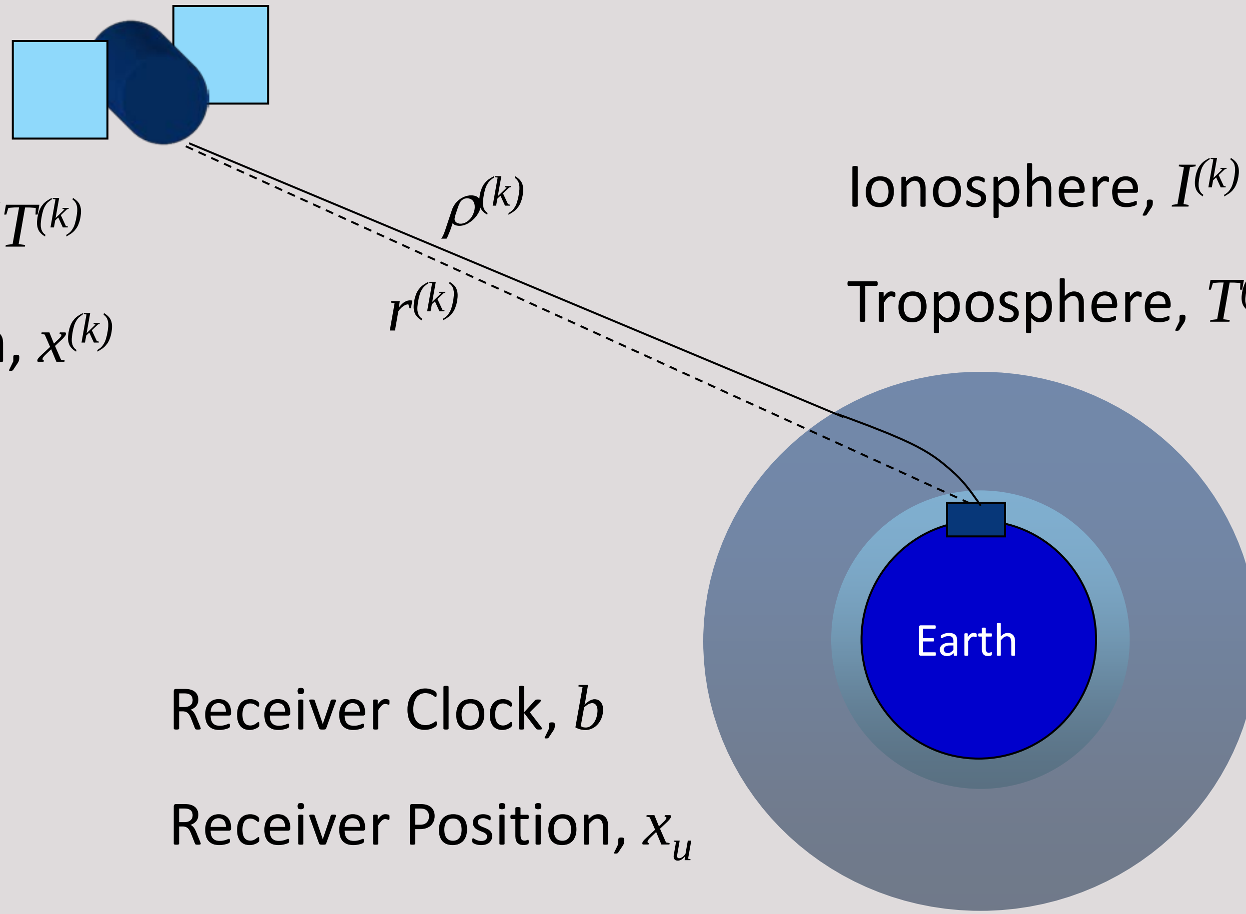


GNSS Measurements & Error Sources

SV Clock, $dT^{(k)}$

SV Position, $x^{(k)}$



Ionosphere, $I^{(k)}$

Troposphere, $T^{(k)}$

Receiver Clock, b

Receiver Position, x_u

Receiver Measurement Error and Multi-path, $\varepsilon_{\rho}^{(k)}$

Code Phase Position Fix Measurement Equation

- Nonlinear measurement model of pseudorange measurement, $\rho^{(k)}$, in meters from k^{th} satellite to user receiver, u

Range Clocks Atmospheric Other

$$\rho_u^{(k)} = \left\| x^{(k)} - x_u \right\| + b - c\left(dT^{(k)}\right) + I^{(k)} + T^{(k)} + \varepsilon_\rho^{(k)}$$

- Nonlinear least squares (NLLS) estimation used
  - Combine pseudorange measurements to form an estimate of receiver position and clock bias (four unknowns)
- Can be augmented to use Extended Kalman Filter if motion model known
  - Many GNSS receivers include options for walking, car, aircraft etc.
  - Many also include channels to integrate inertial measurements, wheel odometry

GPS Error Sources

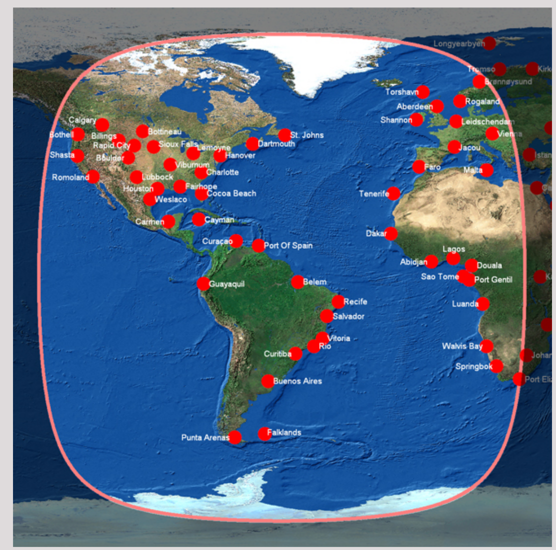
Error Source	User Equivalent Range Error - UERE (m)
Signal arrival C/A (civilian)	±3
Signal arrival P(Y) (military)	±0.3
Ionospheric effects	±5
Ephemeris errors	±2.5
Satellite clock errors	±2
Multipath distortion	±1
Tropospheric effects	±0.5
UERE Total (RMS)	6.7 (m)

- UERE – Error in a range measurement from satellite to receiver caused by a particular error source.
- Can be converted to position estimate standard deviation by multiplication by Position Dilution of Precision.

SBAS and PPP

- Through a national/global network of reference stations
  - Track Ionospheric and Tropospheric errors, clock and ephemeris
- Through a network of geosynchronous satellites
  - Broadcast correction models to remove errors
- Challenge remains with tropospheric correction, too local and rapidly varying to model accurately

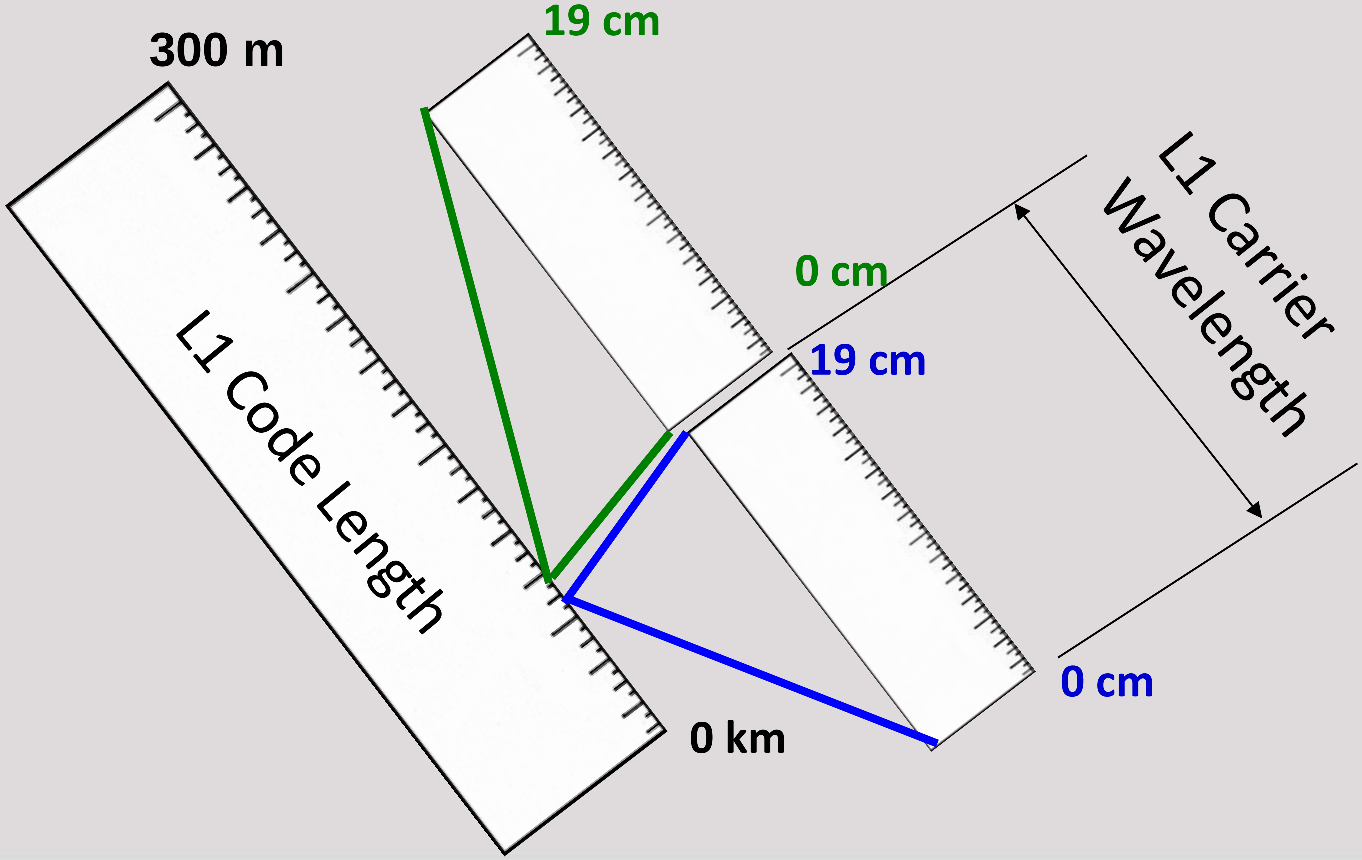
SBAS systems



OmniStar MSV coverage and base stations

Refining Position Estimates through Carrier Phase

- Its possible to track the carrier phase of GPS signal along with code phase and use it to improve position accuracy
  - Higher frequency, shorter wavelength, higher precision measurements



Carrier Phase Measurements Equation

- Carrier phase measurement equation

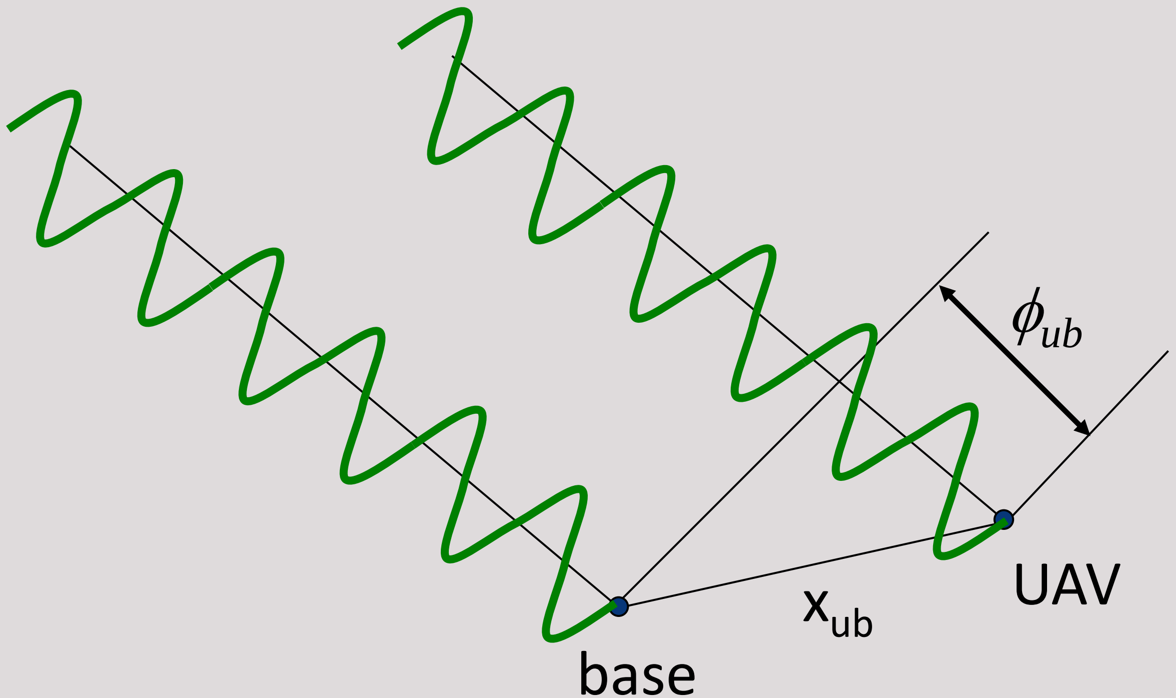
Range | Clocks | Atmospheric | **Integer Ambiguity** | Other

$$\lambda\phi_u^{(k)} = \left\| x^{(k)} - x_u \right\| + b - c\left(dT^{(k)}\right) + I^{(k)} + T^{(k)} + \lambda N_u^{(k)} + \varepsilon_c^{(k)}$$

- Measurement precision of millimeters
- Error sources in meters
- Integer wavelengths to satellite, N_u unknown
  - Not an issue for code phase, 300 m wavelength
  - Major issue for carrier phase, 19 cm differences lost in measurement errors

Double Difference Technique

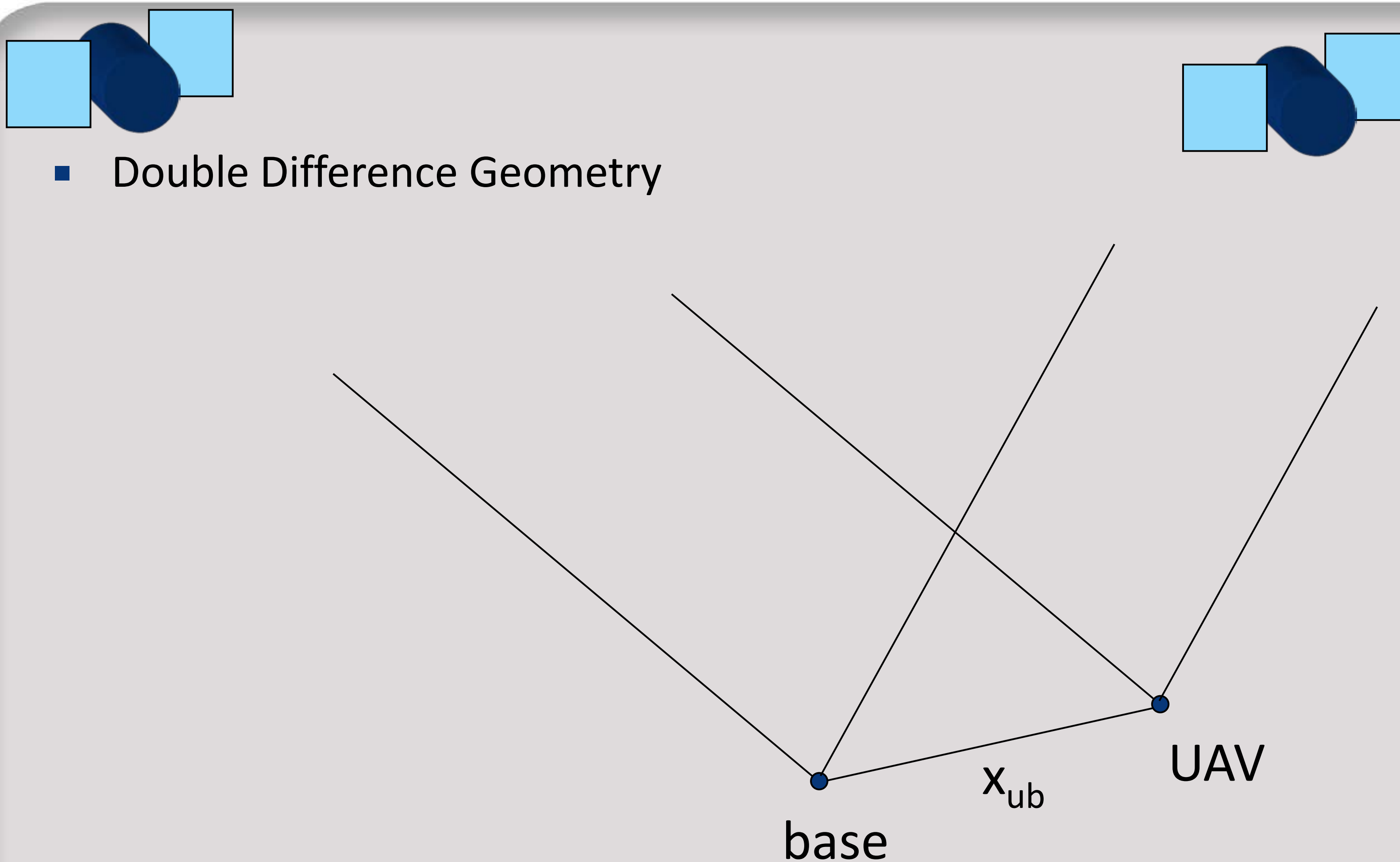
- Single Difference Geometry



- Single Difference removes Iono, Tropo, SV Clock, but adds base clock error

Double Difference Technique

- Double Difference Geometry



- Double difference also removes base clock error
  - Useful technique, leads to 1-2 cm position error for methods like RTK, PPS

RTK and PPK

- Employ the double difference technique and integer ambiguity resolution to determine positioning solution
  - RTK: Real-time kinematic solutions available onboard the vehicle
    - Relies on extended Kalman filtering for real-time updates
    - Requires a communication link from a base station to send updates @ 30-60 seconds
    - If connection lost, revert to PPP/SBAS
  - PPK: Post-processed kinematic solutions are applied offline
    - Can take advantage of smoothing, instead of filtering alone
    - No communication required, simply record measurables on both vehicle and ground
    - High quality GPS solution not available for flight control
- Because corrections depend on a single ground station, benefit degrades as a function of distance traveled

GPS Correction Method Accuracies

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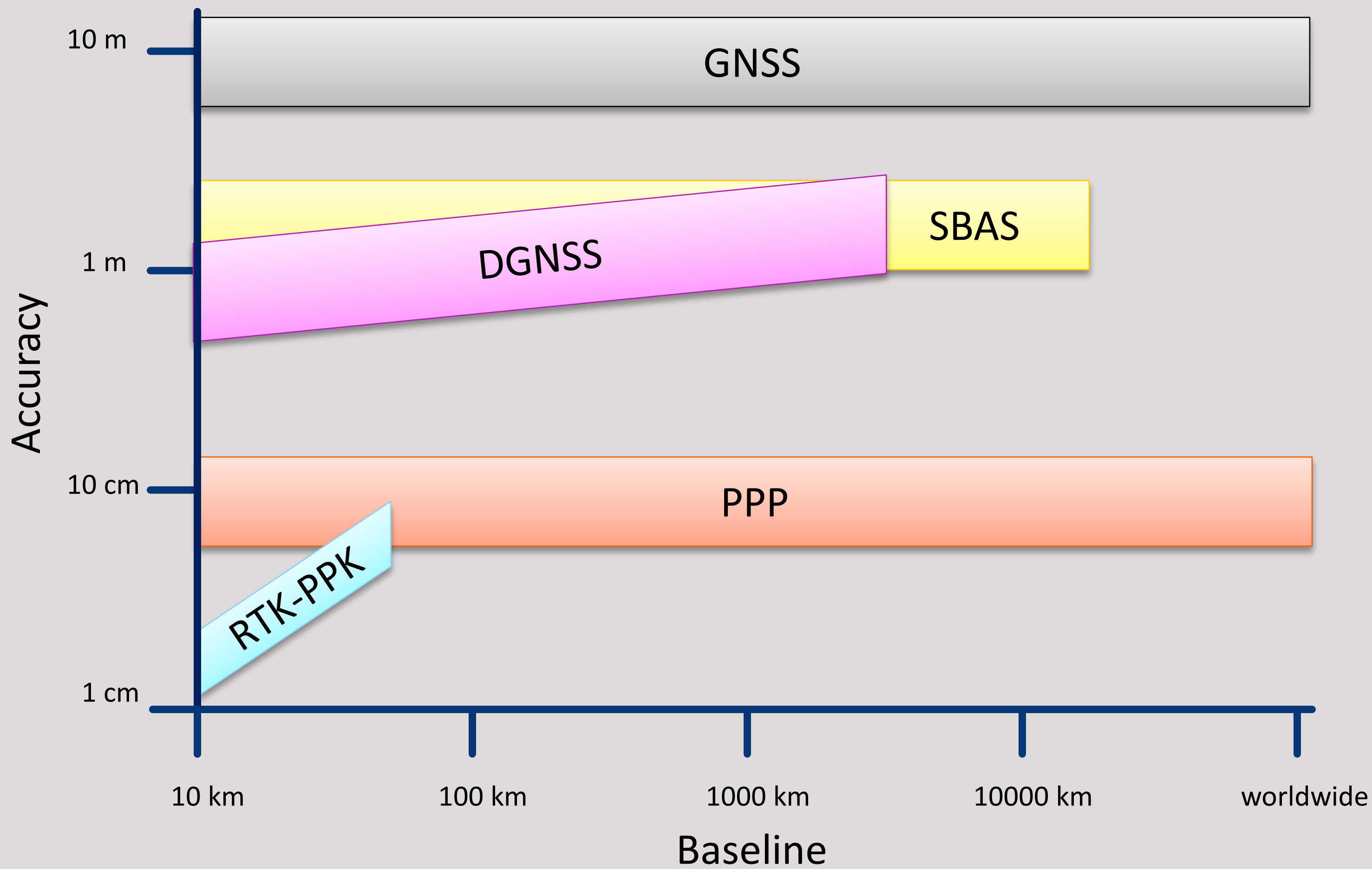
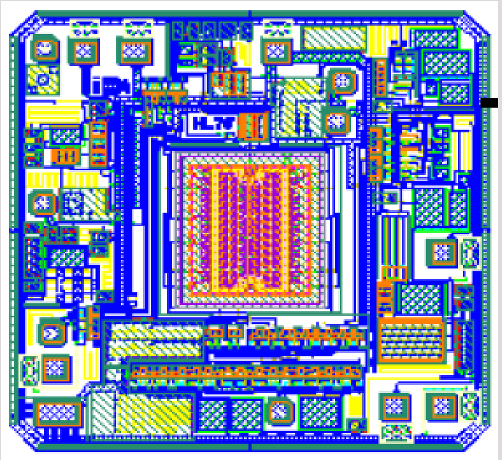
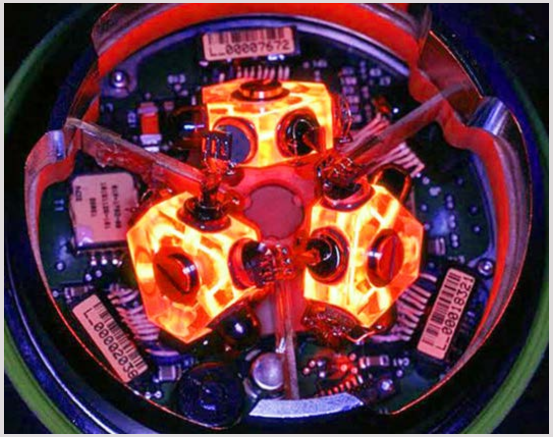


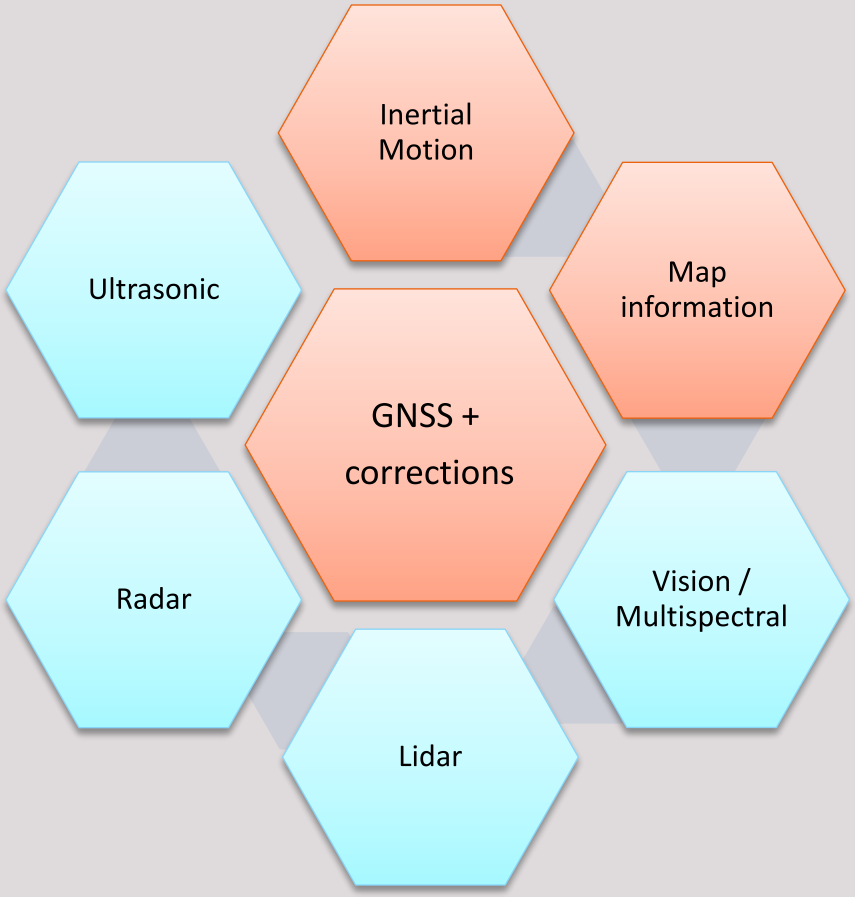
High-Accuracy Positioning Options – Inertial Sensing

- A major error source of all mapping and inspection tasks is camera orientation estimation
  - Explosion of MEMS devices, continuously improving accuracy (1-3000 °/hr)
    - Gyroscopes for rotation rates
    - Accelerometers for acceleration
    - Magnetometers for magnetic field vector
  - High end includes Ring Laser and Fiber Optic Gyroscopes (0.0001 – 0.1 ° /hr)
    - RLG measures accumulated rotation directly
    - FOG measures rate, but very accurately through many cable turns
- Tight coupling of GNSS and INS allows major improvements to complete solution
  - Tracking, integer ambiguity resolution, measurement fusion and estimation accuracy





- All sensor data onboard a vehicle can be fused in the same manner
  - Absolute measurements directly measure pose of vehicle or its rate of change
    - GNSS, IMU, Map data
  - Relative measurements are between the vehicle and the environment
    - Vision, Lidar, Radar, Ultrasonic
- Fusion is comprised of two pieces
  - Determining validity of individual measurements
  - Combining all valid measurements so as to minimize state uncertainty



Drone & Data

Solution for utility and industry

Bastien Mancini
Founder and Managing Director
delair tech

Who we are

Founded in 2011 – Based in Toulouse

50 Employees – 2M€ CA

Strong Financial and R&D Partnership

Worldwide development

DT18 - the only BVLOS mini-drone

Since 2012

- **Wingspan/length** : 1.8 m/1.2 m
- **Cruise speed** : 60 km/h
- **Communication range** : up to 20 km
- **Flight altitude Ceiling** : up to 3,000 m ASL
- **Deployment**: Less than 5 minutes
- **Operational temperatures** -20°C to +50°C

100 km: range
2 hour: endurance
2 kg: weight
Launch: hand or catapult
PPK: option
3G: option

Direction de la Sécurité de l'Aviation Civile

Liberté • Égalité • Fraternité
République Française

Attestation de Conception de Type N° B/003-NO/NAV

Ce document n'est valable que sur le Territoire de la République Française

La présente attestation de conception de type pour aéronef télépiloté est délivrée conformément aux dispositions de l'annexe II de l'arrêté du 11 avril 2012 relatif à la conception des aéronefs civils qui circulent sans aucune personne à bord, aux conditions de leur emploi et sur les capacités requises des personnes qui les utilisent.

Le titulaire de cette attestation peut produire en série des aéronefs télépilotés conformes au type couvert par cette attestation ou passer un accord commercial avec un autre constructeur pour qu'il produise des aéronefs conformes au type.

Le constructeur délivre aux propriétaires des aéronefs télépilotés produits une attestation de conformité au type.

1 -Désignation de l'aéronef télépiloté :

- Classe : **avion**
- Catégorie(s) : **D**
- Type/Modèle : **DT-18**

2 -Titulaire :

DELAIR-TECH
3 avenue Dider Daurat
31400 Toulouse
France

Délivrée le 19 OCT 2012

Pour le Ministre chargé de l'Aviation Civile :

Ce document comporte un verso

For? Linear Infrastructure Monitoring
Precision Agriculture
Geographic Information Systems (GIS)

DT26X—Unparalleled sensors quality

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Financed by the French Ministry of Defence

- **Wingspan/length:** 3,3 m/1.6 m
- **Cruise speed:** 50 km/h
- **Communication range:** up to 20 km
- **Flight altitude Ceiling:** up to 4 000m
- **Deployment:** 10 minutes
- **Operational temperatures:** -20°C to +50°C

150 km: range (3hours)

2,5 hour: endurance

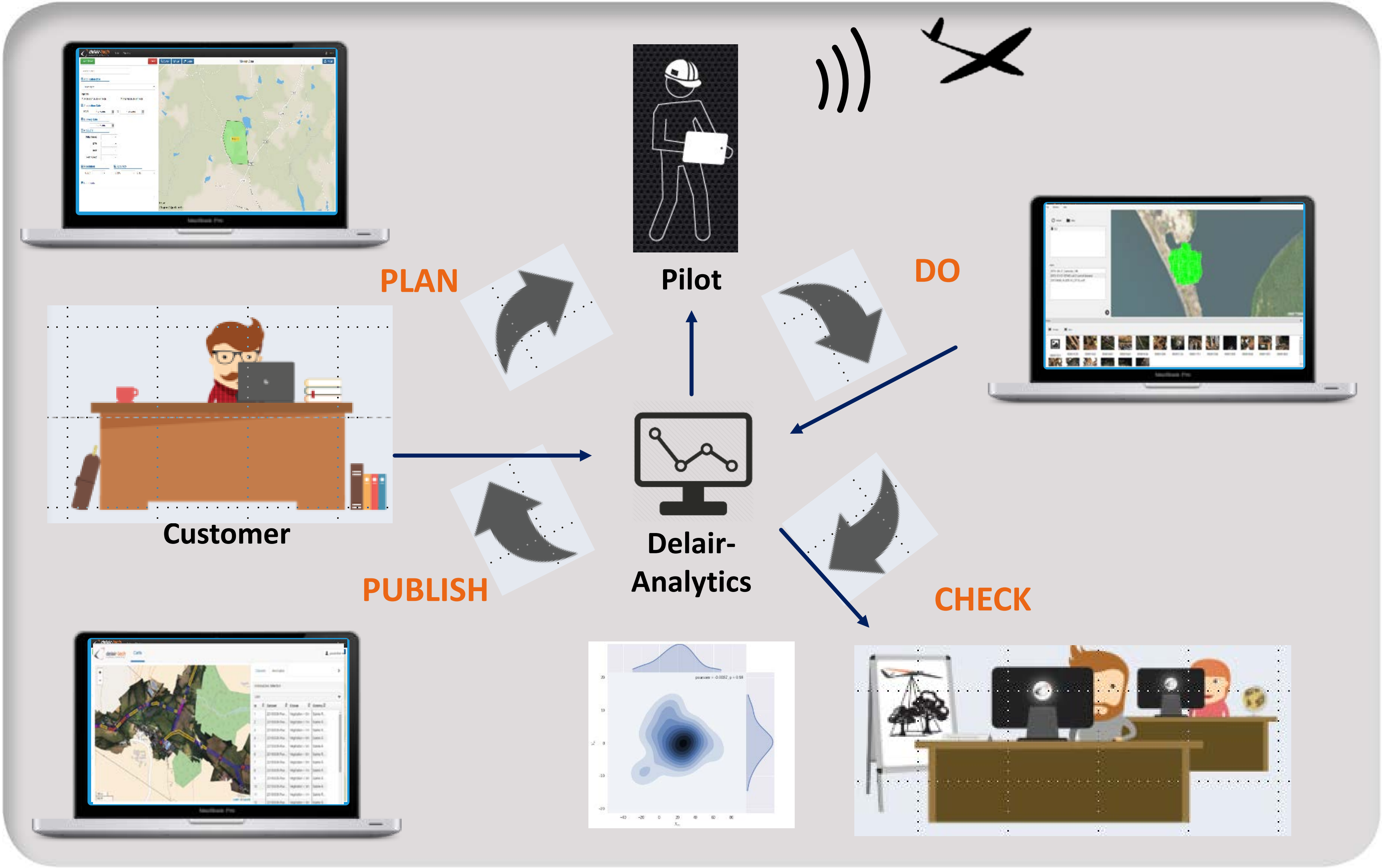
50 km2: mapped per flight

15 kg: weight

Launch: by catapult

For? Surveillance and Reconnaissance
Linear Infrastructure Monitoring
High Value added sensors

Delair-Analytics



Real Time Quality Check

Dual Band + IMU

GNSS Receiver

< 10µs timestamp

Global Shutter Camera

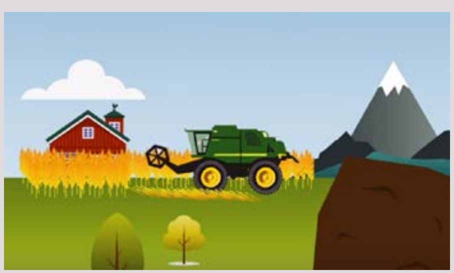
On Board Computer

Real Time Histogram

Real Time Fix Status

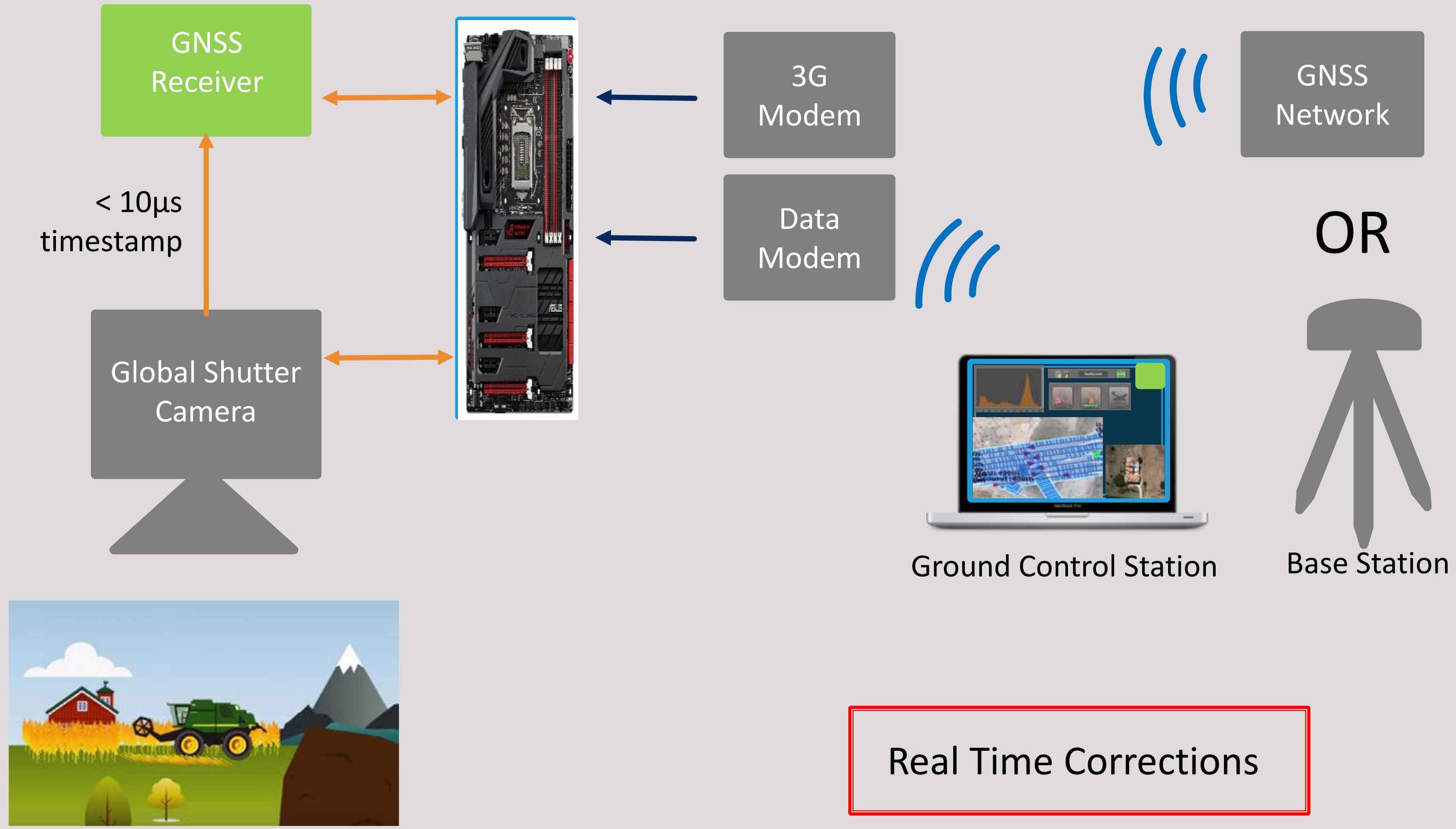
Real Time Footprint

Real Time Pictures



Real Time Quality Check = Pictures + Navigation Data

Communications



Accuracy for Efficiency

ON BOARD

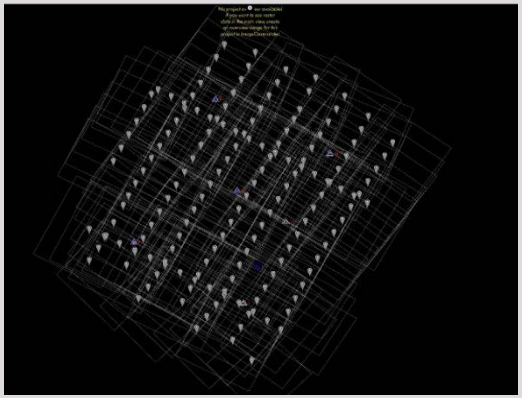
	X	Y	Z
Mean (cm)	0	0	0
Sigma (cm)	0.6	0.6	0.9
RMS (cm)	0.6	0.6	0.9

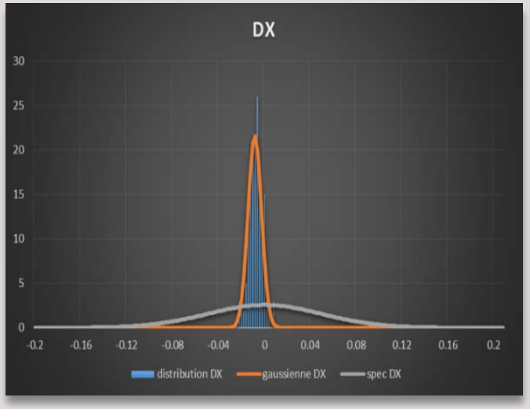
ON GROUND

	X	Y	Z
Mean (cm)	-0.5	-1.1	7.3
Sigma (cm)	1.3	2.7	5.5
RMS (cm)	1.3	2.7	8.9

High Accuracy IMU :

- **0.025°** Roll & Pitch
- **0.080°** Yaw





Less Overlap (< 50%)
More Area Covered

No need for GCPs
Faster Operations

Ask the Experts – Part 1

Dr. Steven Waslander
Assoc. Professor, Department of Mechanical and Mechatronics Engineering
University of Waterloo

Bastien Mancini
Founder & Managing Director
delair tech

Francois Gervaix
Product Manager
Surveying
senseFly

Poll #2

Primary demand for RTK's performance in small UAV applications comes from:
(Please select one)

- ***Precision agriculture users***
- ***Construction industry users***
- ***Mining industry users***
- ***Mapping and surveying***
- ***Infrastructure inspection***

Drone & Data

Solution for utility and industry
Part II

Bastien Mancini
Founder and Managing Director
delair tech

Topography

Acquaresi mining site
Sardinia Italy

Old mining site
frequent landslide

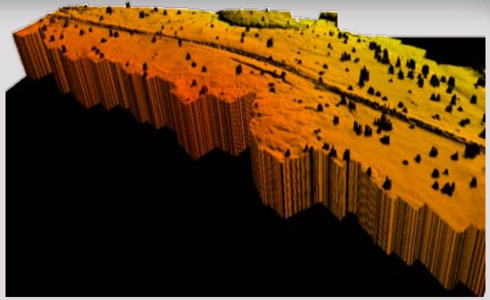
European Commission
Copernicus Program

GSD – 4,3 cm
Accuracy – 10 cm
10 km² - 2 flights

Topographic Survey

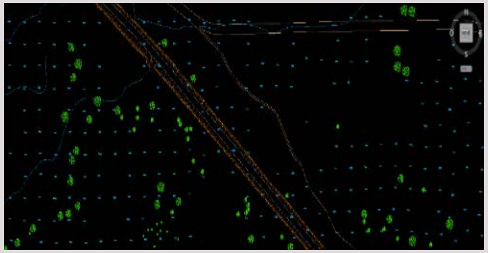
Orthophoto, 5cm

DSM, DTM

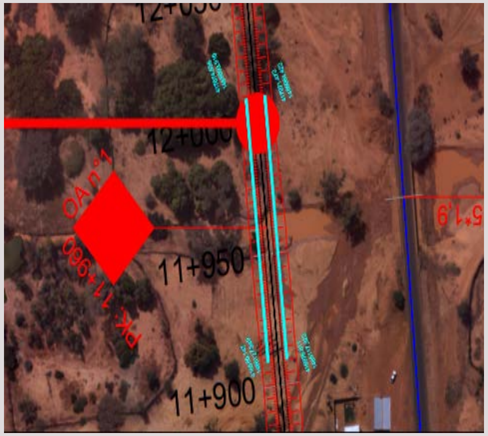


Resolution up to 5 cm / pixel

Digitizing



Topography
DXF



Railroad construction - Niger
150 km x 400 m - 18 flights
4 days acquisition
45 000 pictures

Powerline

Powerline

delair-tech AIRBORNE SENSORING | Carte | powerline

Datasets | Anomalies

Informations Sélection

Liste

Id	Dataset	Classe	Commu...
1	20150608-Pow...	Végétation < 5m	Sainte-R...
2	20150608-Pow...	Végétation < 1m	Sainte-R...
3	20150608-Pow...	Végétation < 1m	Sainte-R...
4	20150608-Pow...	Végétation < 5m	Sainte-R...
5	20150608-Pow...	Végétation < 5m	Sainte-R...
6	20150608-Pow...	Végétation < 5m	Sainte-R...
7	20150608-Pow...	Végétation < 5m	Sainte-R...
8	20150608-Pow...	Végétation < 1m	Sainte-R...
9	20150608-Pow...	Végétation < 3m	Sainte-R...
10	20150608-Pow...	Végétation < 3m	Sainte-R...
11	20150608-Pow...	Végétation < 1m	Sainte-R...
12	20150608-Pow...	Végétation < 3m	Sainte-R...

Industrial services - Pipeline

Objective – Automatic detection of potential hazards & anomalies in proximity to the pipeline.

Operations

- **38 km** of pipeline
- **1 flight, 40 minutes**
- **2,000+ photos** generated

Algorithm processing

Detection of various anomalies

Deliverable

Web-based georeferenced map on detected anomalies with infos

Report
1 page per hazard, with GPS coordinates
name of the area
Identified anomaly

Surveillance

Tracking function

DT-26X UAV
DT-EYE XL sensor

Night Vision

DT-26X UAV
DT-EYE XL sensor

Performance

HFOV : 2°
Distance : 785m

Performance

HFOV: 3.4°

Distance: 1298m

Performance

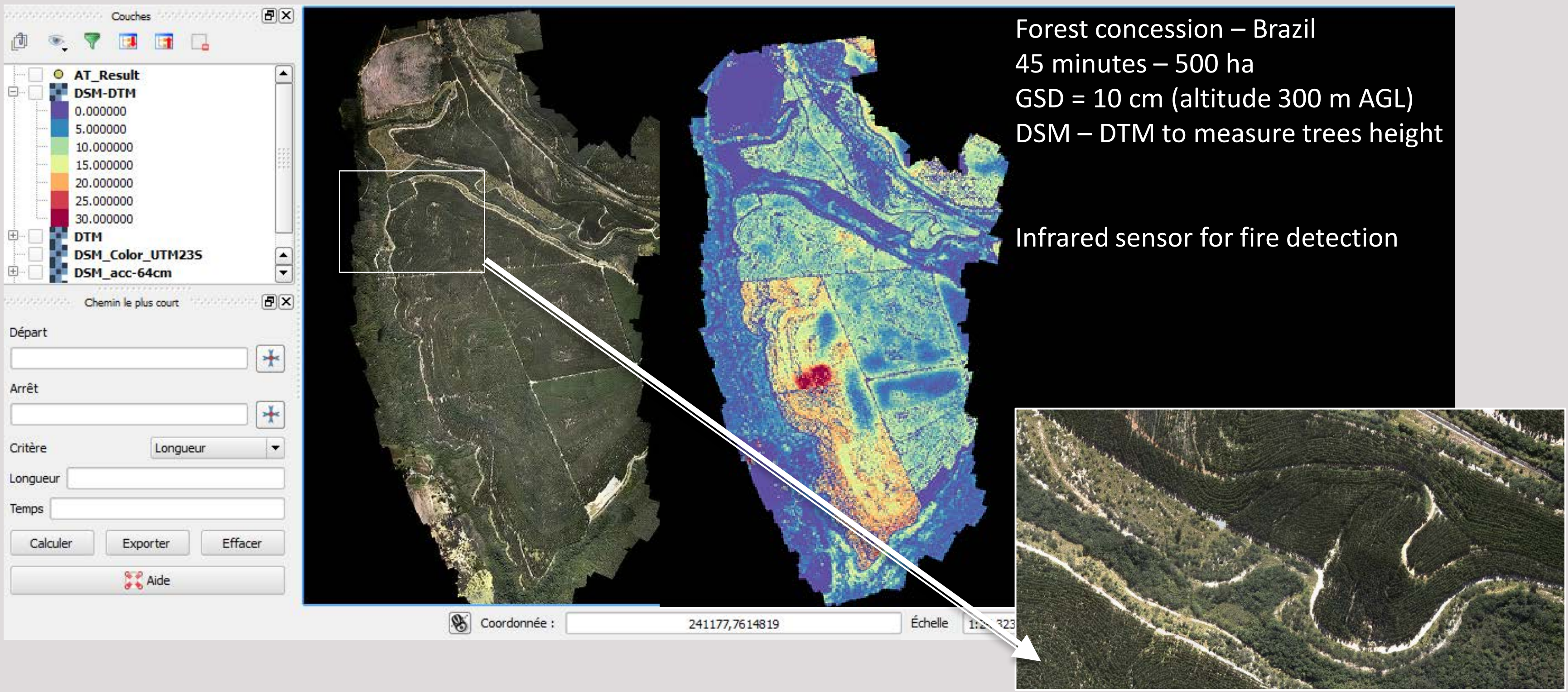
HFOV: 1.7°

Distance: 1347m

Stabilization

Mobile objects Detection

Forestry



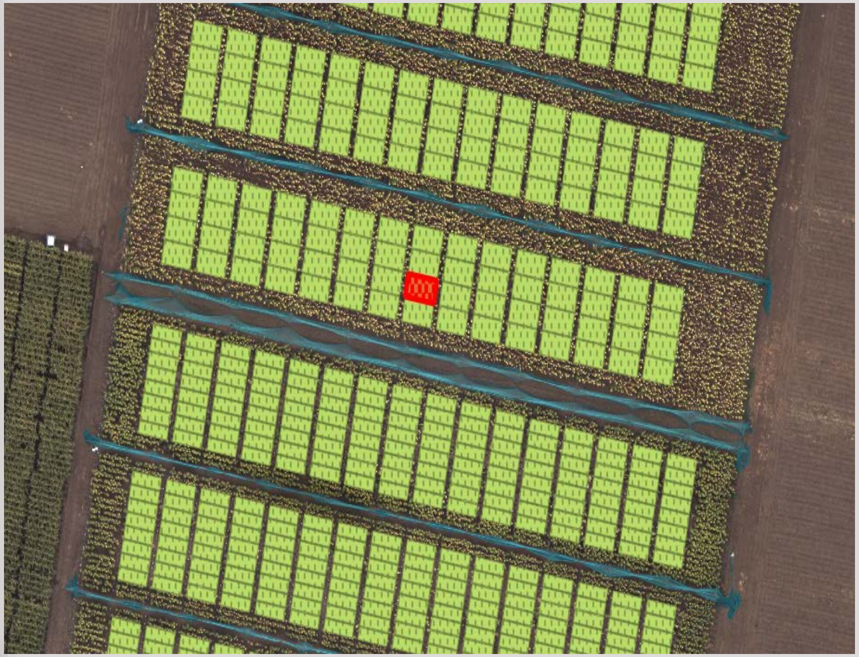
Forest concession – Brazil
45 minutes – 500 ha
GSD = 10 cm (altitude 300 m AGL)
DSM – DTM to measure trees height

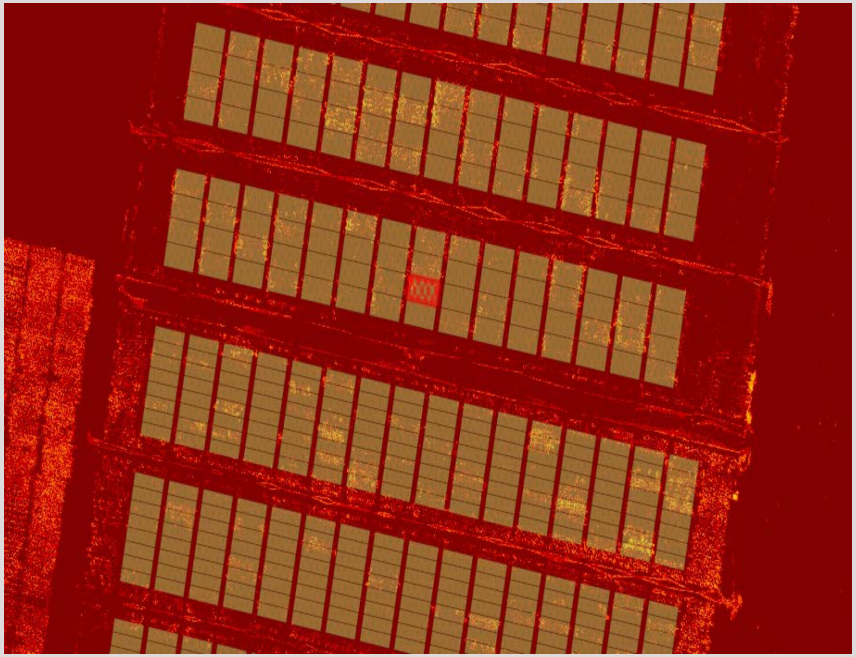
Infrared sensor for fire detection

Precision Agriculture

Multispectral data collection : R + G +B + NIR + RedEdge
Plants counting
Chlorophyl emission
Yield estimation
Early health diagnosis
Hydric stress

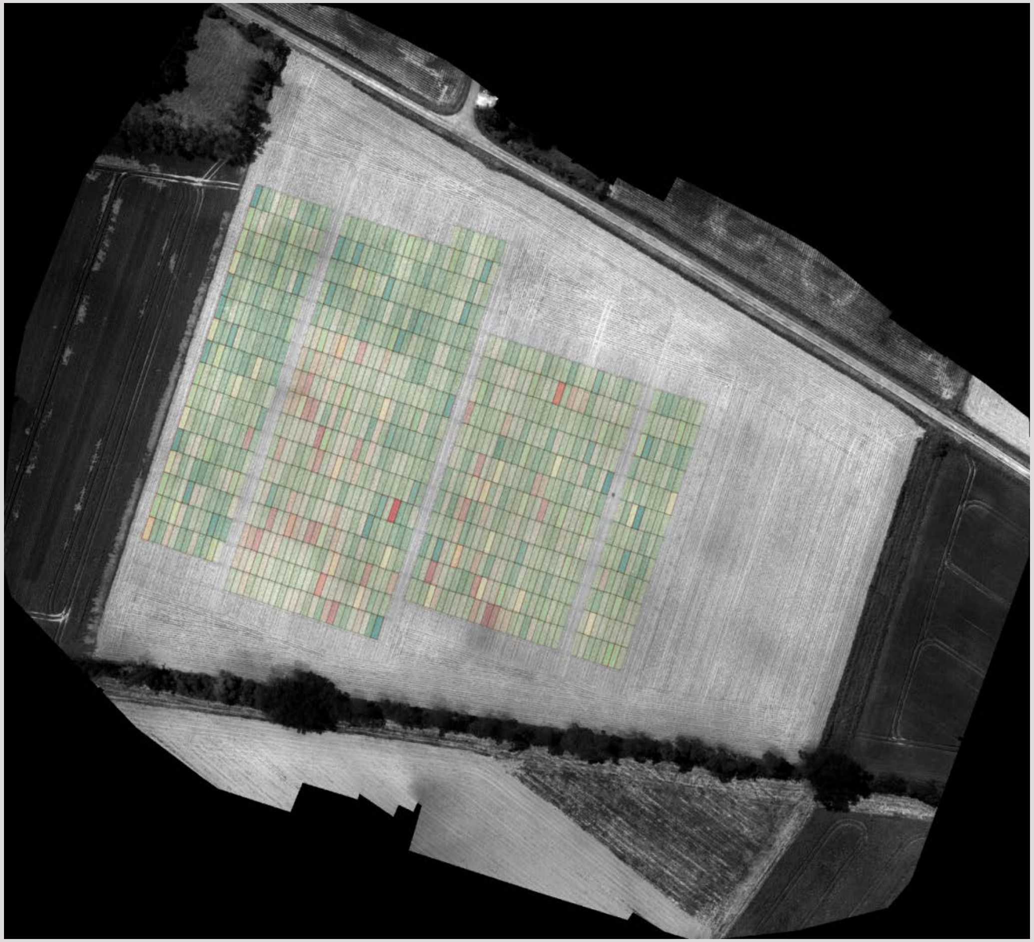
SGS Nvirocrop in South Africa
Using the DT18 UAV and DT-5Bands sensor
Since june 2015





Precision Agriculture

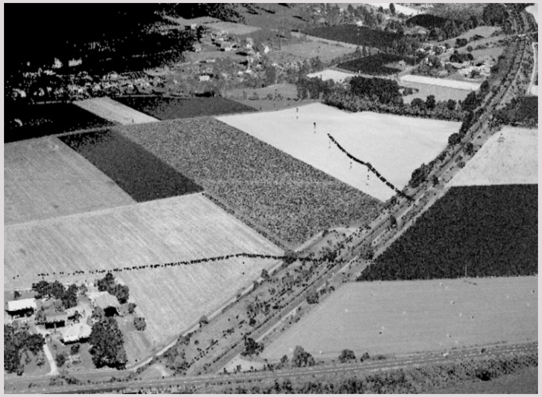
Sunflower
Seeds



Delair-Tech Technology

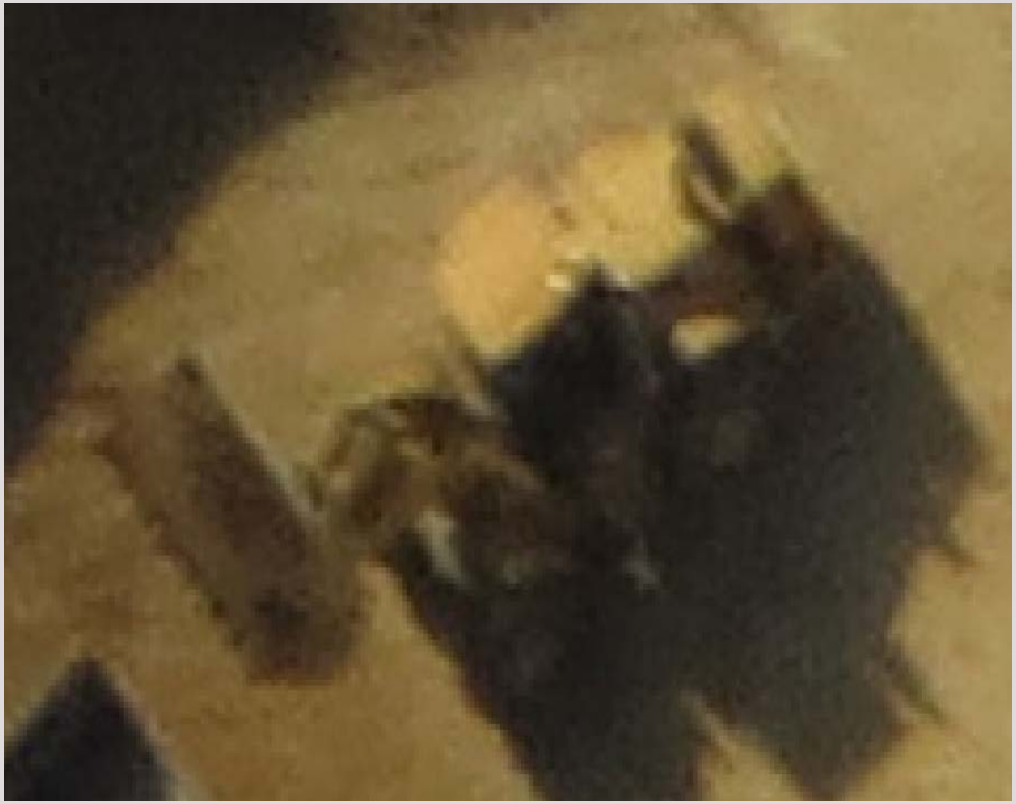
Coming Soon

SENSOR	COMPATIBILITY	STRENGTHS	WHAT FOR?
APRIL 2016 LIDAR (Riegl Technology)		1,5 hours endurance 350,000 measurements/sec Range accuracy: 10 mm	
SEPT 2016 Hyperspectral		640 Spatial lines 270 spectral bands	Environmental protection Mining Exploration Precision agriculture Forestry Reef Survey



Resolution vs. Sampling

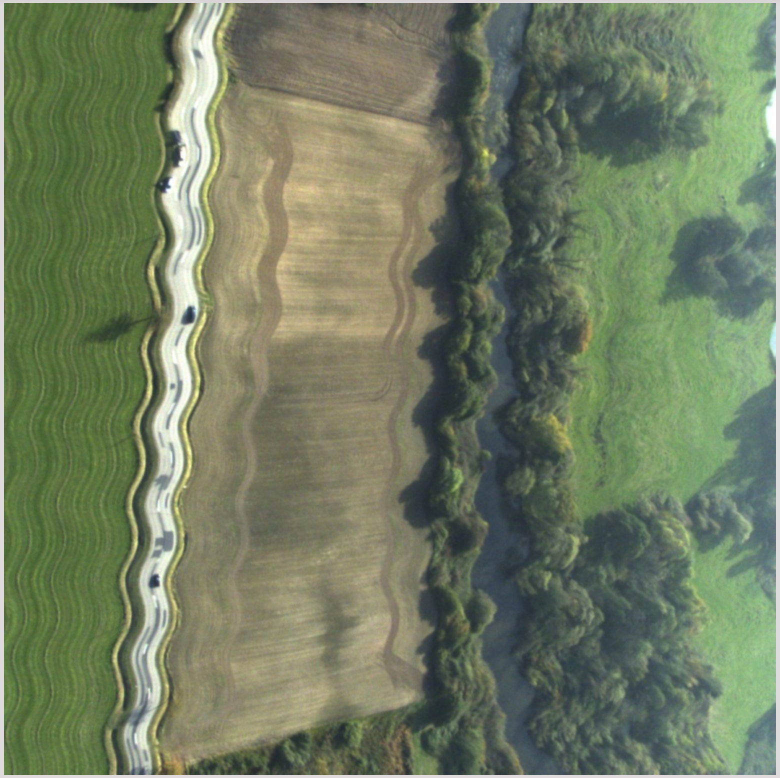
Which image has more Megapixels ?



20 Mpix Consumer Camera

5 Mpix DT-3Bands

Rolling or Global Shutter ?



Markets & References

GLENCORE
VINCI AUTOROUTES
Bolloré AFRICA LOGISTICS
CGG

Rte Réseau de transport d'électricité
eDF
SNCF RÉSEAU
TOTAL
saur
TRAPIL
eRDF ELECTRICITE RESEAU DISTRIBUTION FRANCE
VEOLIA ENVIRONNEMENT
GDF SUEZ

biogemma
Arterris L'Art de la Terre
groupe coopératif Vivadour
MAÏSADOUR semences

European Commission
Allianz

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AIRBORNE SENSORING

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31100 Toulouse, France
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http://www.delair-tech.com

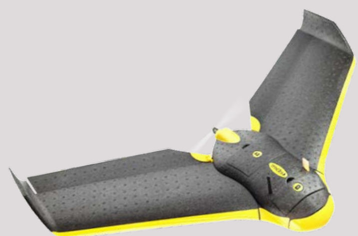
eBee RTK

Francois Gervaix
Product Manager
Surveying
senseFly

About senseFly

- A team of **over 120** passionate people
- **100-200** units/month
- **#1** in fixed-wing mapping drones (worldwide unit sales)
- **Very light** UAS (0.5kg to 1.5kg), inherently safe, **fail-safe behaviors**
- **Fully automated** (with eMotion)

eBee senseFly
eBee senseFly
RTK eBee senseFly
eXom senseFly



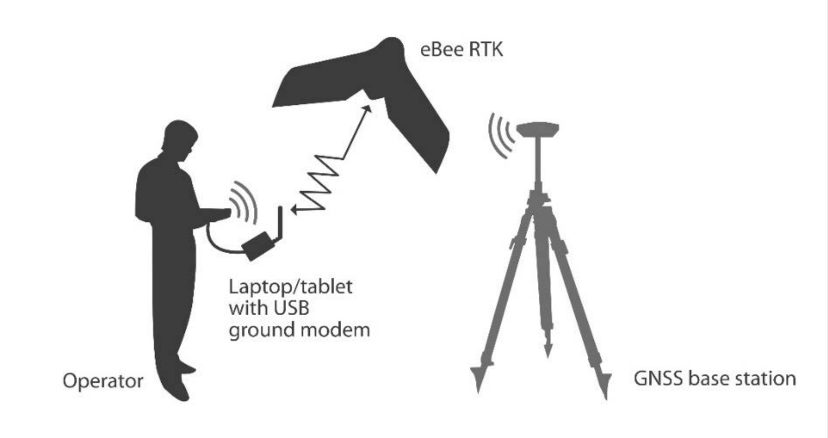
Drones
eBee/ eBee Ag/ eBee RTK/eXom

eMotion
Flight planning & control

The eBee RTK

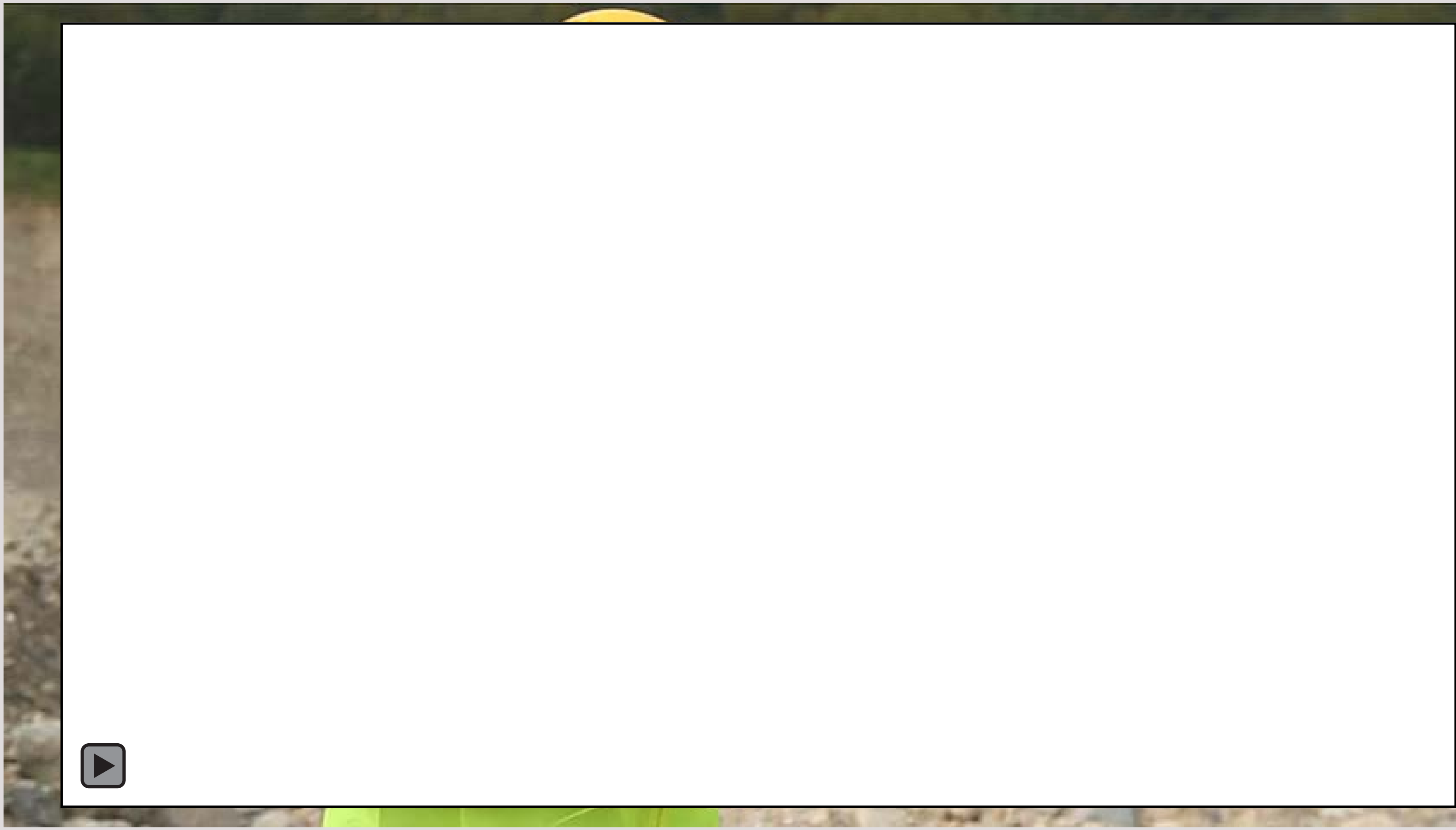
- Built-in RTK-capable GNSS antenna (GPS, GLONASS L1 and L2)
- In-flight application of RTK corrections to geotags
- Ability of eMotion to receive corrections via VRS
- Post-processing engine in eMotion to correct the absolute base position (using Rinex data)

Geotag accuracy: 2 cm horizontal / 3 cm vertical
Processed project accuracy: 1-3 x GSD (without GCPs!)



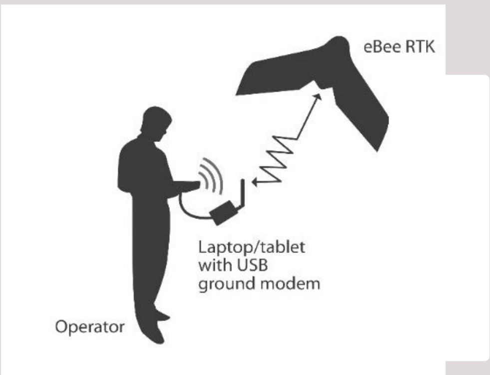
Note: The position measurements are all done in WGS84 (when using a base station)
(the datum and coordinate system can be changed in Postflight Terra 3D)

How it works

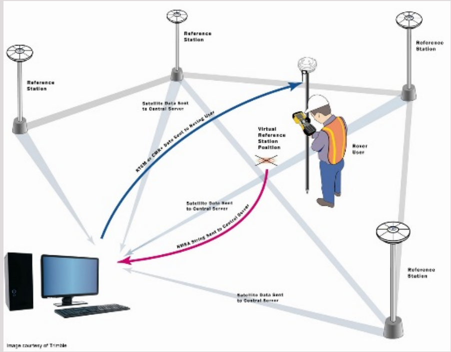


4 modes of operation

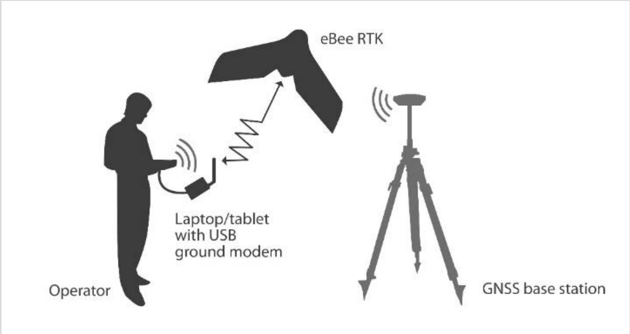
Standalone:



Virtual Reference Station:

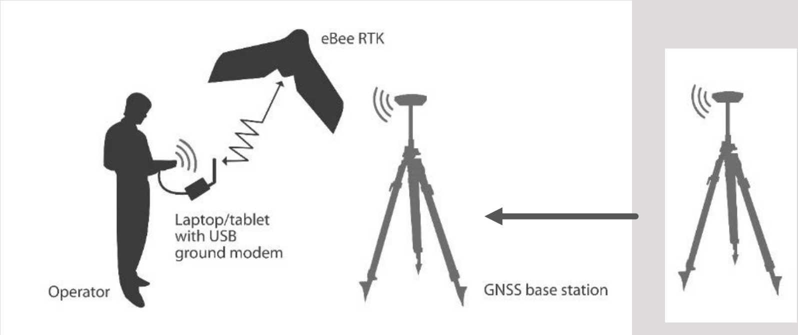


Local base, known point:



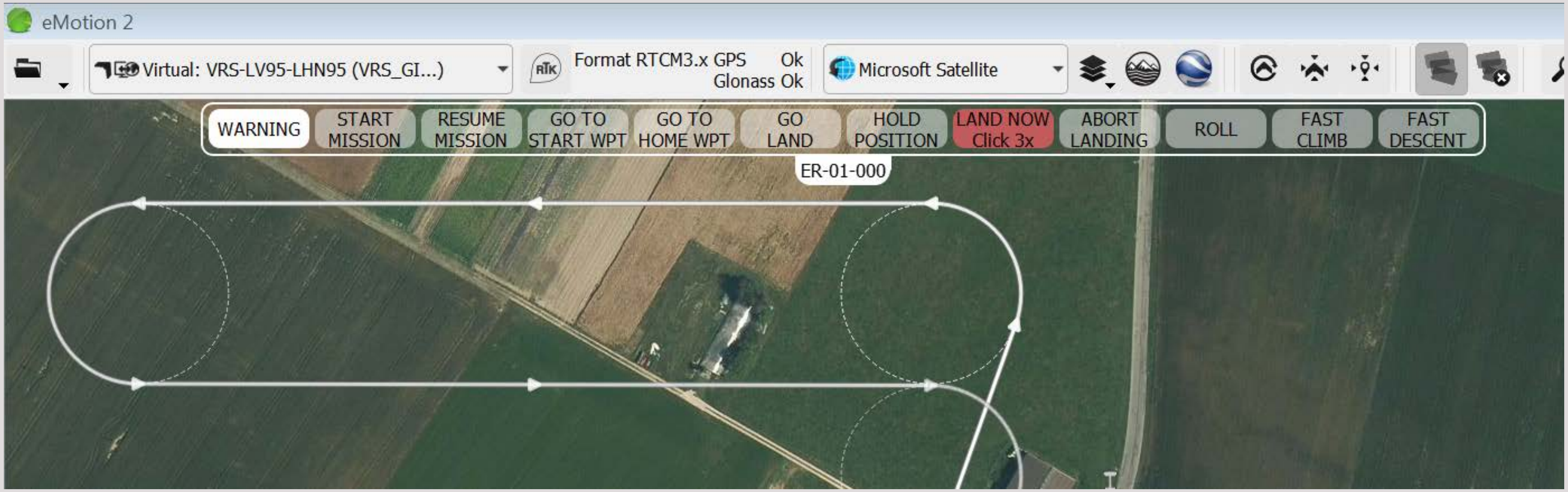
Local base, unknown point:

Rapid Static surveying



Why RTK?

- **GNSS accuracy guaranteed** in field, right **before flight**
- **Same** software & modem for a stand-alone **or** a RTK supported mission
- **No** additional work or software
- **“Job done”** confidence when returning to the office



= airborne RTK a must

eBee RTK Accuracy Assessment

Creating a dataset with Ground Check Points (GCkP)
Number of GCkPs: 19 over an area of 0.2 km^2
Device: Double-frequency GPS/GLONASS receiver
Correction Source: swisstopo's Automated GNSS Network for Switzerland (AGNES) (Accuracy: 5 mm horizontal / 10 mm vertical)

Download the whitepaper:
sensefly.com/eBeeRTK

eBee RTK Accuracy Assessment

InsideGNSS · u-blox · inside unmanned systems

Flights

	Flight 1	Flight 2
Purpose	Test the maximum accuracy	Impact of adverse lighting and weather
RTK Source	VRS	VRS
Area	20 ha (0.2 km^2)	20 ha (0.2 km^2)
GSD	2.5 cm/px (81 m/ATO)	5 cm/px (162 m/ATO)
Overlap	80% lateral, perpendicular	80% lateral
Conditions	Sunny	Low light, wind speed 9 m/s

eBee RTK Accuracy Assessment

InsideGNSS u-blox inside unmanned systems

Results:

Point Cloud (optimal conditions)

	X (mm)	Y (mm)	Z (mm)
Mean error	8	1	-23
Standard deviation	19	15	21
RMSE	20	15	**31**
RMSE XY	**26**		

→ **Accuracy:** 2.6 cm horizontal & 3.1 cm vertical

Orthomosaic & DSM:

	X (m)	Y (m)	Z (m)
Mean error	2	-5	-23
Standard deviation	22	23	26
RMSE	23	23	**35**
RMSE XY	**33**		

→ **Accuracy:** 2.6 cm horizontal & 3.1 cm vertical

10% correction uplink lost

	X (mm)	Y (mm)	Z (mm)
Mean error	15	-1	-46
Standard deviation	18	15	16
RMSE	23	15	48
RMSE XY	28		

→ **Accuracy:** 2.8 cm horizontal & 4.8 cm vertical

Point Cloud (adverse conditions)

	X (mm)	Y (mm)	Z (mm)
Mean error	-45	-69	-49
Standard deviation	19	29	46
RMSE	49	75	70
RMSE XY	89		

→ **Accuracy:** 8.9 cm horizontal & 7.0 cm vertical

within 1-3 x the GSD (5 cm / px)

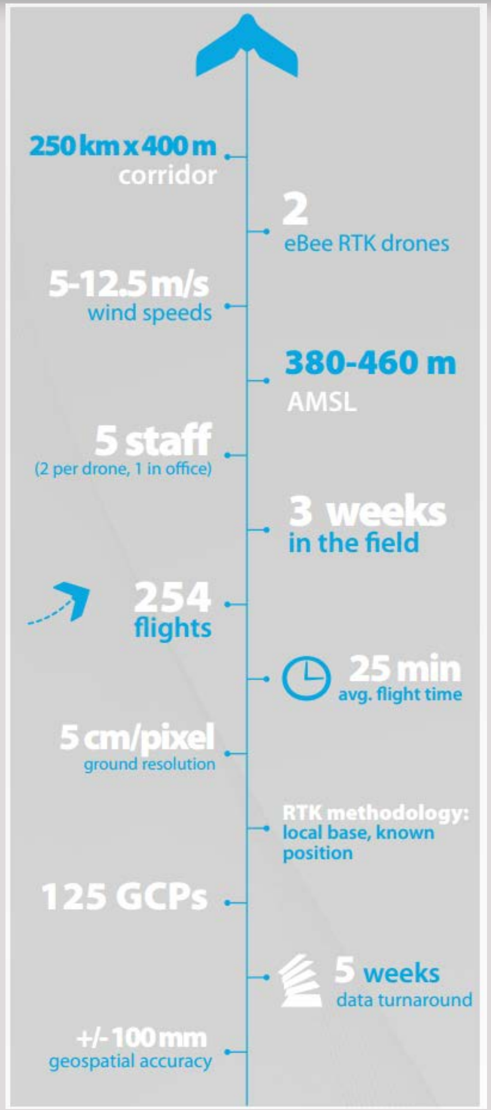
Corridor mapping in remotest Australia

- **Scope**
  - Provide an aerial survey of a 400m wide corridor along the 250km Talawana Access Track (Western Australia)

- **Deliverables;**
  - 3D co-ordinated data with accuracy to +/-100 mm
  - Contoured topographic data
  - Orthomosaic photos to 5 cm resolution
  - Digital model with 1m x 1m grid of 3D points

Corridor mapping in remotest Australia

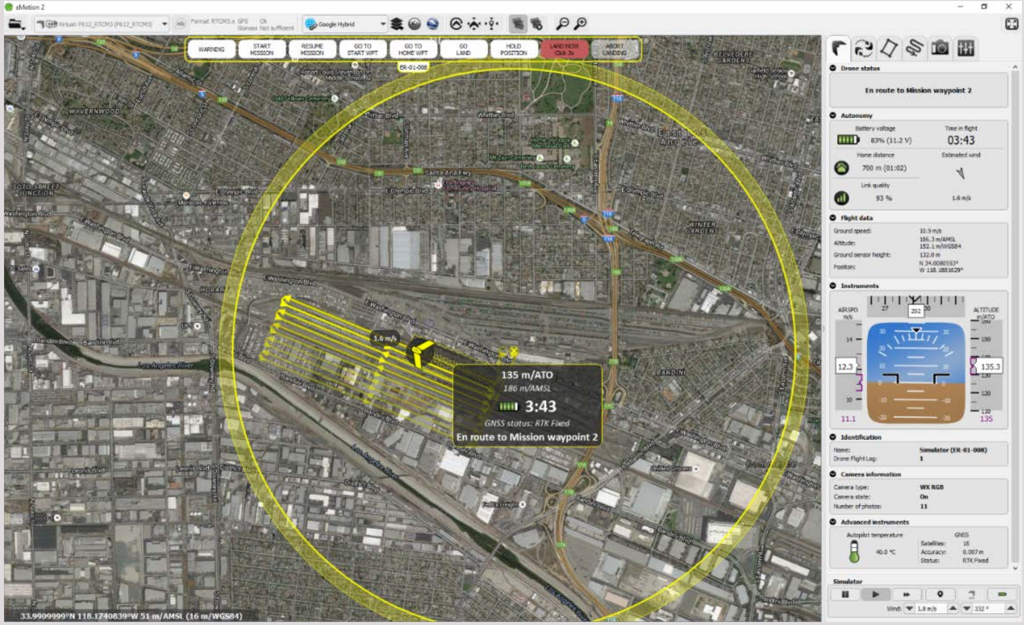
- Control observed using GPS equipment logging data to post process using Geoscience Australia AUSPOS software
- Only three existing Standard Survey Marks available to make connection along the 250 km corridor
- Corridor divided into 15 km sections
- RTK base station established at the middle of the section over a new established control station
- Existing road was surveyed every 20 m using RTK GPS and Ground Control Points (GCPs) established every 2 km



Californian high-speed rail route

- JL Patterson, transportation engineering company
- First professional drone deployment
- 30-mile rail corridor with an eBee RTK
- Reported “phenomenal” data accuracy

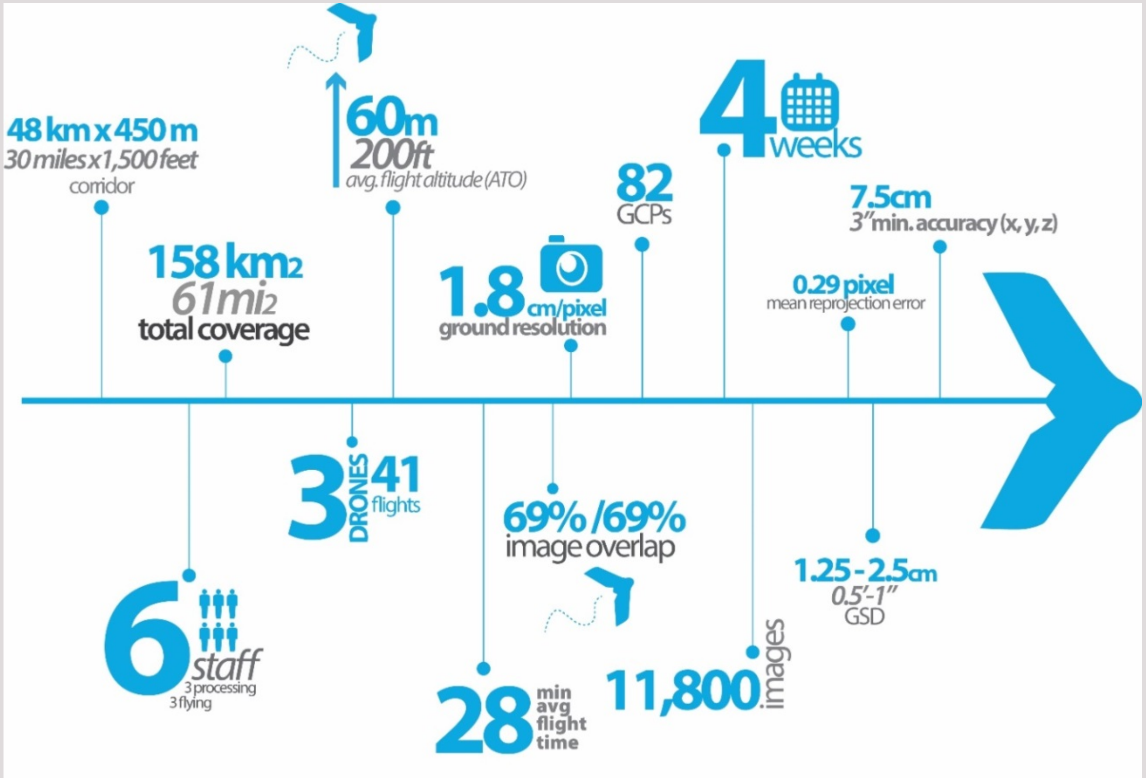
  - Completed the job in **<u>a quarter of the time</u>** of terrestrial surveying and **<u>half the cost</u>** of employing manned aerial services.



Californian high-speed rail route

- **"Traditional surveying would have required lengthy permits to access the railroad right-of-way and constant interruptions due to train traffic"**
  - RTK reduces drastically the amount of work on the ground

- Since mapping its first rail corridor, JLP has put its eBee RTKs to work on a range of subsequent projects, achieving similarly impressive outcomes.



Summary

- **Why RTK?**
  - Compatible with existing base stations
    - The eBee RTK is compatible with most leading brands of base station, working seamlessly alongside your existing portfolio of instruments
  - Fully integrated workflow
    - The eBee RTK's supplied flight planning & control software (eMotion) connects to the base station and broadcasts correction data to the rover (eBee RTK) – no additional logger or third-party software required.
  - Survey-grade accuracy
    - Absolute orthomosaic & digital surface model accuracy of down to 3 cm (1.2 in) without the need for GCPs – meaning less time spent in the field and high precision in even the most inaccessible areas.

Next Steps

- **Visit www.insidegnss.com/webinars** for a PDF of the presentations and a list of resources.
- Review the recorded version of today's webinar

Contact Info:

- **Inside GNSS- www.insidegnss.com**
- **u-blox – www.u-blox.com/en**

NEO-M8P is high precision for the mass market

- Affordable cm-level GNSS module
- Integrated Real Time Kinematic (RTK)
- Small and light
- Energy-efficient

https://www.u-blox.com/en/product/neo-m8p

Poll #3

Having attended today's webinar, my plans to purchase or acquire GNSS RTK has (please select one)

- ***Increased***
- ***Was just researching but now intend to purchase***
- ***Was just researching but now see no need to purchase***
- ***Decreased***

Ask the Experts – Part 2

Dr. Steven Waslander
Assoc. Professor, Department of Mechanical and Mechatronics Engineering
University of Waterloo

Bastien Mancini
Founder & Managing Director
delair tech

Francois Gervaix
Product Manager
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Thank you!

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