UAV-basierte LiDAR-Datenerfassung – so genau und so einfach wie möglich

Philipp Amon

Manager ULS Business Division,
RIEGL LMS GmbH

EPOSA Anwendertreffen 2024, 17.10.2024

Headquarters Austria | *Firmenzentrale Österreich*

The ***RIEGL* headquarters in Horn, Austria,** provides – all in all in a number of buildings – more than 74,000 square feet of working space for research, development, production, testing as well as for marketing, sales, training, and administration.

In addition, 350,000 square feet of open space are available and used for product testing.

*Die **RIEGL Zentrale in Horn** bietet – verteilt auf verschiedene Gebäude – mehr als 6.850 m² Arbeitsfläche für Forschung, Entwicklung, Produktion und Tests sowie für Marketing, Vertrieb, Schulung und Verwaltung.*

Weitere 32.500 m² Freifläche stehen für zusätzliche Tests zur Verfügung.

Headquarters Austria | *Firmenzentrale Österreich*

seit 1996
since 1996

seit 2006
since 2006

seit 2014
since 2014

seit 2021
since 2021

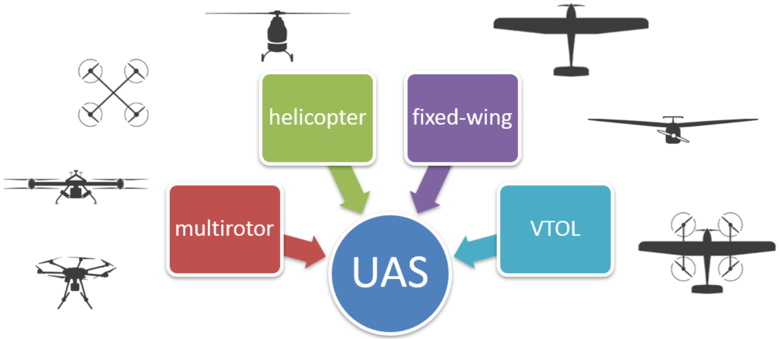
RIEGL Laser Scanners & Scanning Systems

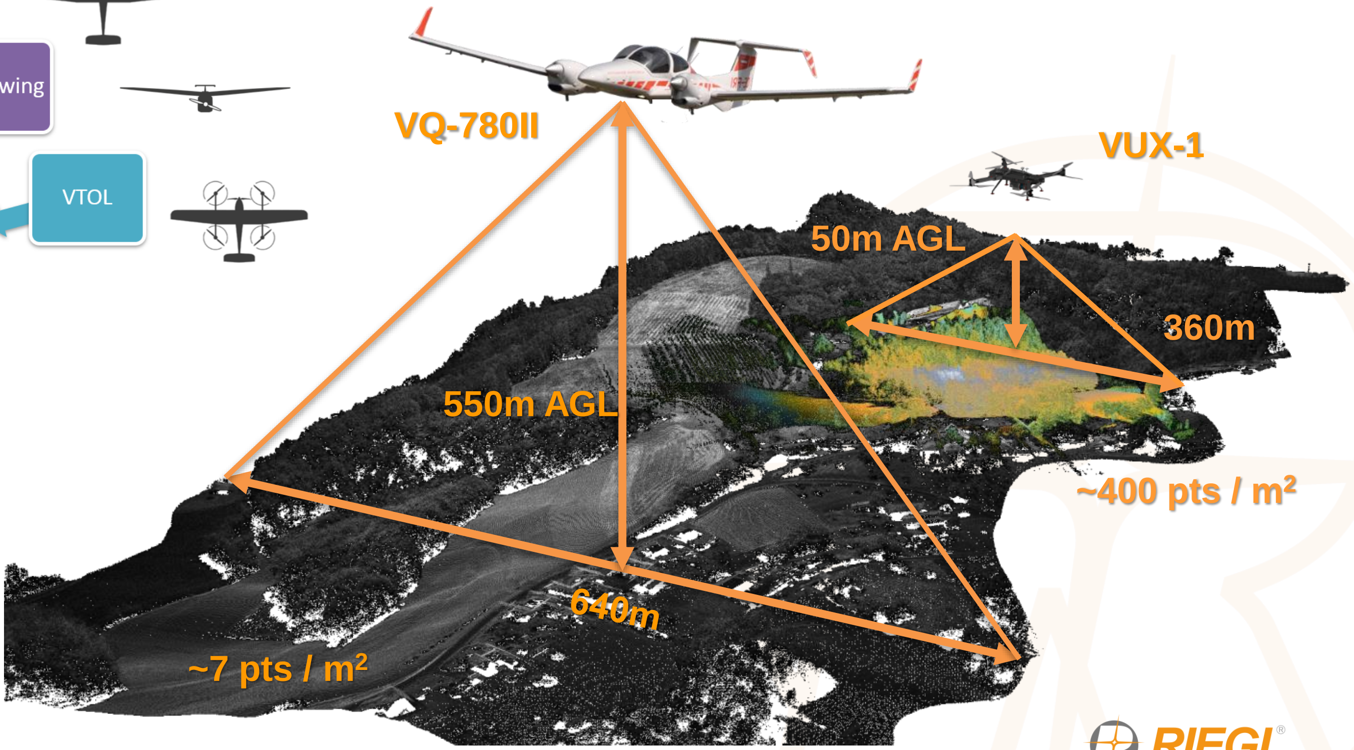
RIEGL Laserscanner & Scanning-Systeme

UAV-based Laser Scanning | *UAV-basiertes Laserscanning*

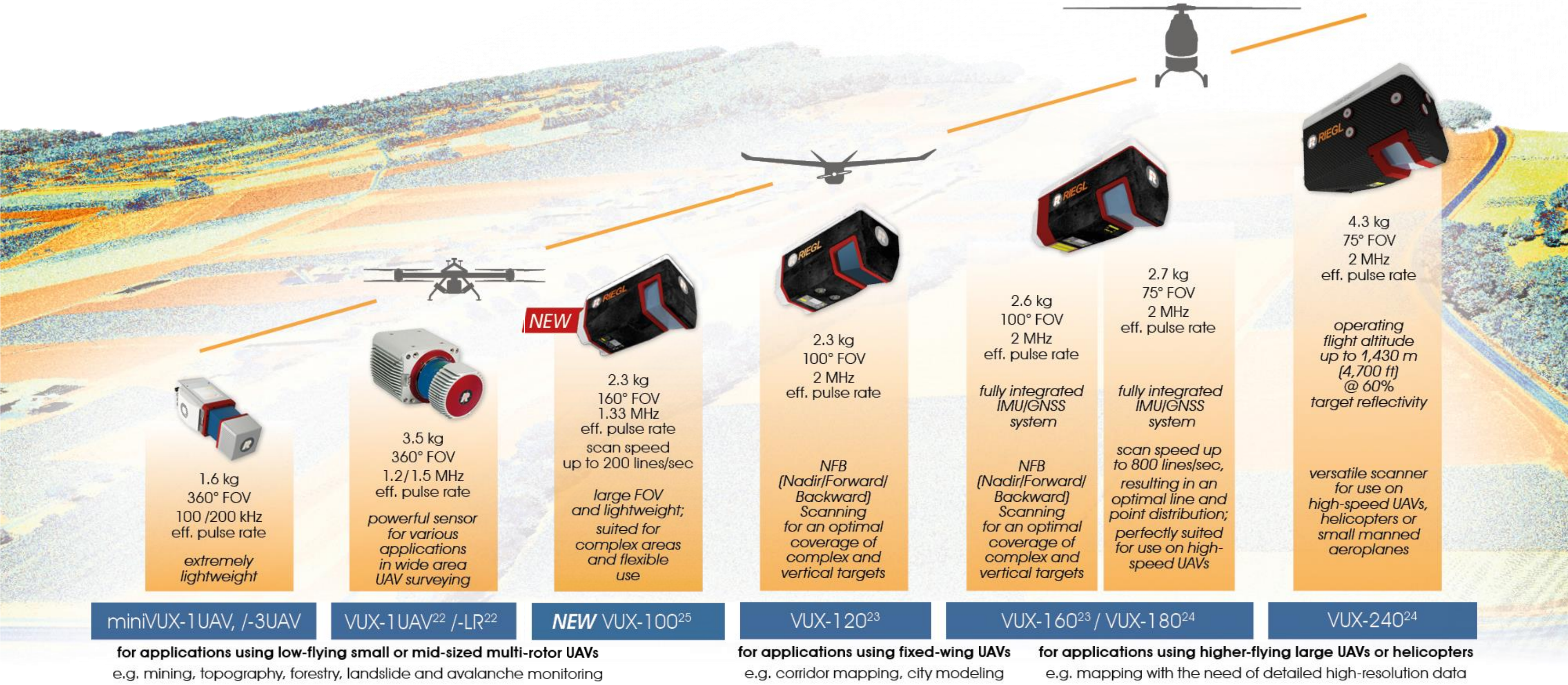
RIEGL®

Bemanntes (ALS) vs. UAV-basiertes Laser Scanning





RIEGL UAV-based Laser Scanning – Product Overview



“Open platform” configuration (VUX-1 series)

- unterschiedliche Systemkonfigurationen auf derselben standardisierten Montageplatte
- verschiedene Kameraoptionen verfügbar:
  - **RGB - Sony α6100, α7R III, α7R iV**
  - **RGB - Sony ILX-LR1 in Industriequalität**
  - **Multispektralkamera (basierend auf Sony αx)**
  - **Wärmebildkamera (Flir Tau 2)**
- bis zu 3 Kameras
  - nadir, verschiedene schräge Winkel
- Gewichts- und Balance-Optionen
- shock-gedämpfte Platte (optional)
- Stromversorgung und Ansteuerung via Scanner

UAV Integration Examples | *UAV Integrationsbeispiele*






RIEGL®

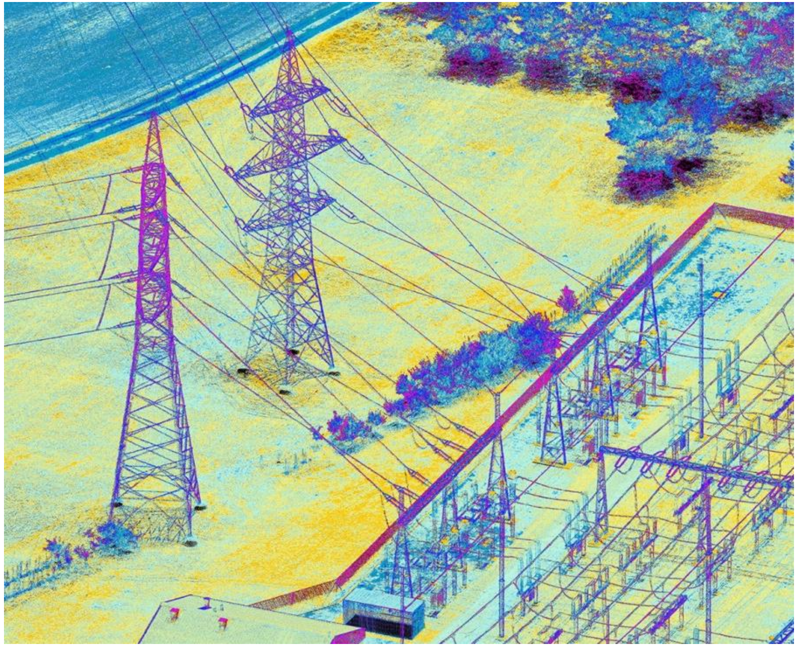
VTOL Integration Examples

RIEGL

RIEGL VUX-100^{25}

NEW

Stromleitungsbefliegung



RiLOC-E / RiLOC-F
Location and Orientation Component

RIEGL miniVUX-3UAV with RiLOC-E

Innovation in 3D

Motivation

Entry level system

User friendly

Versatile

Safe

Fast

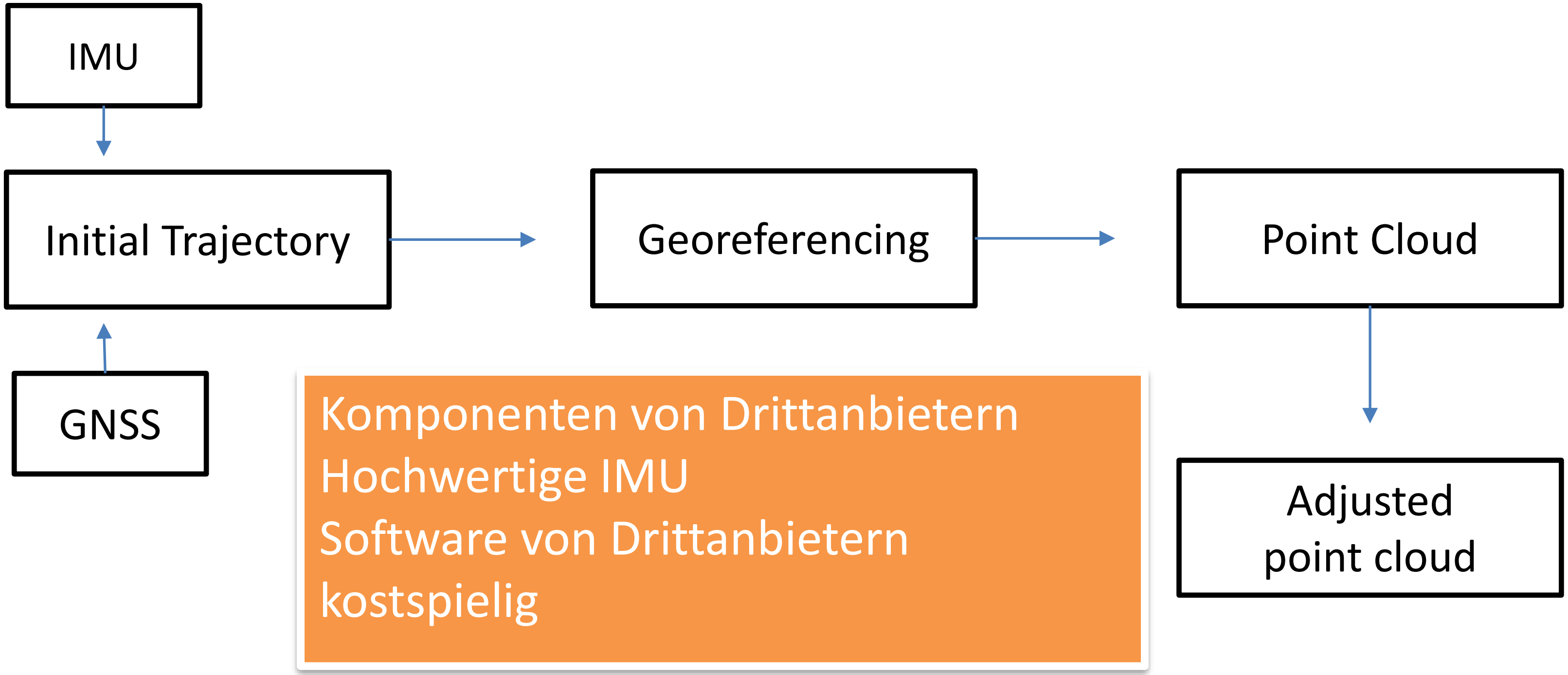
Efficient

Accurate

Attractive price level

no third party components

Status quo

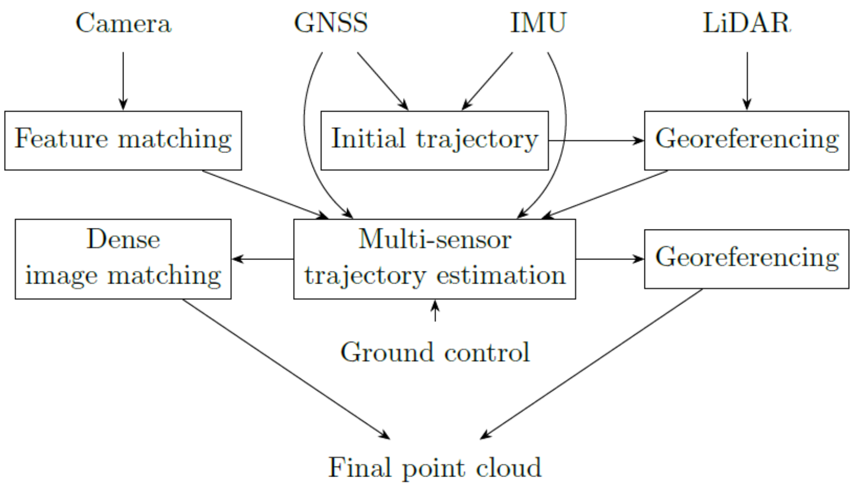

IMU
Initial Trajectory
GNSS
Georeferencing
Point Cloud
Adjusted point cloud
Komponenten von Drittanbietern
Hochwertige IMU
Software von Drittanbietern
kostspielig

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria




ISPRS Journal of Photogrammetry and Remote Sensing 196 (2023) 287–305

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Integrated trajectory estimation for 3D kinematic mapping with GNSS, INS and imaging sensors: A framework and review

Florian Pöppl *, Hans Neuner, Gottfried Mandlburger, Norbert Pfeifer

Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria

ARTICLE INFO

Keywords:
Sensor orientation
Sensor fusion
Georeferencing
LiDAR
Camera

ABSTRACT

Trajectory estimation refers to the task of obtaining position and orientation estimates by fusing various sensor inputs. In kinematic mapping, global navigation satellite systems (GNSS) and inertial navigation systems (INS) are traditionally used to compute a trajectory which then serves as basis for direct or integrated orientation of the imaging sensors. As an inherently interdisciplinary problem, literature on trajectory estimation is broad. Apart from remote sensing itself, many recent advances come from autonomous navigation and robotics. This paper aims to provide a unified view of trajectory estimation with a focus on its role in kinematic mapping, specifically on the integration of GNSS, INS, laser scanners and cameras, as well as a survey of the related literature. Recent trends and challenges in trajectory estimation are identified and discussed.

1. Introduction

Laser scanning and photogrammetric imaging are widely used for remote sensing tasks such as mapping and surveying (Toth and Jóźków, 2016). These techniques rely on optical imaging sensors, specifically laser scanners and frame cameras, to obtain georeferenced 3D point clouds and other 3D models of the environment. *Kinematic mapping* refers to mapping with moving sensor platforms. It includes mobile mapping (e.g., car- or train-based) and airborne mapping (e.g., drone-, helicopter-, or plane-based). Modern kinematic mapping systems are multi-sensor systems (MSS), where all sensors are mounted together on a moving platform. In addition to the imaging sensors, the MSS typically includes a global navigation satellite system (GNSS) and an inertial navigation system (INS) to facilitate the determination of the platform *trajectory* (position and orientation over time).

The aim of this contribution is to provide an as-yet missing unified view of trajectory estimation, with focus on mapping and surveying applications and the accompanying requirements with respect to accuracy and sensors used. *Trajectory estimation* refers here to the task of estimating a trajectory based on various sensor inputs with respect to a given georeferenced coordinate system. In contrast to navigation, trajectory estimation emphasizes the recovery of position and orientation not just for the current moment but over a period of interest. More generally, *estimation* is the problem of recovering a systems' internal state from noisy measurements (Jazwinski, 1970).

In the context of surveying, the industry standard for trajectory estimation is GNSS/INS integration through Kalman filtering, exploiting the synergy between inertial sensors and satellite navigation (Groves, 2013; Toth and Jóźków, 2016). The resulting trajectory may still exhibit significant errors, especially in the case of challenging GNSS conditions, making the quality of the trajectory a limiting factor for the quality of the 3D model. These trajectory errors can be partially mitigated at the trajectory level, e.g., via subsequent trajectory correction (Glira et al., 2019; Zhou et al., 2021) by exploiting redundancy in the imaging sensor measurements. Alternatively, other additional sensors may be used to improve trajectory accuracy: In mobile mapping, distance measuring instruments commonly provide wheel odometry information (Meng et al., 2017). Magnetic field sensors provide heading information (Sabatini, 2006), but are hard to calibrate due to systematic distortions of the magnetic field. Range cameras, event cameras, 2D laser scanners and low-cost variants thereof are popular in robotics (Cadena et al., 2016; Chen et al., 2018b). However, this work focuses on survey-grade 3D laser scanners and frame cameras as imaging sensors, as used in high-accuracy mapping applications.

The ubiquity of sensors and the associated wealth of (possibly unsynchronized) measurements require versatile estimation methods capable of fusing the various types of sensor input. Many such methods fall under the umbrella of *simultaneous localization and mapping* (SLAM, cf. Cadena et al., 2016). The focus is on real-time capability, often for the purpose of autonomous navigation (Kolar et al., 2020). While the SLAM map is in many cases only of interest insofar as it provides a means for reliable and globally consistent localization,

* Corresponding author.
E-mail addresses: florian.poeppl@geo.tuwien.ac.at (F. Pöppl), hans.neuner@geo.tuwien.ac.at (H. Neuner), gottfried.mandlburger@geo.tuwien.ac.at (G. Mandlburger), norbert.pfeifer@geo.tuwien.ac.at (N. Pfeifer).

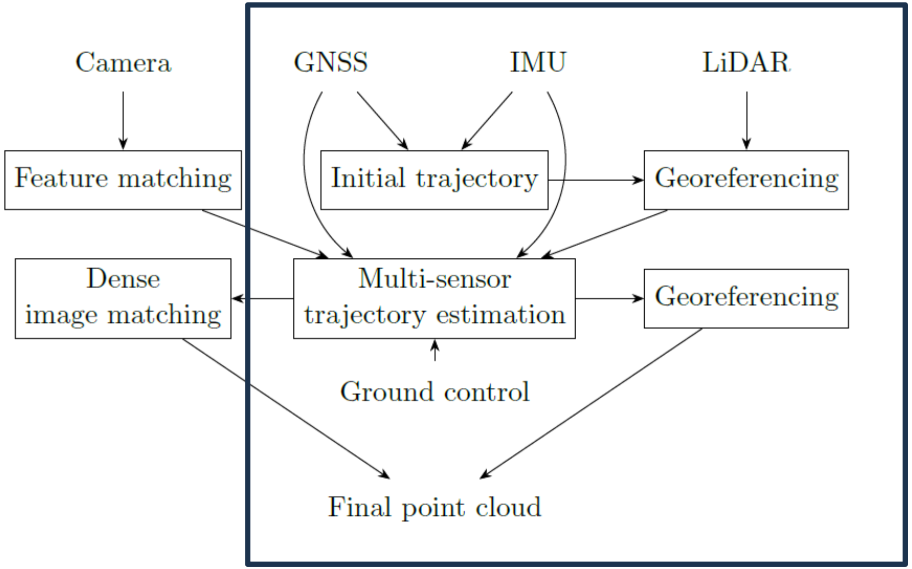
https://doi.org/10.1016/j.isprsjprs.2022.12.022
Received 2 July 2022; Received in revised form 4 November 2022; Accepted 22 December 2022
Available online 12 January 2023

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria

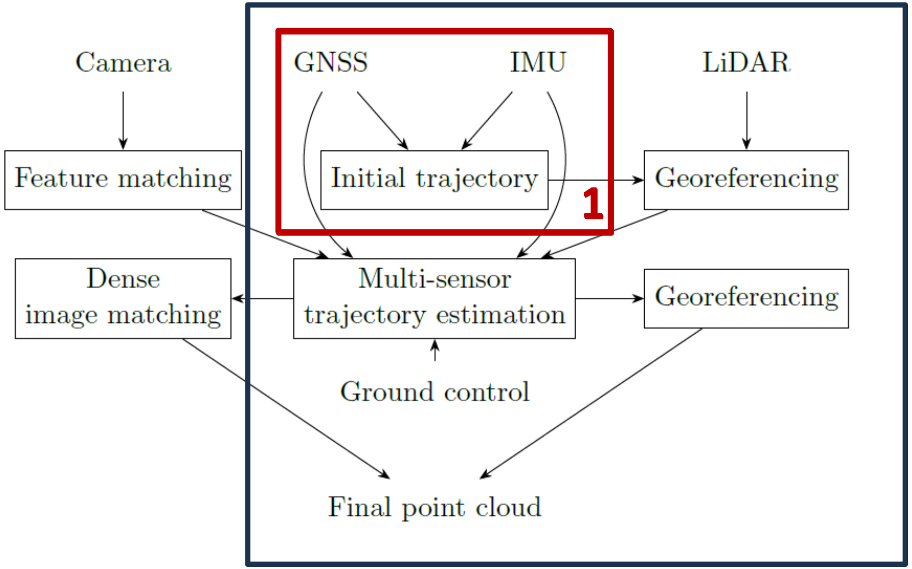


Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria



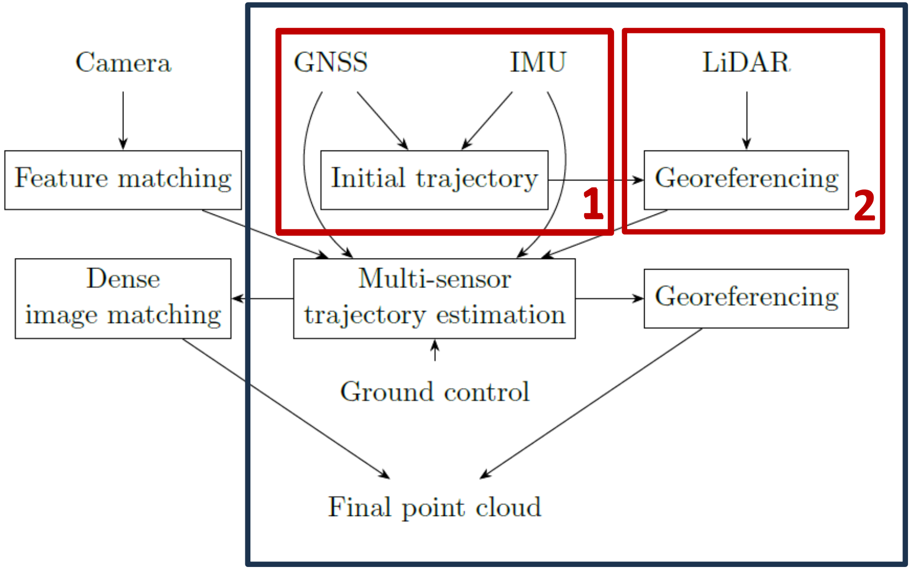
1. calculating initial trajectory

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]*Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria*



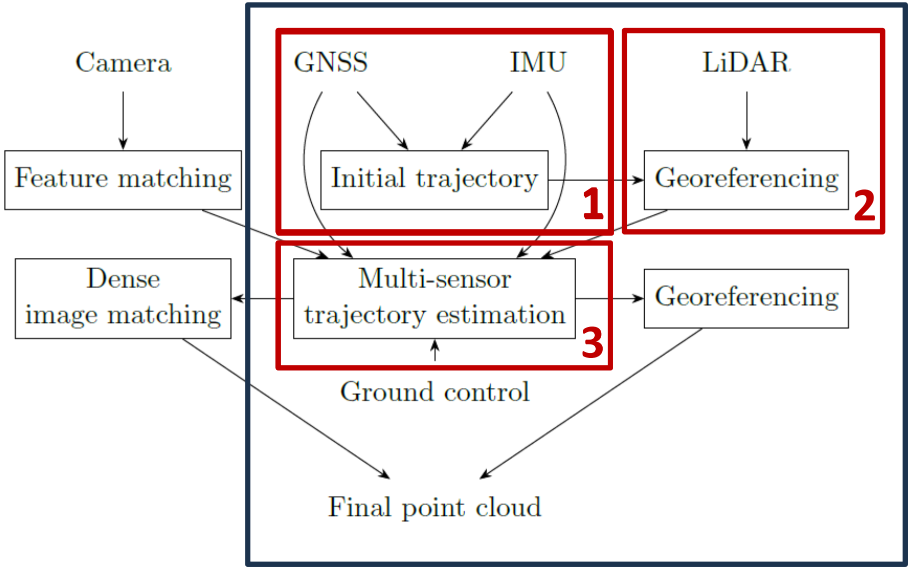
1. calculating initial trajectory
2. initial georeferencing of lidar data

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]*Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria*



1. calculating initial trajectory
2. initial georeferencing of lidar data
3. re-calculating trajectory from IMU **raw** data, GNSS positions, and lidar/image observations

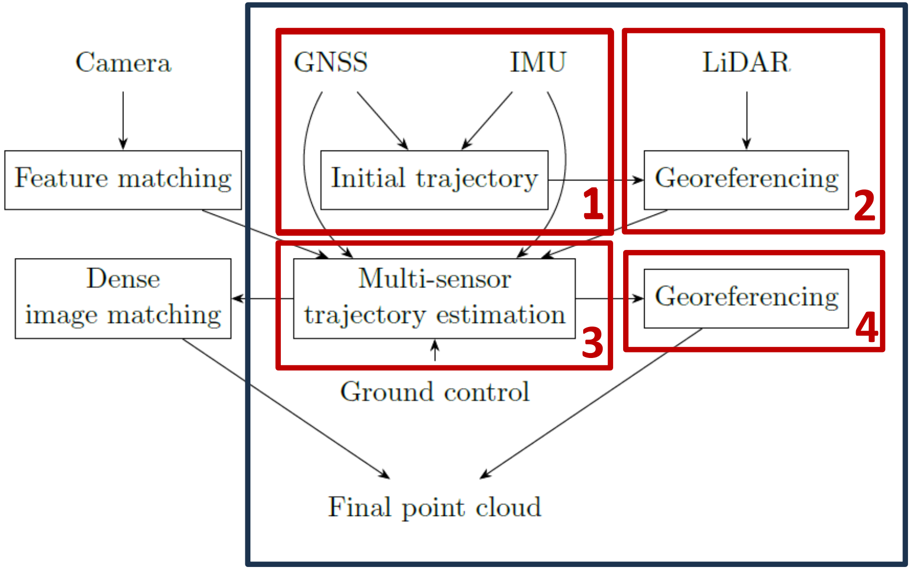
RIEGL®

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a]Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria



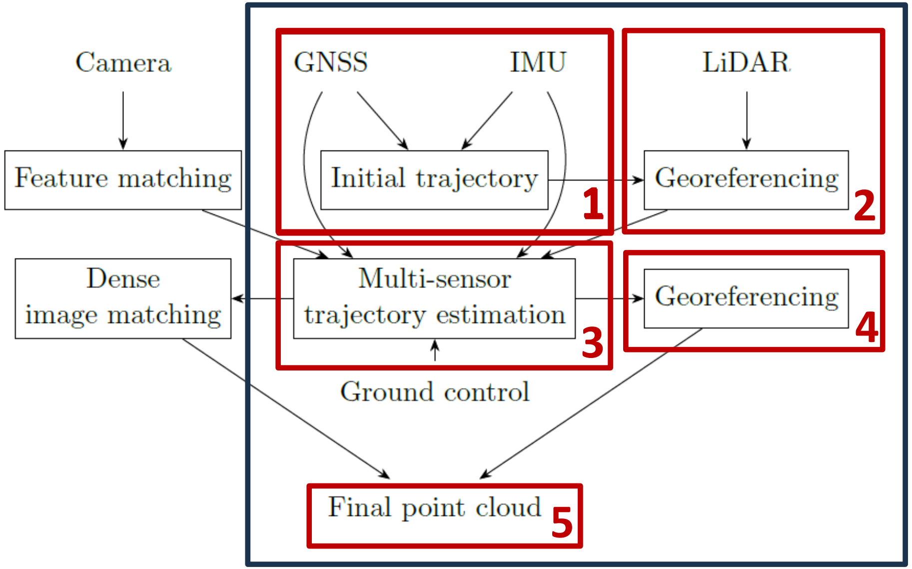
1. calculating initial trajectory
2. initial georeferencing of lidar data
3. re-calculating trajectory from IMU **raw** data, GNSS positions, and lidar/image observations
4. final georeferencing of lidar data

Theoretische Grundlagen

Integrated Trajectory Estimation for 3D Kinematic Mapping with GNSS, INS and Imaging Sensors: A Framework and Review

Florian Pöppl[a], Norbert Pfeifer[a], Hans Neuner[a]

[a] *Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8/E120, 1040 Wien, Austria*



1. calculating initial trajectory
2. initial georeferencing of lidar data
3. re-calculating trajectory from IMU **raw** data, GNSS positions, and lidar/image observations
4. final georeferencing of lidar data
5. final point cloud

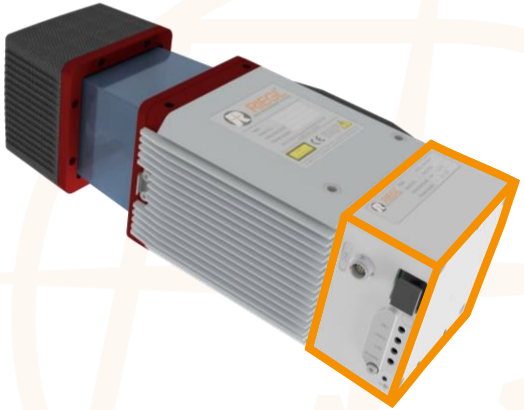
RIEGL RiLOC-E

Location and Orientation Component

- **Specifications**
  - MEMS-based IMU + GNSS system
  - multiband GNSS: L1/L2
    (GPS, GLONASS, Galileo, BeiDou)
  - IMU sampling rate: > 800 Hz
  - IMU angular rate range: ± 500 °/s
  - Performance, position: 0.02 – 0.05 m
  - total system weight: **1.75 kg** / 3.86 lbs

- **Highlights**
  - ✓ **fully integrated system**
  - ✓ **no 3rd party hardware needed**
  - ✓ **no 3rd party software required**

RIEGL's entry-level IMU/GNSS solution for miniVUX series laser scanners



→ perfect entry-level system
→ for small multirotor UAVs

NEW

RIEGL RiLOC-F

Location and Orientation Component

- **Specifications**
  - **high-precision** MEMS-based IMU
  - multi-constellations (GPS, GLONASS, Galileo, BeiDou) & **up to triple-frequency**
  - IMU sampling rate: > 700 Hz
  - IMU angular rate range: ± 300 °/s
  - performance, position: **0.02 – 0.03 m**
  - RiLOC-F weight: **0.36 kg** / 0.8 lbs

- **Highlights**
  - ✓ **fully integrated IMU/GNNS system**
  - ✓ **no 3rd party hardware needed**
  - ✓ **no 3rd party software required**

RIEGL's IMU/GNSS solution for VUX-series laser scanners

system total weight (directly attached):

- **VUX-100²⁵**: 2.51 kg
- **VUX-120²³**: 2.66 kg

Innovation in 3D

Integration on various UAVs

Integration kit for DJI M300 & M350 RTK

IK300/350 components:

- mounting plate + shock absorbers
- GNSS antenna (Callian UAV antenna) + cables + antenna mount
- electrically fully integrated (with OSDK module)

Supported systems:

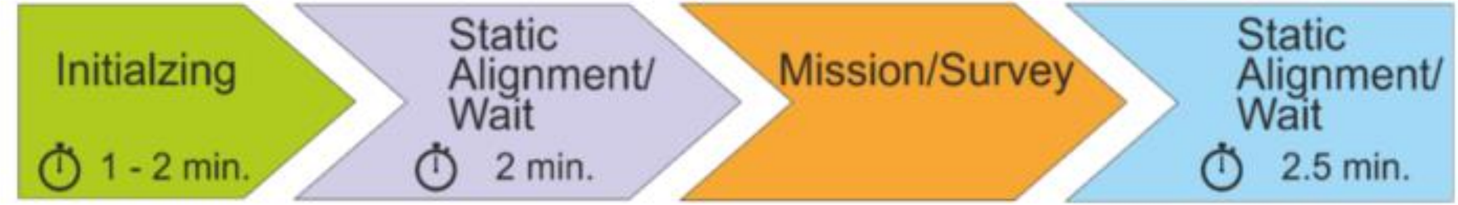
- **miniVUX-1/-3UAV + RiLOC** (1.75 kg / 3.86 lbs)
- miniVUX-1/-3UAV + APX-15 UAV (2.2 kg / 4.85 lbs)
- camera weight additional and fully supported

Key features:

- fast, easy and user-friendly integration
- instruction manual included
- fully automatic operation running RiACQUIRE-Embedded
- no user action required during operation → RXP Cutter

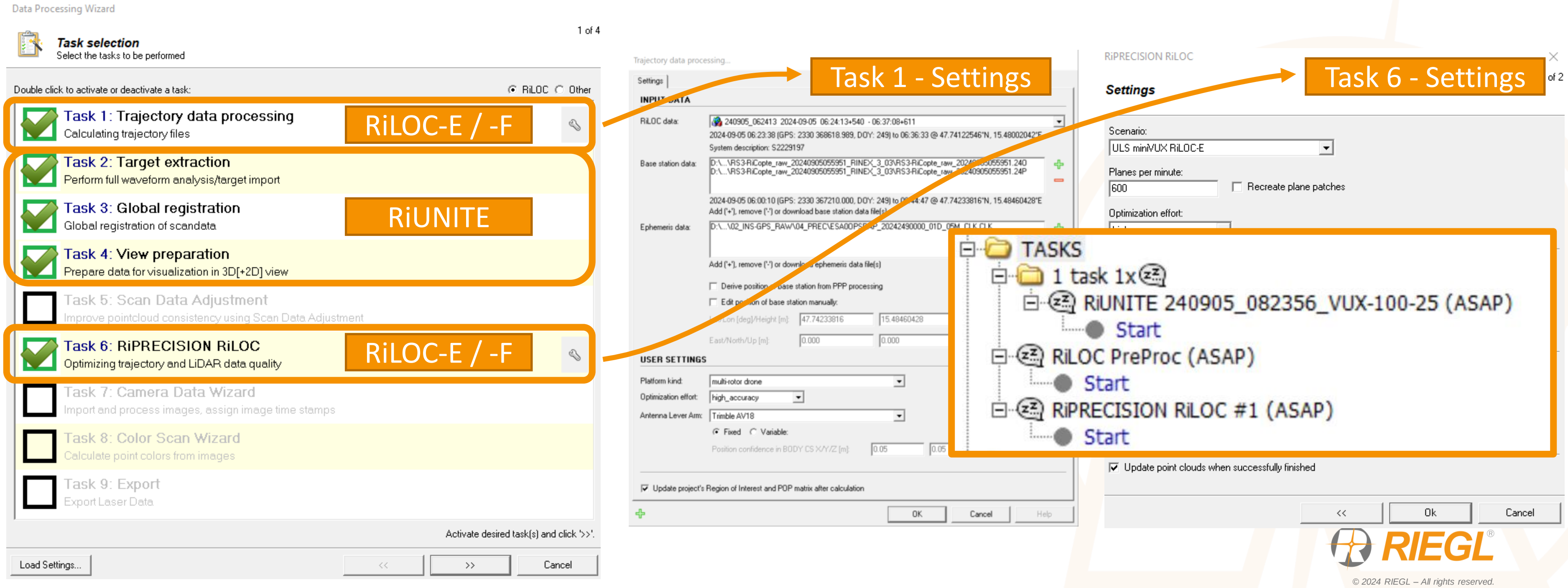
Datenaufnahme – Was ist dabei zu beachten?

- RISD vorbereitet für DJI M350 RTK, Acecore Noa, - Zoe UAV Plattformen
- **SINGLE** Basisstation + RTK (kurze Basislinie < 10 km) oder VRS
- überschneidende Flugstreifen mit mindestens 25% Überlappung
- Höhenänderungen und/oder künstliche Objekte mit ebenen Merkmalen



RiPROCESS RiLOC-E/-F – post-processing workflow

- nahtlose Integration in den Post-Processing-Workflow
- Automatisierung über RiPROCESS – Data Processing Wizard



RIEGL VUX-120 with RiLOC-F

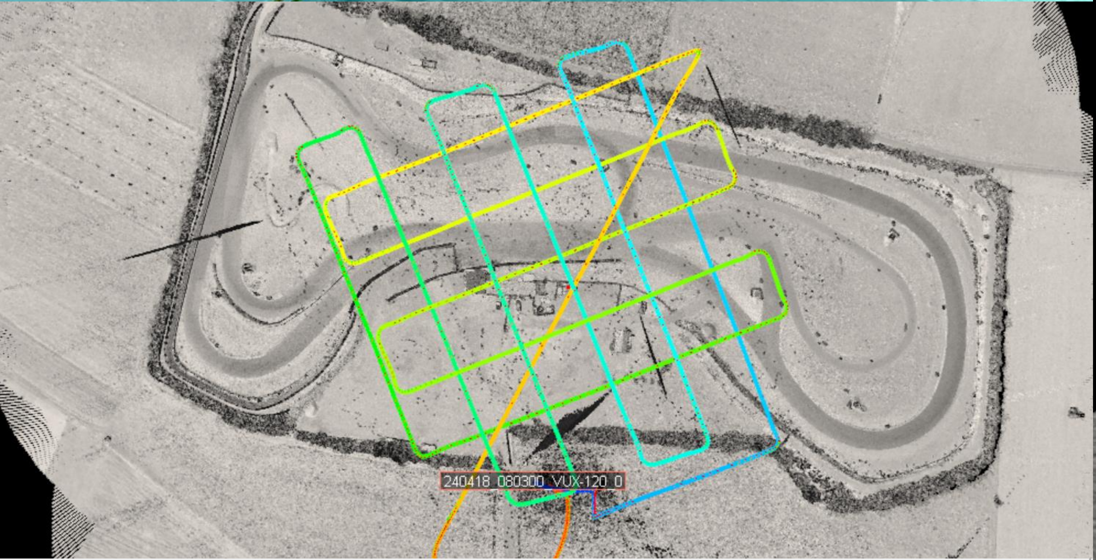
lokale Rennstrecke

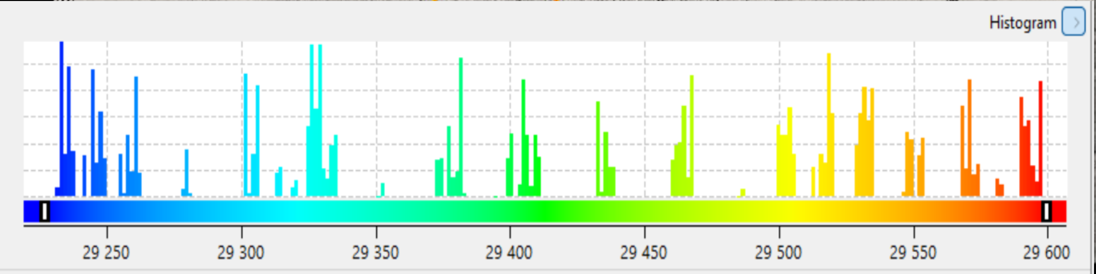
- viele horizontale Flächen, wenige Gebäude
- Betriebshöhe: 75 m AGL
- Mäanderförmiges Flugmuster
- kontinuierliche Datenaufzeichnung (auch in Kurven)

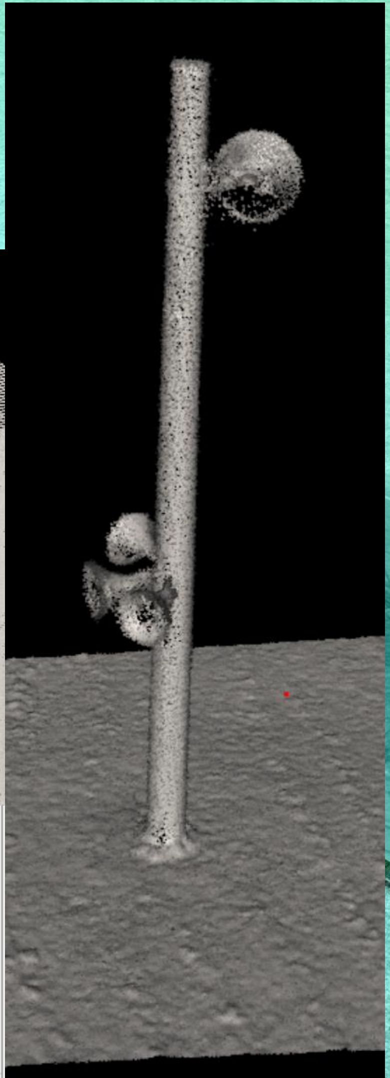

VUX-120 + RiLOC-F
Height + Reflectance combined

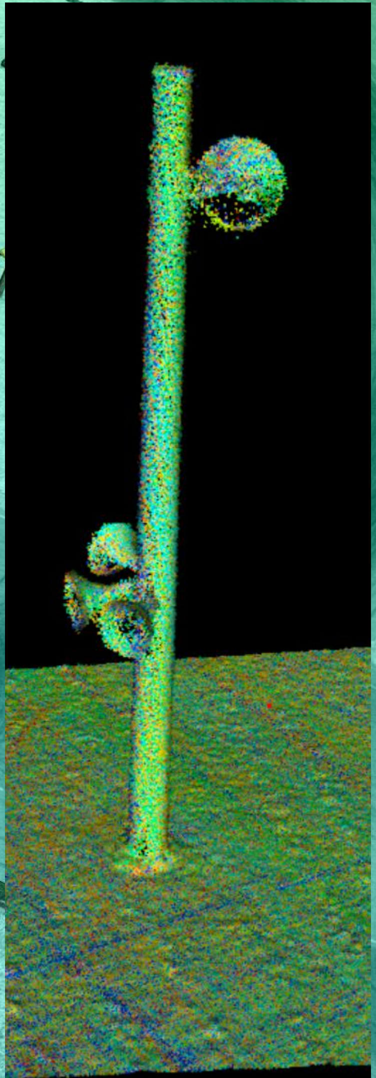
VUX-120 + RiLOC-F

Alignement of traces



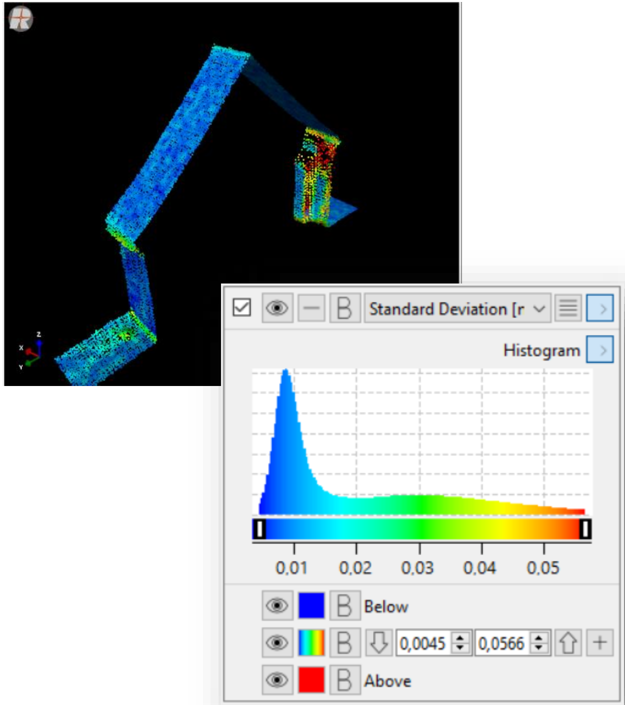


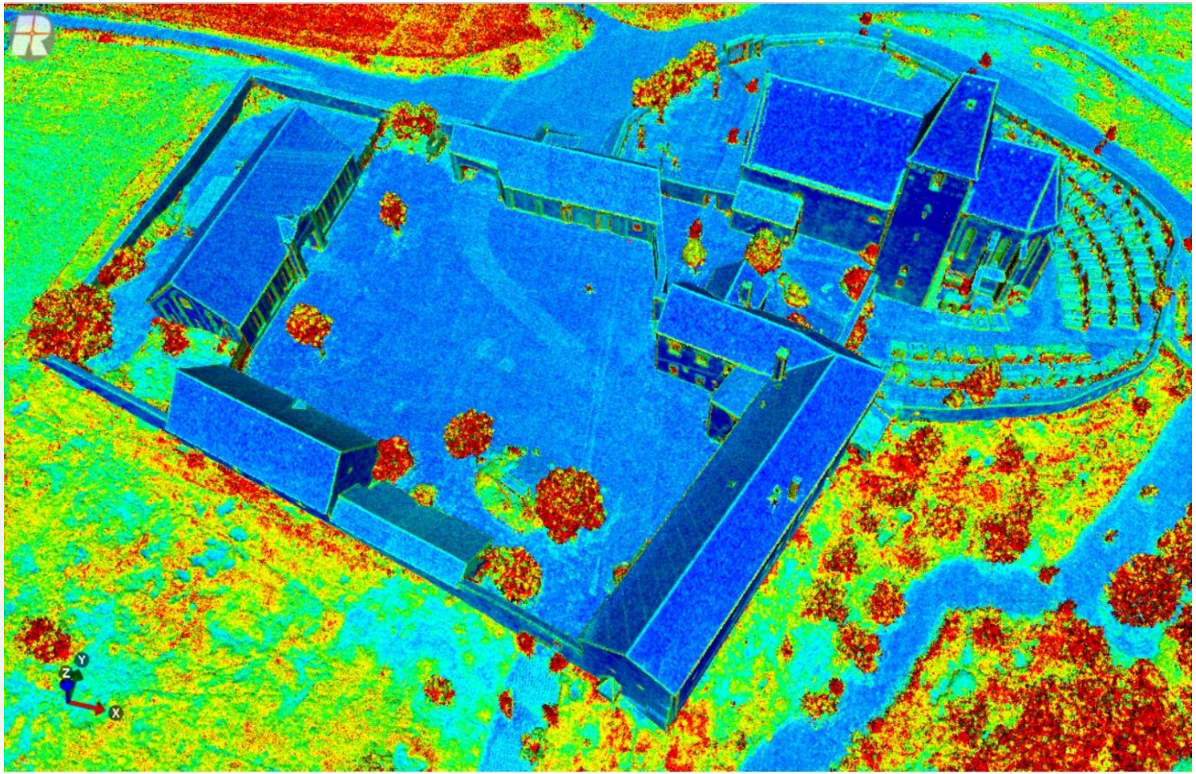




RIEGL

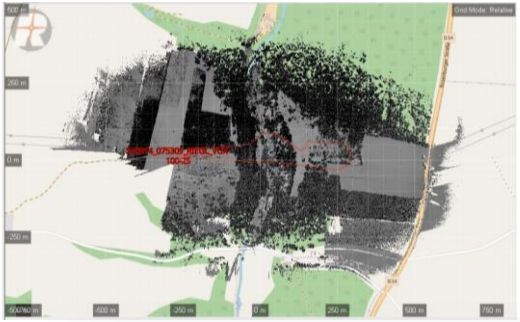
Datenqualität (StdDev.)

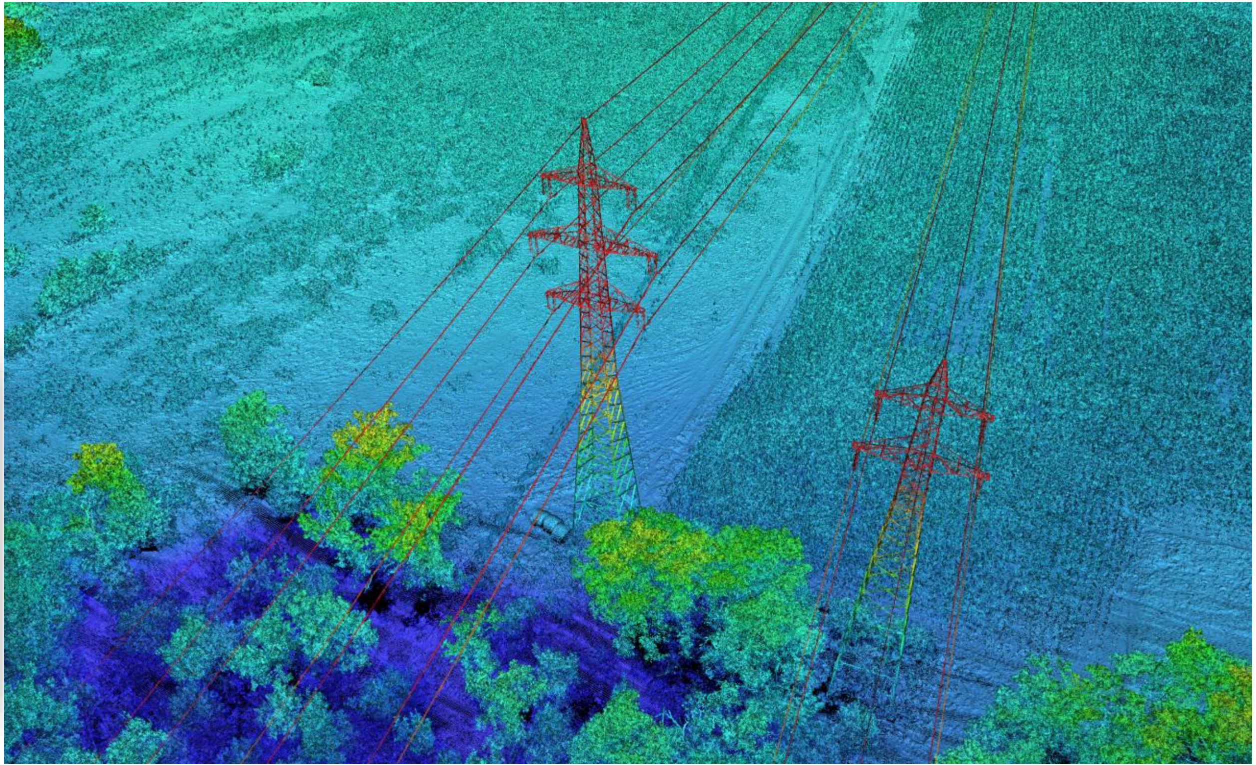




RIEGL

VUX-120 + RiLOC-F





RIEGL VUX-120 with RiLOC-F

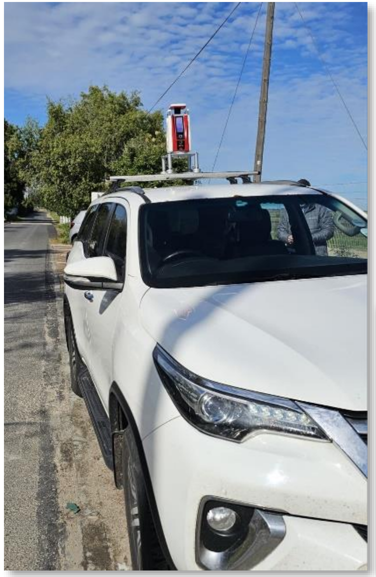
Substation, power lines

- few buildings, transformers
- meandering flight pattern and
- “stitch flight” along power line

Kinematic App

Kinematic App

...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen





photos are showing experimental testing platforms

RIEGL®

Kinematic App

...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen

***RIEGL* VZi GNSS RTK Receiver**
L1+L2 receiver, real-time
base station correction data

low € high

***RIEGL* VZ-2000i / VZ-600i**
long range (up to 2.5 km)
high speed (up to 500k meas/sec)

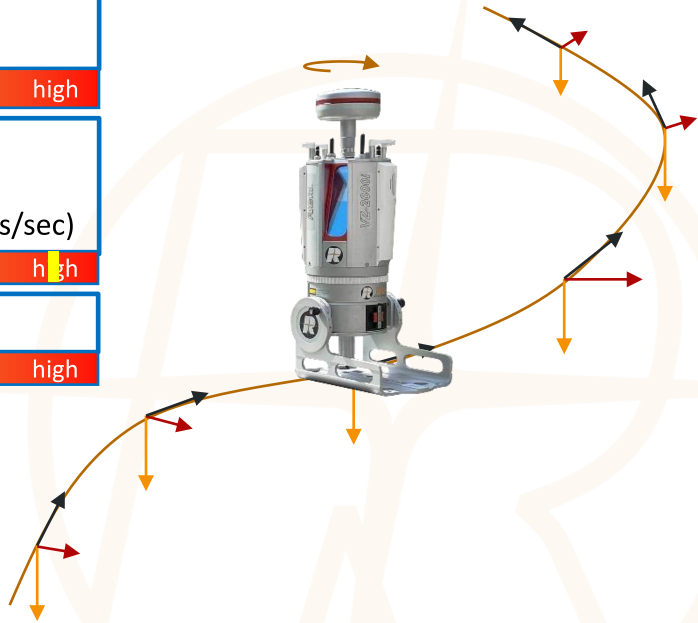
low € high

Internal IMU

low € high

Internal data processing and storage

***RIEGL* Add-On Battery**
3x Li-Ion batteries



RIEGL®

Kinematic App

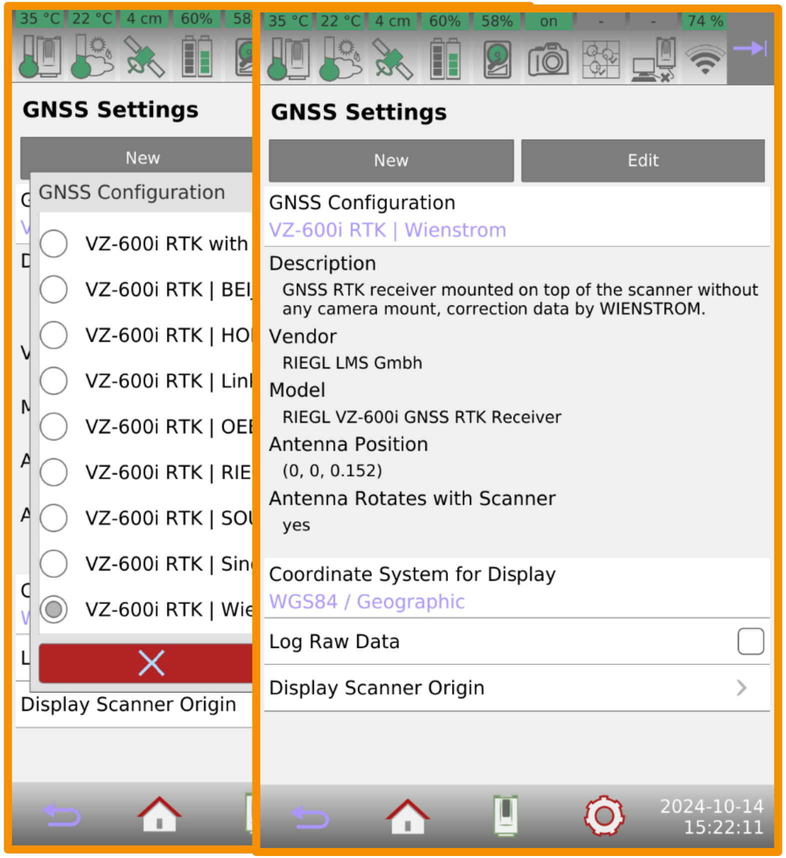
...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen

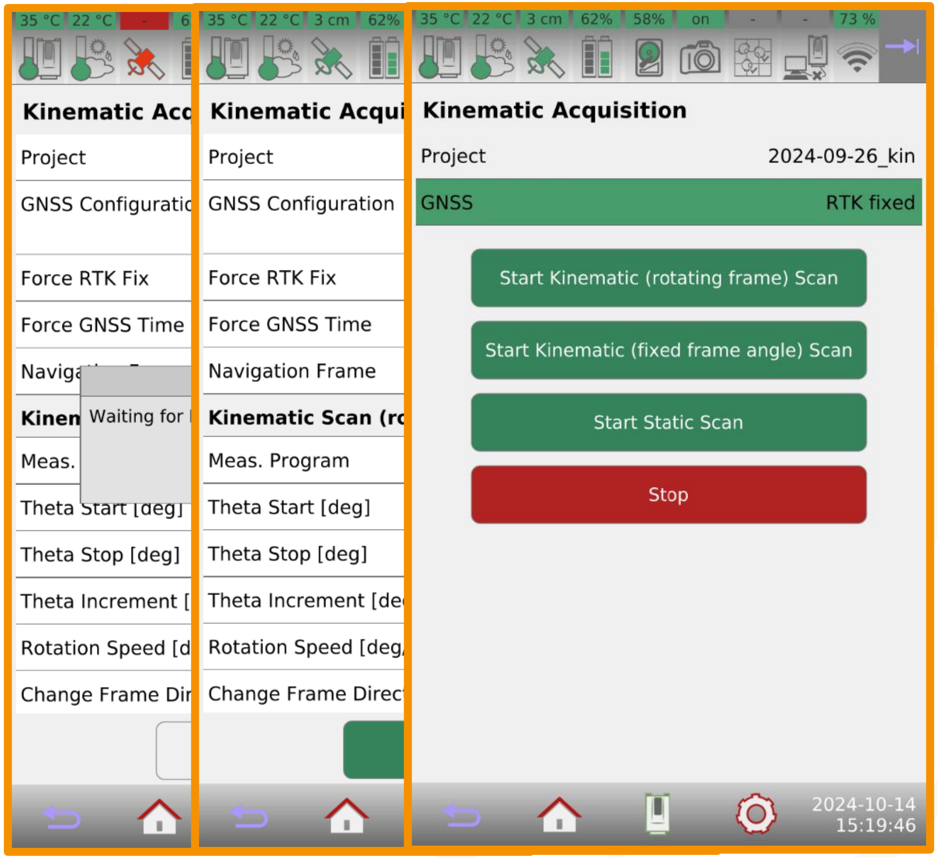
Empfehlungen zur Erzielung hochwertiger Endergebnisse:

- RTK-Korrekturdaten erforderlich
- maximale Geschwindigkeit der Plattform 15km/h (10mph)
- Meiden von GNSS schwachen Gebiete
- Sicherstellung einer stabilen Position für den statischen Scan zu Beginn und am Ende Ihres mobilen Projekts

RIEGL®

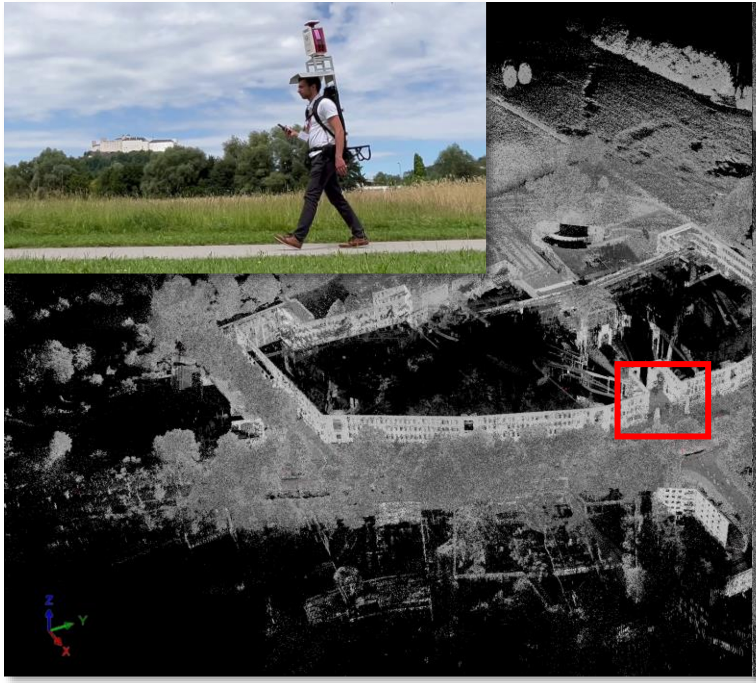
RTK Einstellungen am Scanner

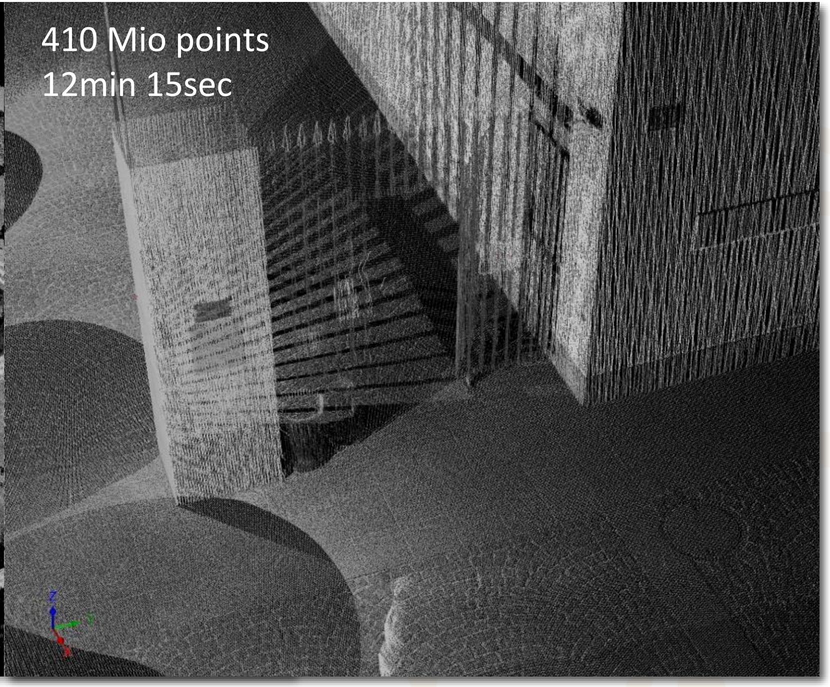




Kinematic App

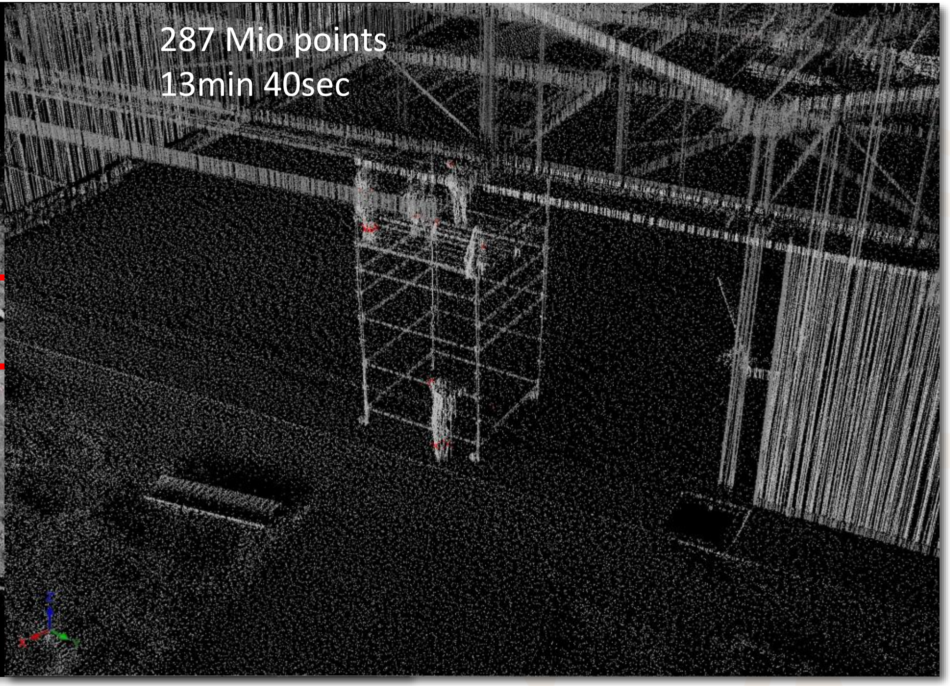
...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen





Kinematic App

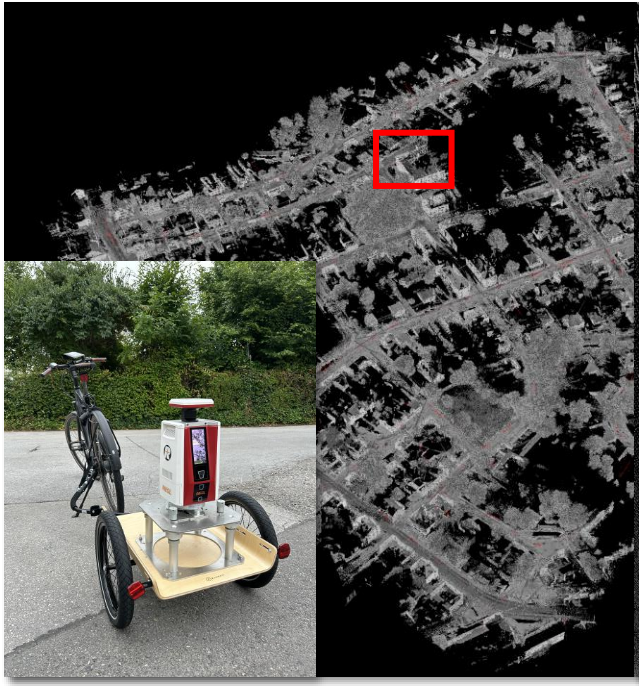
...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen



RIEGL

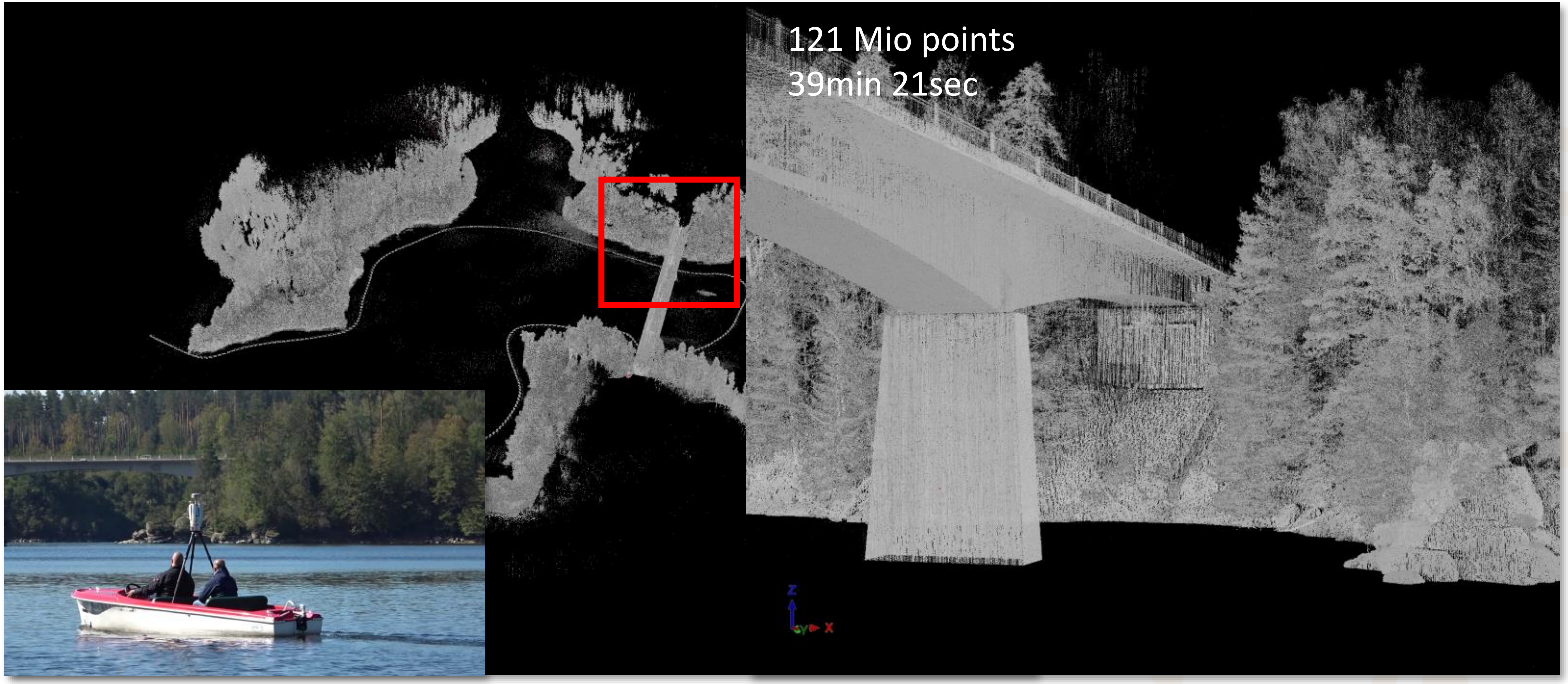
Kinematic App

...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen



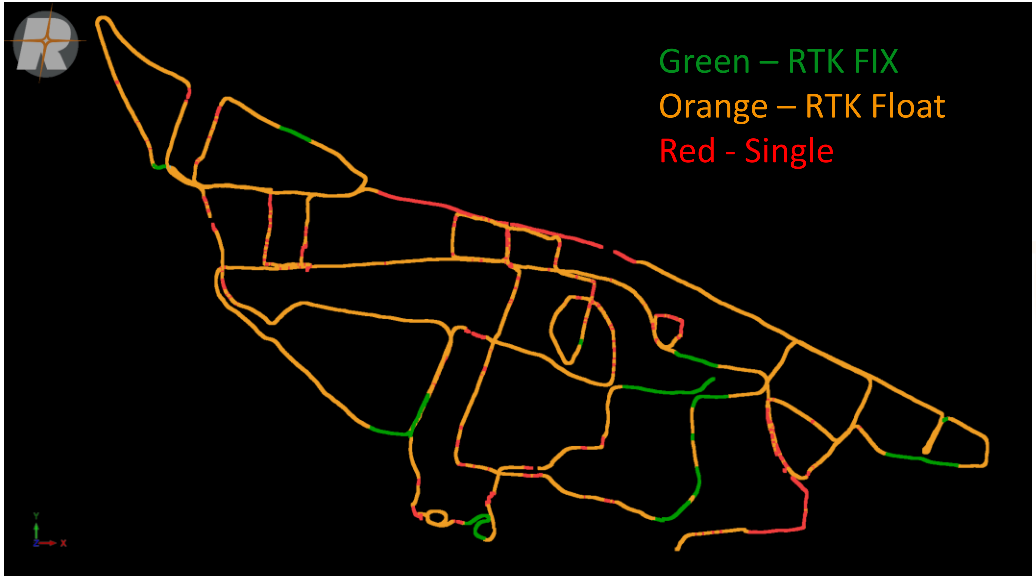
Kinematic App

...für die kinematische Datenerfassung von verschiedenen beweglichen Plattformen



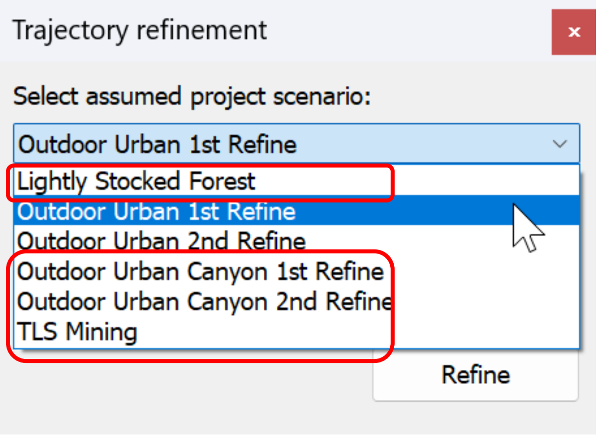
Further Improvements on VZ-i Series Kinematic App

- Datenerfassung bei schlechter GNSS-Qualität
- beim Start der Trajektorie ist ein „RTK-Fix“ obligatorisch
- während der Datenerfassung kann die GNSS-Qualität vorübergehend auf RTK-Float oder sogar eine einzige Lösung fallen



Further Improvements on VZ-i Series Kinematic App

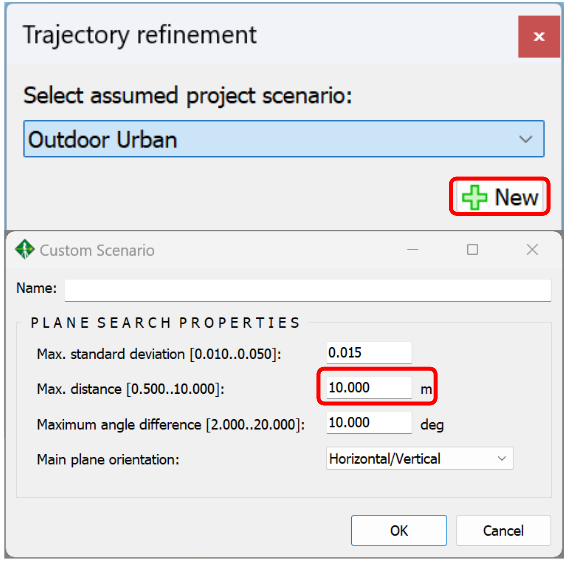
- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios

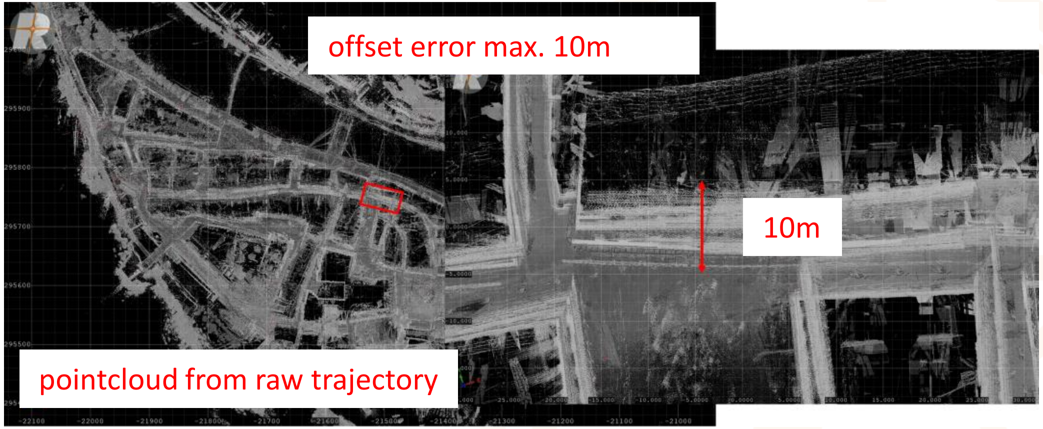


RIEGL

Further Improvements on VZ-i Series Kinematic App

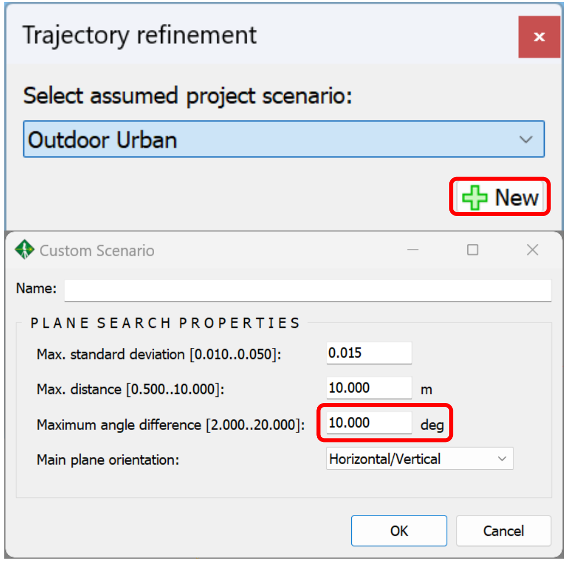
- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios

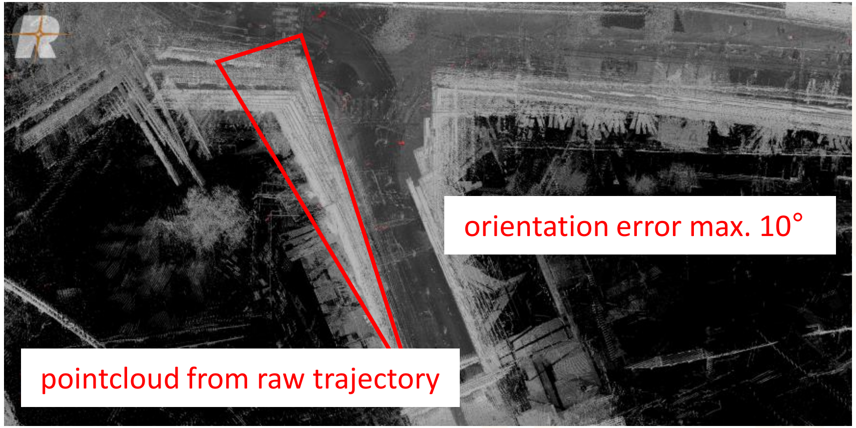




Further Improvements on VZ-i Series Kinematic App

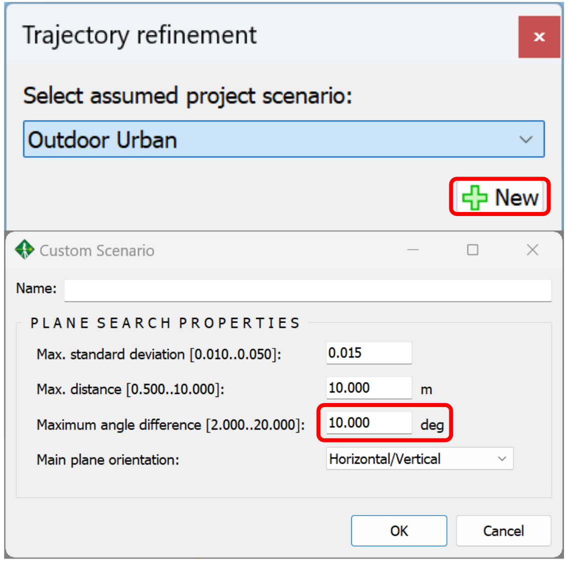
- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios

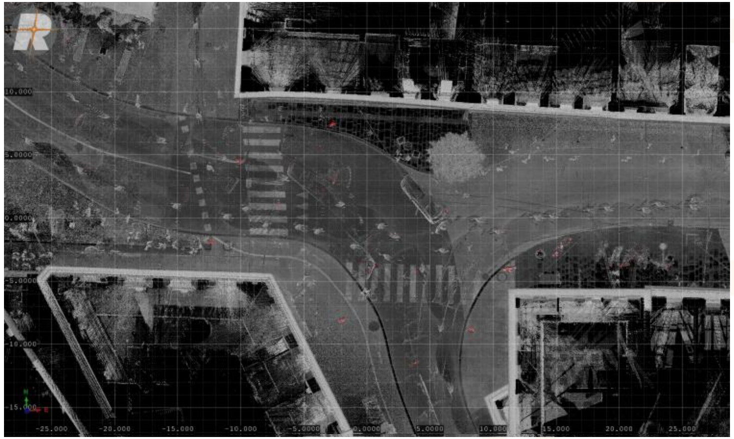




Further Improvements on VZ-i Series Kinematic App

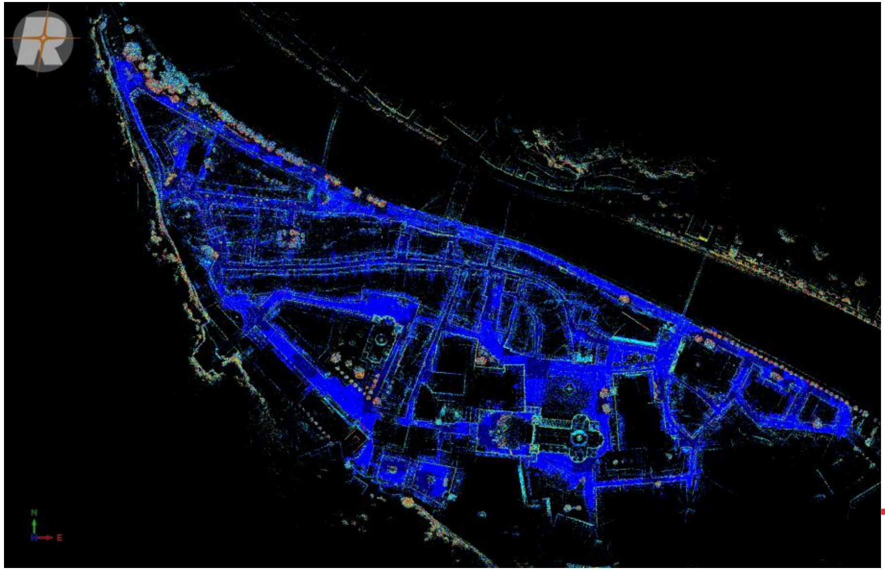
- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios

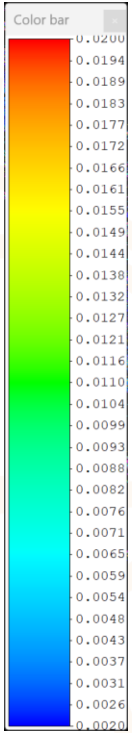




Further Improvements on VZ-i Series Kinematic App

- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios
- nachgewiesene objektbasierte Genauigkeit durch gescannte Objekte über Voxel-Datensatz

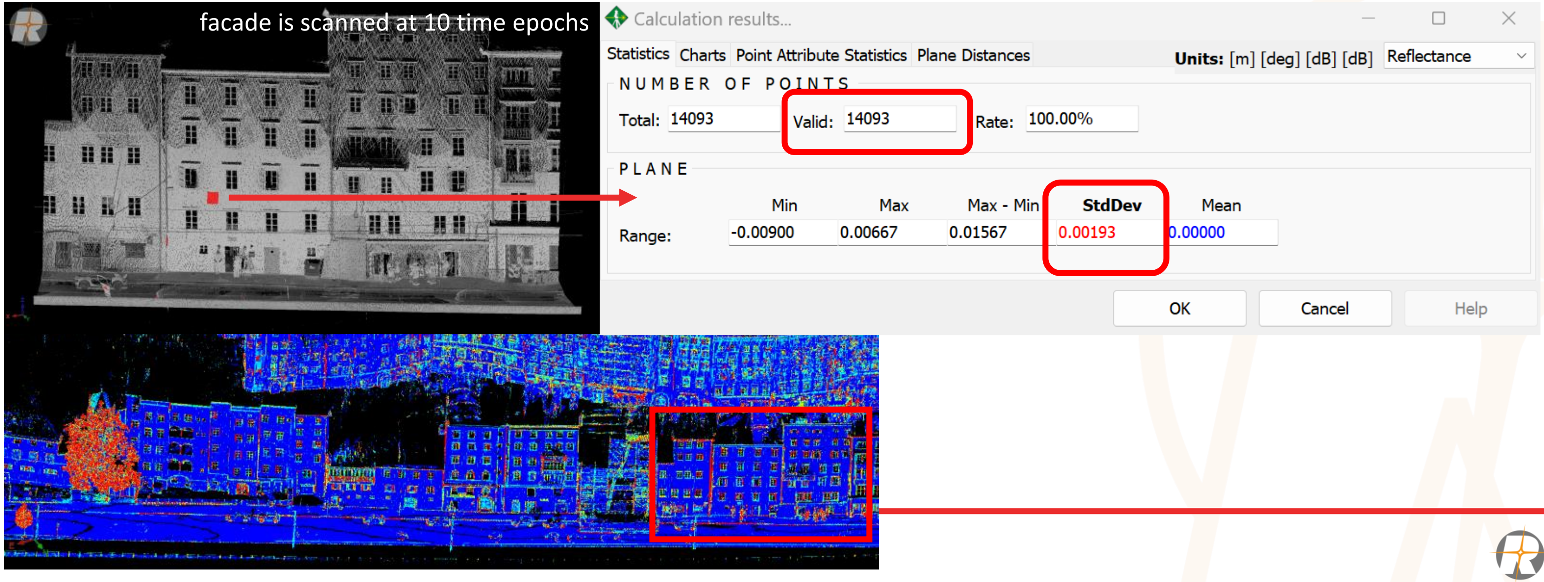


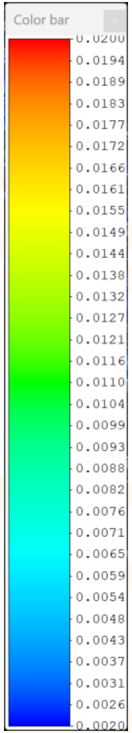


RIEGL

Further Improvements on VZ-i Series Kinematic App

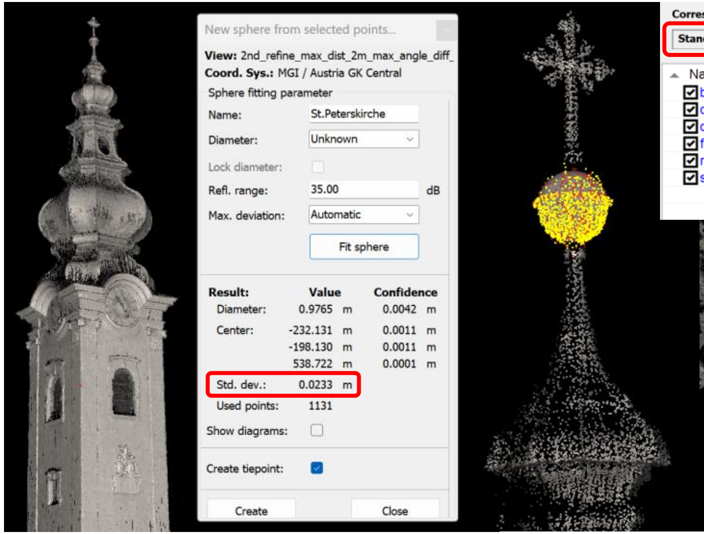
- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios
- nachgewiesene Genauigkeit im CRS durch Kontrollpunkte (Genauigkeit 2-3cm)





Further Improvements on VZ-i Series Kinematic App

- die maximale Länge der Aufnahme ist nicht mehr auf 30 Minuten begrenzt
- Datenerfassung auch bei schlechter GNSS-Qualität
- neue verfeinerte Trajektorienberechnungsszenarien + Definition eines eigenen Szenarios
- nachgewiesene Genauigkeit im CRS durch Kontrollpunkte (Genauigkeit 2-3cm)



Corresponding tiepoints: 6
Standard deviation [m]: 0.0206
Avg. radial deviation [m]: 0.0015
Avg. theta deviation [m]: 0.0036
Avg. phi deviation [m]: 0.0001

Name	Link	RefCount	Size	X	Y	Z	ΔX	ΔY	ΔZ
blasiuskirche	blasiuskirche	0	0.00	-569.494	127.188	510.724	0.005	-0.007	-0.015
dom_nord	dom_nord	0	0.00	-113.117	-88.911	545.302	0.010	-0.004	-0.017
dom_sued	dom_sued	0	0.00	-116.504	-128.350	545.230	0.002	-0.016	-0.032
franziskanerkirche	franziskanerkirche	0	0.00	-250.902	-91.135	548.653	-0.014	-0.003	-0.001
rathaus	rathaus	0	0.00	-213.110	133.864	506.903	-0.002	0.027	0.025
st_peterskirche	st_peterskirche	0	0.00	-232.131	-198.130	538.720	0.000	0.003	0.040

RIEGL

RIEGL®

Danke für Ihre Aufmerksamkeit!

Philipp Amon, RIEGL | pamon@riegl.com

Innovation in 3D