Exterior Orientation in a Box
Cost-Effective RTK/IMU-Based Photo Geotagging

M. Wieser [1], G. Verhoeven [2], B. Wild [1], N. Pfeifer [1]
martin.wieser@geo.tuwien.ac.at, geert.verhoeven@univie.ac.at

[1] Department of Geodesy and Geoinformation - TU Wien
[2] Department of Prehistoric and Historical Archaeology - University of Vienna

Low-Cost 3D, 12.11.2024

TU WIEN
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH DIVISION PHOTOGRAMMETRY

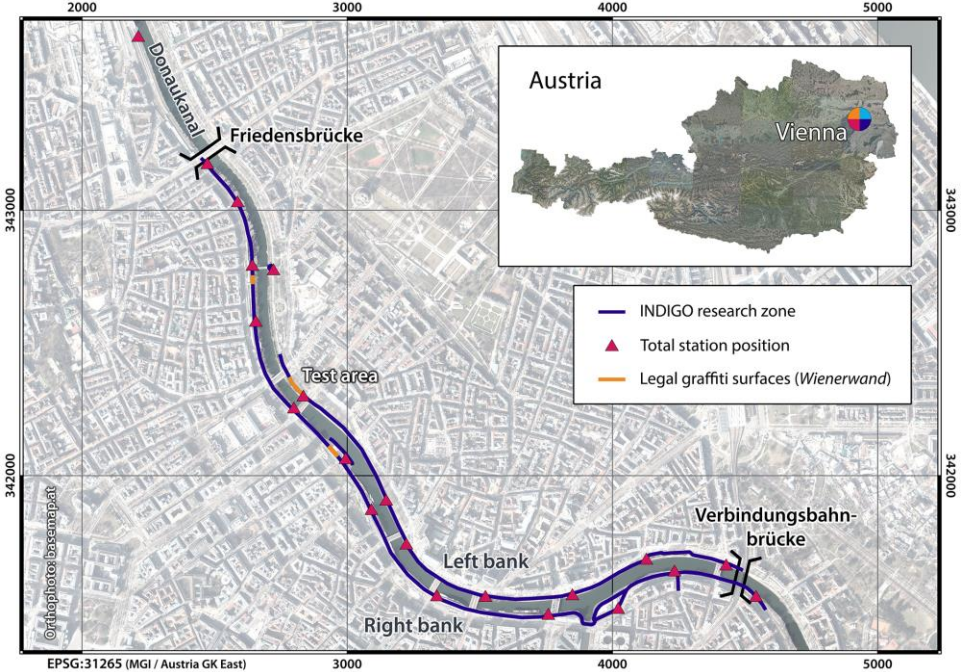
universität wien

ÖAW Stadt Wien

Project INDIGO

IN-ventory and DI-sseminate G-raffiti along the d-O-naukanal

~13km of structures with graffiti
2x total coverage image survey
On average 4000/month additional images to track changes.



RTK/IMU Device – Main Components

Built from **Sparkfun & Adafruit open-source components.**
Libraries are provided for all sensors dealing with communication and settings

RTK/IMU Device – Main Components

Built from **Sparkfun & Adafruit open-source components.**
Libraries are provided for all sensors dealing with communication and settings

Hot Shoe Port
used for image synchronisation

RTK/IMU Device – Main Components

Built from **Sparkfun & Adafruit open-source components.**
Libraries are provided for all sensors dealing with communication and settings

Hot Shoe Port
used for image synchronisation

Ublox ZED-F9P (GNSS receiver)
multi-constellation
multi-band
RTK

Sparkfun Board:
PPS signal
communication port

RTK/IMU Device – Main Components

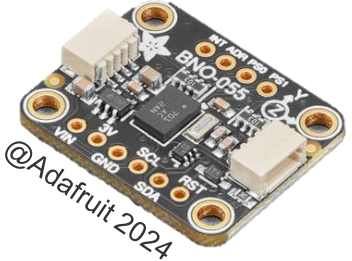
Built from **Sparkfun & Adafruit open-source components.**
Libraries are provided for all sensors dealing with communication and settings

Hot Shoe Port
used for image synchronisation

Ublox ZED-F9P (GNSS receiver)
multi-constellation
multi-band
RTK

Sparkfun Board:
PPS signal
communication port

Bosch BNO055 (IMU - 9 DoF)
3-axis 14bit accelerometer
3-axis close-loop 16bit gyroscope
3-axis geomagnetic sensor



Adafruit Board:
communication port

RTK/IMU Device – Main Components

Built from **Sparkfun & Adafruit open-source components.**
Libraries are provided for all sensors dealing with communication and settings

Hot Shoe Port
used for image synchronisation

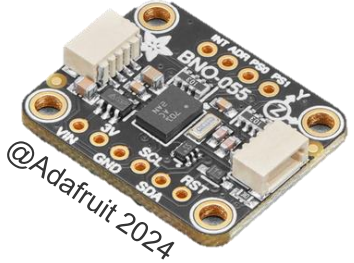
Ublox ZED-F9P (GNSS receiver)
multi-constellation
multi-band
RTK

Sparkfun Board:
PPS signal
communication port

ESP32-S2 WROOM
Xtensa® Single-Core 32-bit
(up to 240MHz)
Built-in WIFI

Sparkfun Board:
USB-C also for battery charging
GPIOs, Communication Ports

Bosch BNO055 (IMU - 9 DoF)
3-axis 14bit accelerometer
3-axis close-loop 16bit gyroscope
3-axis geomagnetic sensor



Adafruit Board:
communication port

RTK/IMU Device – Operation & Firmware

RTK/IMU Device – Operation & Firmware

Time-critical synchronisator

- time frame via GNSS using PPS and Ublox-protocol
- time stamp camera sync signal

RTK/IMU Device – Operation & Firmware

Time-critical synchronisator
- time frame via GNSS using PPS and Ublox-protocol
- time stamp camera sync signal

Exterior ORI. processor
- communication with GNSS receiver and the IMU
- IMU calibration

RTK/IMU Device – Operation & Firmware

Time-critical synchronisator
- time frame via GNSS using PPS and Ublox-protocol
- time stamp camera sync signal

NTRIP processor
- communication with NTRIP server via RTCM protocol
- forwards correction data to GNSS receiver

Exterior ORI. processor
- communication with GNSS receiver and the IMU
- IMU calibration

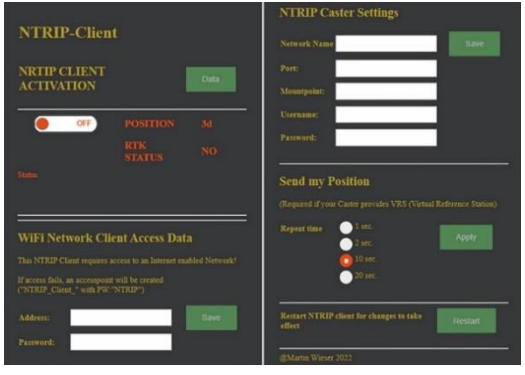
RTK/IMU Device – Operation & Firmware

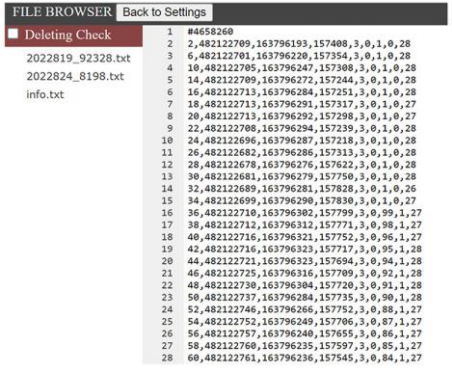
Time-critical synchronisator
- time frame via GNSS using PPS and Ublox-protocol
- time stamp camera sync signal

Exterior ORI. processor
- communication with GNSS receiver and the IMU
- IMU calibration

NTRIP processor
- communication with NTRIP server via RTCM protocol
- forwards correction data to GNSS receiver

User interface
- using WIFI connection
- configure WIFI & RTK
- download recorded data





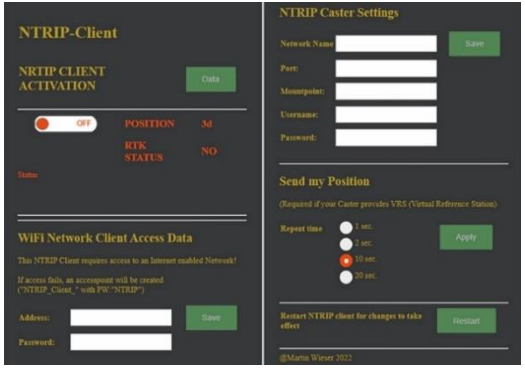
RTK/IMU Device – Operation & Firmware

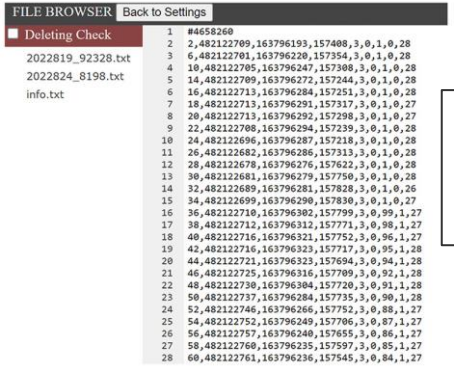
Time-critical synchronisator
- time frame via GNSS using PPS and Ublox-protocol
- time stamp camera sync signal

Exterior ORI. processor
- communication with GNSS receiver and the IMU
- IMU calibration

NTRIP processor
- communication with NTRIP server via RTCM protocol
- forwards correction data to GNSS receiver

User interface
- using WIFI connection
- configure WIFI & RTK
- download recorded data





Visual feedback
- status LEDs
- display

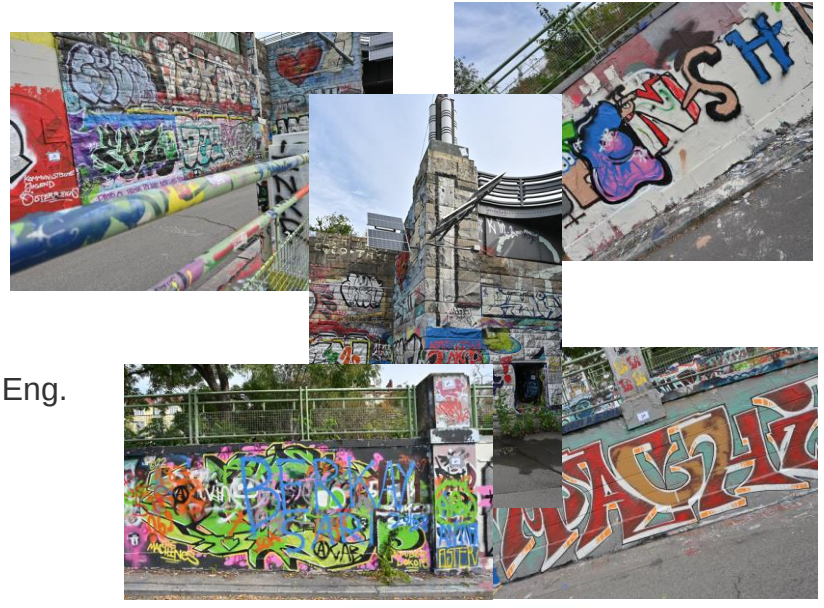
Data Acquisition

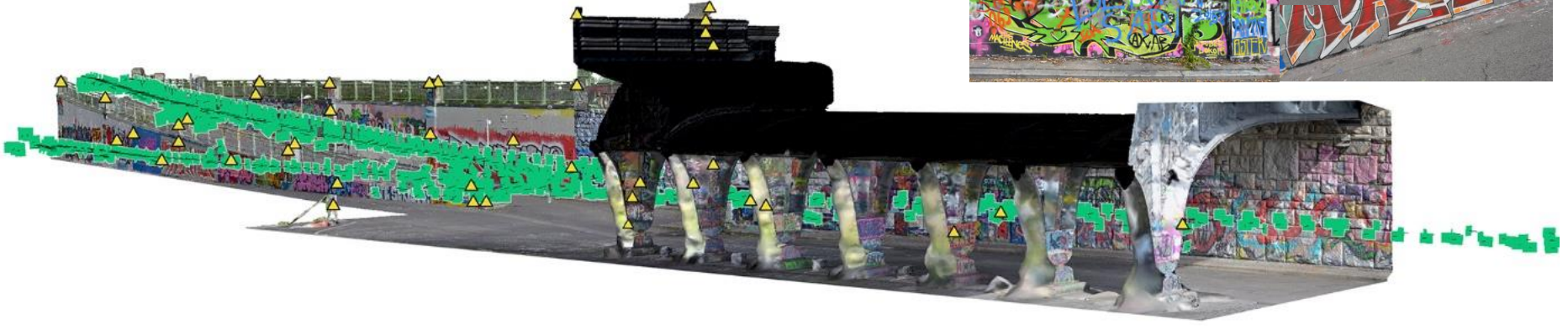
Date: 12th October 2022
Camera: Nikon Z7 II (45 MP)
Lens: Nikkor Z 20mm f/1.8

Imagery: 777 highly overlapping images in different camera orientations.

GCP: 41 coded targets measured by total station

RTK: VRS mode using EPOSA (Echtzeit-Positionierung-Austria, Eng. Real-time positioning Austria) with a mounting point that uses GPS, GLONASS, Galileo and BDS





Post-Processing

Reference Data

41 Coded targets:
4 stations using Leica TS16
Control Points from city of Vienna
Std. Dev. Residuals: XY 9 mm, Z 4mm

Bundle block:
40k interest points / 4k tie points
Targets indicated 1085 times
Self-calibration of IOR

Georeferencing accuracy metric	Value
$RMSE_x$	5.3 mm
$RMSE_y$	4.0 mm
$RMSE_{xy}$ (total planimetric accuracy)	6.6 mm
$RMSE_z$	5.8 mm
$RMSE_{xyz}$ (total 3D positional accuracy)	8.8 mm

Post-Processing

Reference Data

41 Coded targets:
4 stations using Leica TS16
Control Points from city of Vienna
Std. Dev. Residuals: XY 9 mm, Z 4mm

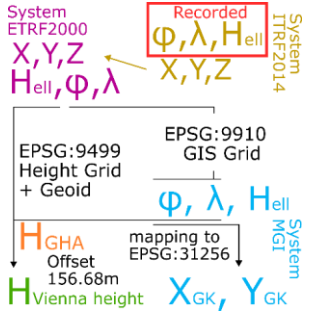
Bundle block:
40k interest points / 4k tie points
Targets indicated 1085 times
Self-calibration of IOR

Georeferencing accuracy metric	Value
$RMSE_x$	5.3 mm
$RMSE_y$	4.0 mm
$RMSE_{xy}$ (total planimetric accuracy)	6.6 mm
$RMSE_z$	5.8 mm
$RMSE_{xyz}$ (total 3D positional accuracy)	8.8 mm

RTK/IMU Device

Synchronise images with log file:
- Equal nr. – direct assignment
- Unequal nr. - correlation of images(camera time) and log signals (GNSS time). Happens rarely

Coordinate transformations:
- ZED-F9P cannot use correction data(parameter, NTv2 grids)
- Sufficient coordinate transformations are not possible on main processor.



Rotation transformation:
Quaternions logged from IMU
Transform to Device's CRS (X forward, Z up)
Corrections: Magnetic declination and grid convergence

Post processing software to perform all necessary operations.

RTK Solution Status – Classification

Solution loss of FIX expected under/near bridge.

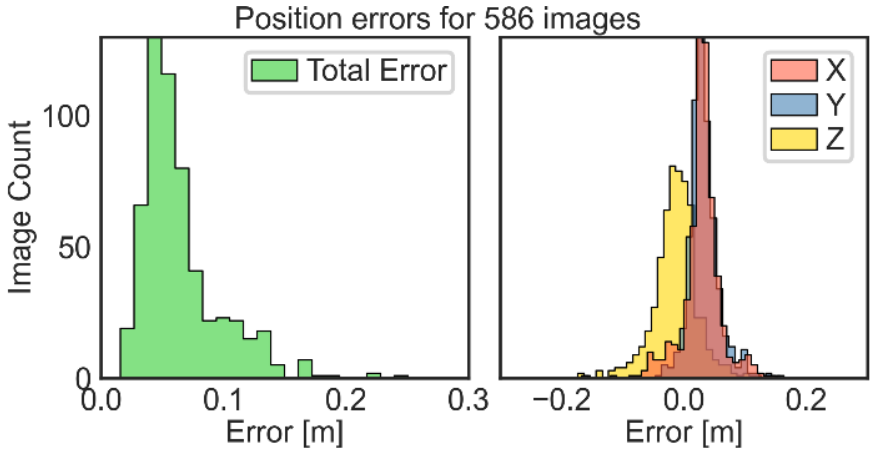
Non expected solution loss in open area:

- shadowing from User
- non-zenith pointing antenna
  (elec. characteristics of helical antenna)

Solution Flag	Images	Recorded Position Accuracy	Total Error to Reference Block
No Solution	46	0.12 m – 1.00 m	0.33 m – 13.00 m
Floating	133	0.01 m – 1.00 m	0.05 m – 21.00 m
Fix	598	0.01 m – 0.03 m	0.02 m – 0.53 m
Class	**Images**	**Recorded Position Accuracy**	**Total Error to Reference Block**
1st order quality	586	0.01 m	0.02 – 0.46 m only 14 >15 cm
All others	191	0.01 m – 1.00 m	0.05 m – 21.00 m

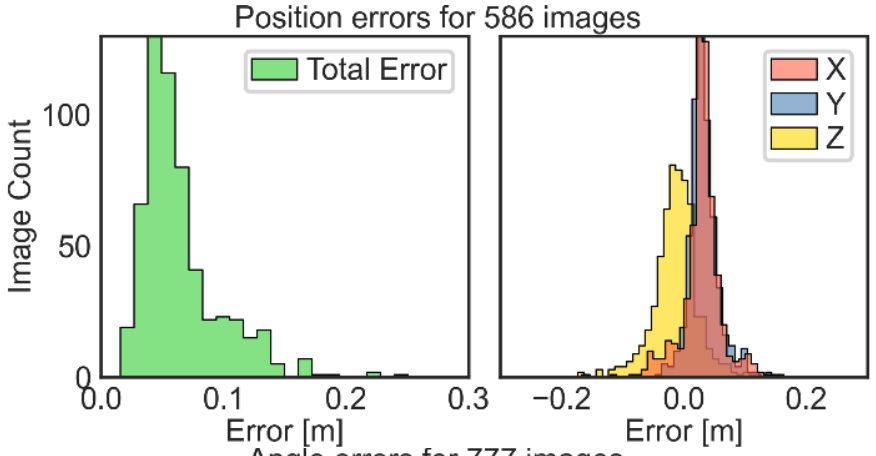
Exterior Orientation vs. Reference Block

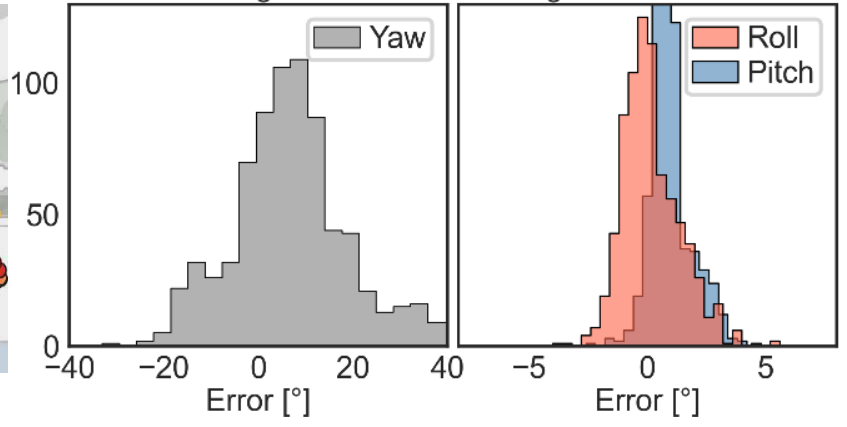
Error	X [cm]	Y [cm]	Z [cm]	Total [cm]	Roll [°]	Pitch [°]	Yaw [°]
Mean	2.9	2.8	-1.9	6.5	0.17	0.73	2.93
Median	3.0	2.5	-1.8	5.4	0.01	0.59	1.79
St. Dev.	3.1	2.7	4.4	3.9	1.22	0.81	15.3
RMSE	4.3	3.9	4.8	7.6	1.23	1.09	15.6



Exterior Orientation vs. Reference Block

Error	X [cm]	Y [cm]	Z [cm]	Total [cm]	Roll [°]	Pitch [°]	Yaw [°]
Mean	2.9	2.8	-1.9	6.5	0.17	0.73	2.93
Median	3.0	2.5	-1.8	5.4	0.01	0.59	1.79
St. Dev.	3.1	2.7	4.4	3.9	1.22	0.81	15.3
RMSE	4.3	3.9	4.8	7.6	1.23	1.09	15.6





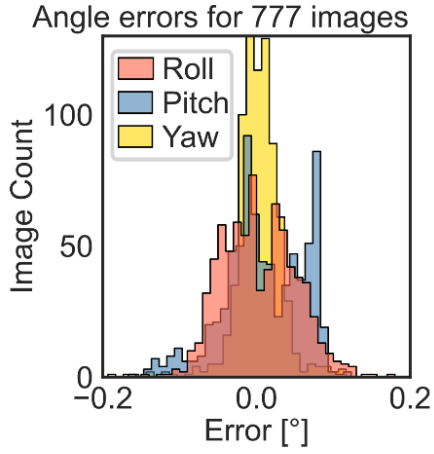
Bundle Block Adjustment with RTK-GNSS Positions

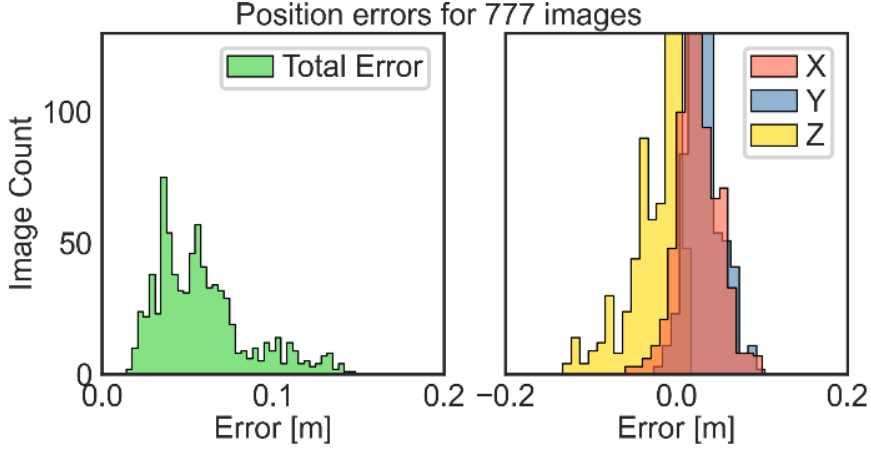
- First order GNSS positions are used as block constraints
- No additional reference data

- Camera Calibration on the job
- Antenna Mounting calibration

No post adjustment/filtering applied

Error	X	Y	Z	Total	Roll	Pitch	Yaw
	[cm]			[cm]	[millidegree]		
Mean	2.4	2.9	-2.9	5.8	3	0	5
Median	2.3	2.6	-1.6	5.3	3	0	4
St. Dev.	2.4	1.9	3.0	2.7	47	67	35
RMSE	3.4	3.5	4.2	6.4	47	67	35





Bundle Block Adjustment with RTK-GNSS Positions

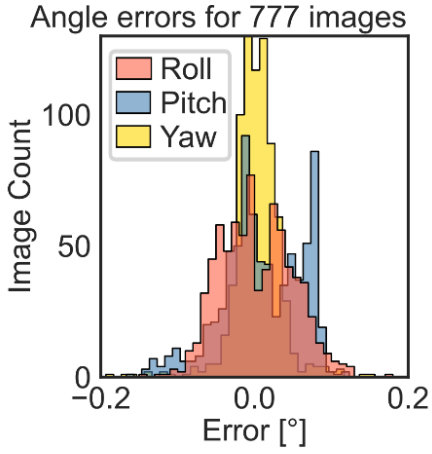
- First order GNSS positions are used as block constraints
- No additional reference data

- Camera Calibration on the job
- Antenna Mounting calibration

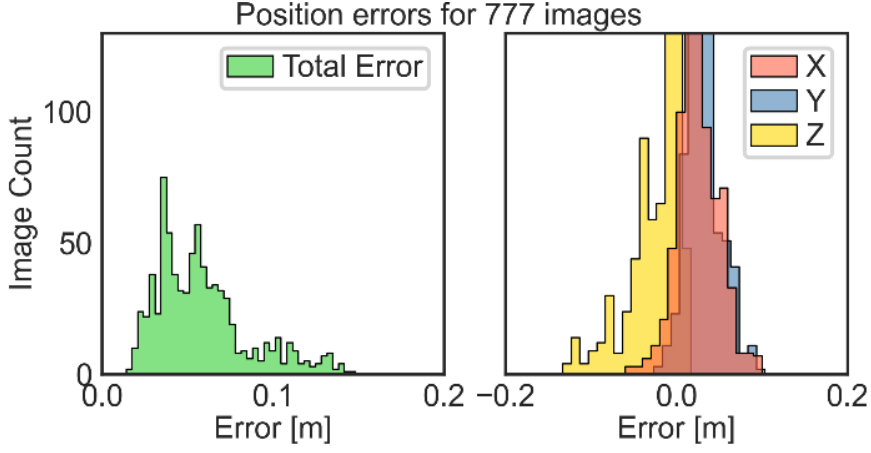
No post adjustment/filtering applied

Accuracy on the object

Targets: Reference to Estimated
RMSE of differences:
Total: 31 cm
X: 2.5 cm, Y: 8.5 cm, Z: 4.0 cm



Error	X	Y	Z	Total	Roll	Pitch	Yaw
	[cm]			[cm]	[millidegree]		
Mean	2.4	2.9	-2.9	5.8	3	0	5
Median	2.3	2.6	-1.6	5.3	3	0	4
St. Dev.	2.4	1.9	3.0	2.7	47	67	35
RMSE	3.4	3.5	4.2	6.4	47	67	35

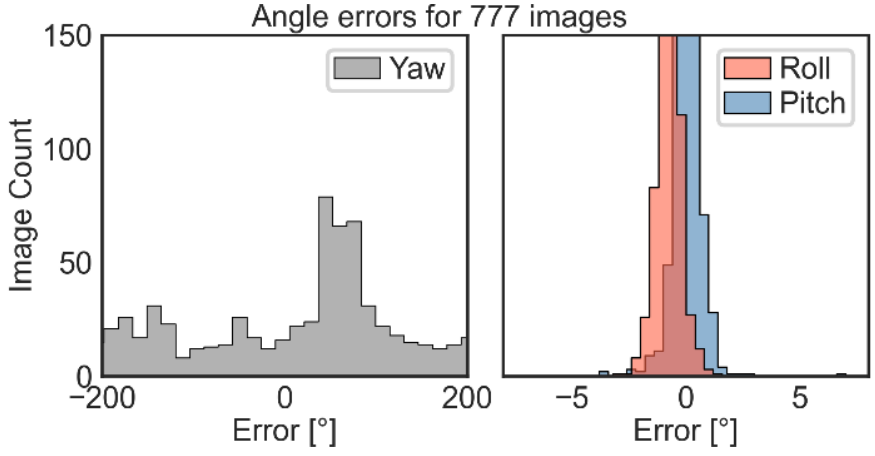


Nikon Angles

IMU of modern cameras store angles in manufacturer-specific Exif Makernote tags

Needed manipulation depending on the rotation of the camera (Exif Orientation tag, ID 274).
Did not find any rotation notation that would have solved that.

Error [°]	Mean	Median	St.dev	RMSE	Min	Max
Roll	-0.7	-0.7	0.5	0.9	-2.8	1.2
Pitch	-0.2	-0.1	0.7	0.7	-3.8	6.5
Yaw	-15.6	-33.5	123.5	124.5	-259.6	350.5



Discussion

Position up to an accuracy of ~6 cm with a **precision of ~3 cm**. Complete EXT. ORI. suffers from magnetometer disturbances.

INDIGO's incremental SfM workflow:
Positions can be used to estimate a temporary bundle block to constrain object space to search for existing features of older images

Low cost: Late 2022 the total cost of the components and the 3D printed case was about € 500

Identified disadvantages:

- additional mass on long duration sessions
- camera does not provide sync signal in silent mode or when using interval priority