Alexander Mölle | TU Bergakademie Freiberg

VERTICAL POSITIONING AND CONDITION MONITORING OF MINESHAFTS USING INERTIAL NAVIGATION

Mine shafts represent a critical bottleneck in underground mining operations and are essential for ensuring safe, efficient, and continuous transport of personnel and materials. As the central interface between surface infrastructure and underground extraction processes, they play a decisive role in both operational performance and safety. Shaft hoisting systems are subject to demanding operating conditions, including high conveying speeds, increasing load requirements, and adverse environmental influences such as moisture, water ingress, and abrasive particles. These factors impose significant mechanical and tribological stresses on system components, particularly on shaft guidance structures, which are continuously exposed to wear and degradation.

In addition to operational demands, shaft installations are governed by strict safety regulations and require periodic inspections and certification by qualified experts. The condition of guiding elements, such as guide rails or track slats, is therefore of particular importance for maintaining system availability and ensuring compliance with regulatory standards.

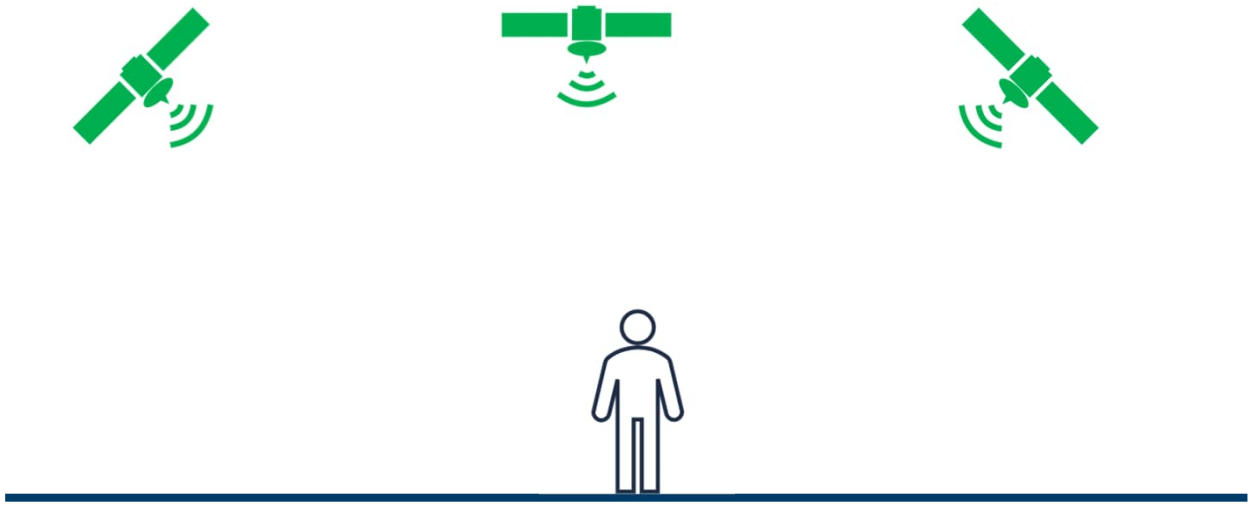
To enable a condition-based assessment of rigid shaft guidance systems, a compact and mobile measurement device has been developed at the Institute of Mechanical Engineering (IMB), TU Bergakademie Freiberg. The system is designed for deployment during ongoing operation and does not require structural modifications to existing infrastructure. It is based on low-cost MEMS-based inertial measurement units (IMUs) combined with a barometric pressure sensor. A customized strapdown algorithm, supplemented by appropriate constraints and boundary conditions, enables the realization of a GNSS-independent inertial navigation system.

During regular hoisting operations, the system records motion data from which kinematic quantities such as accelerations and velocities, as well as position-dependent condition information along the shaft depth, can be derived. The acquired data allows for a reliable evaluation of the condition of shaft guiding elements and supports the early detection of wear-related degradation. The robust design of the sensor system ensures reliable operation under harsh environmental conditions, while an integrated power supply and wireless communication interface enable flexible, autonomous use in practical mining environments.

Deep Sea Sampling

Vertical Positioning and Condition Monitoring of Mineshafts Using Inertial Navigation

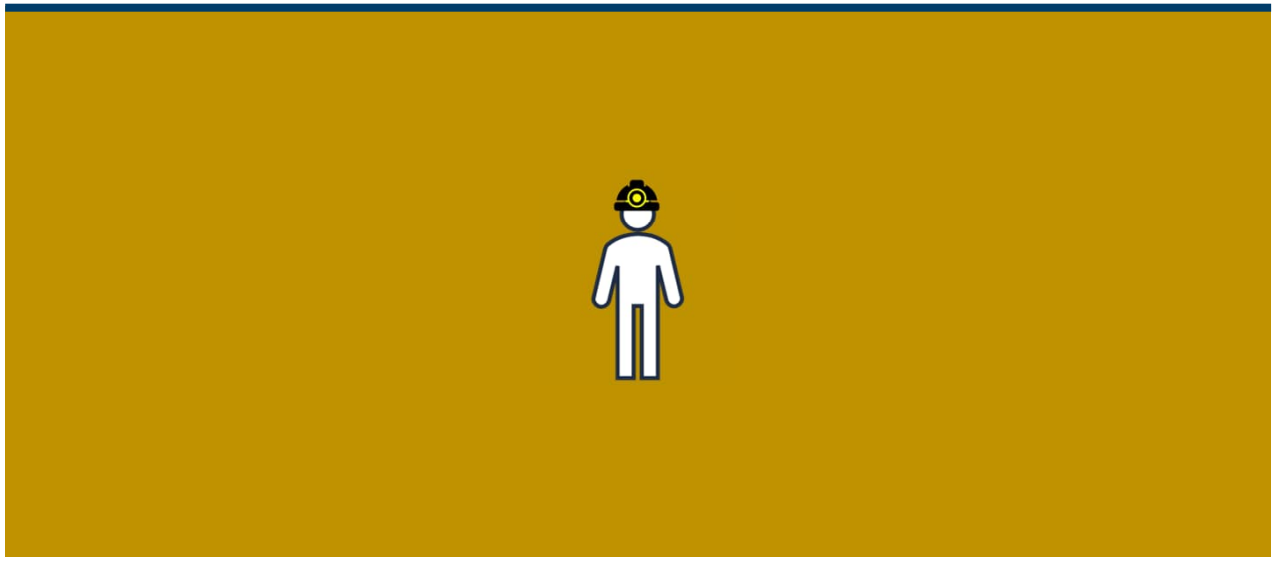
Problem Statement



Task:
Detection of the current

- Position
- Orientation

Problem Statement



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Detection of the current
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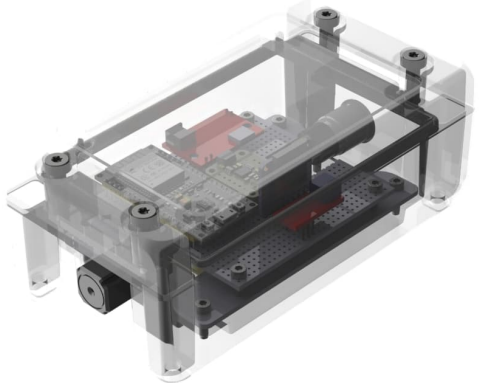
Challenge:
- no satellite reception (GNSS)
- harsh environmental conditions

Aim:
→ compact, mobile, and robust inertial naviagation system



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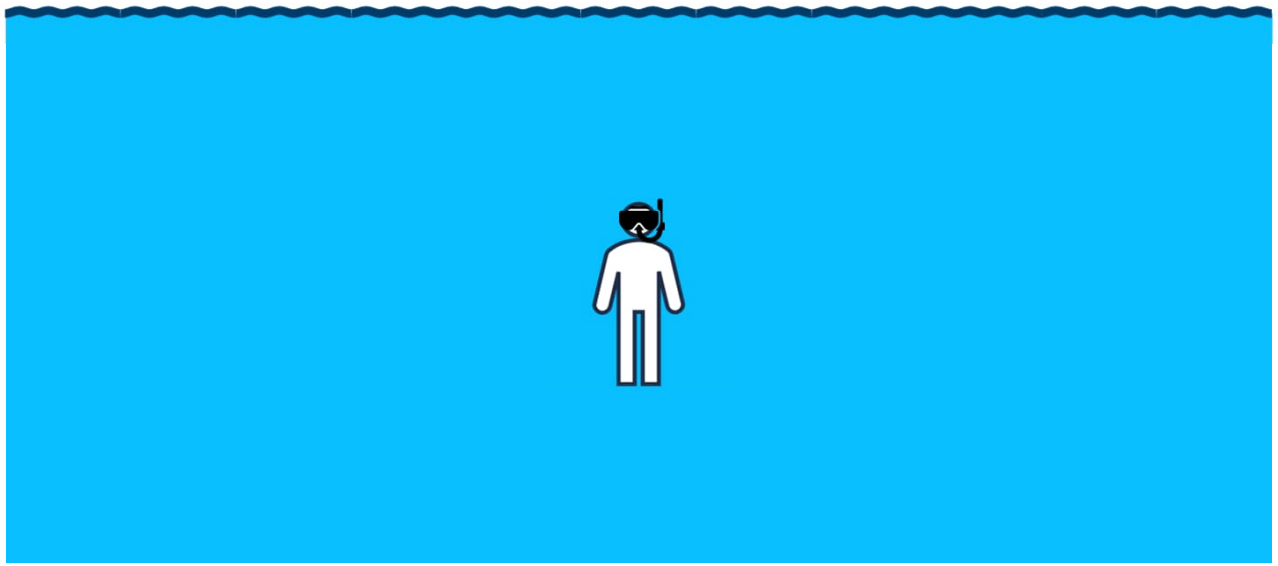

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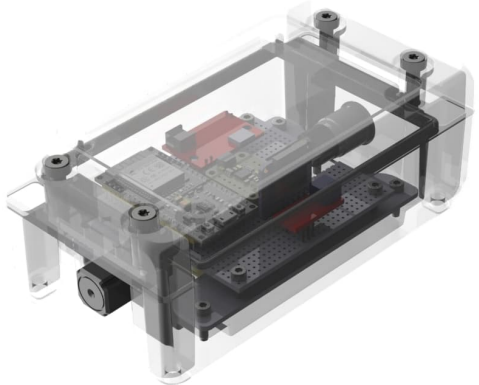
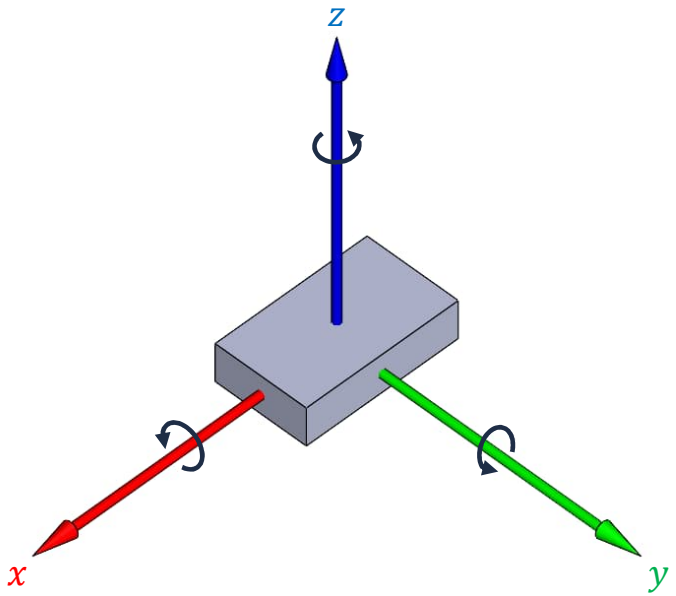
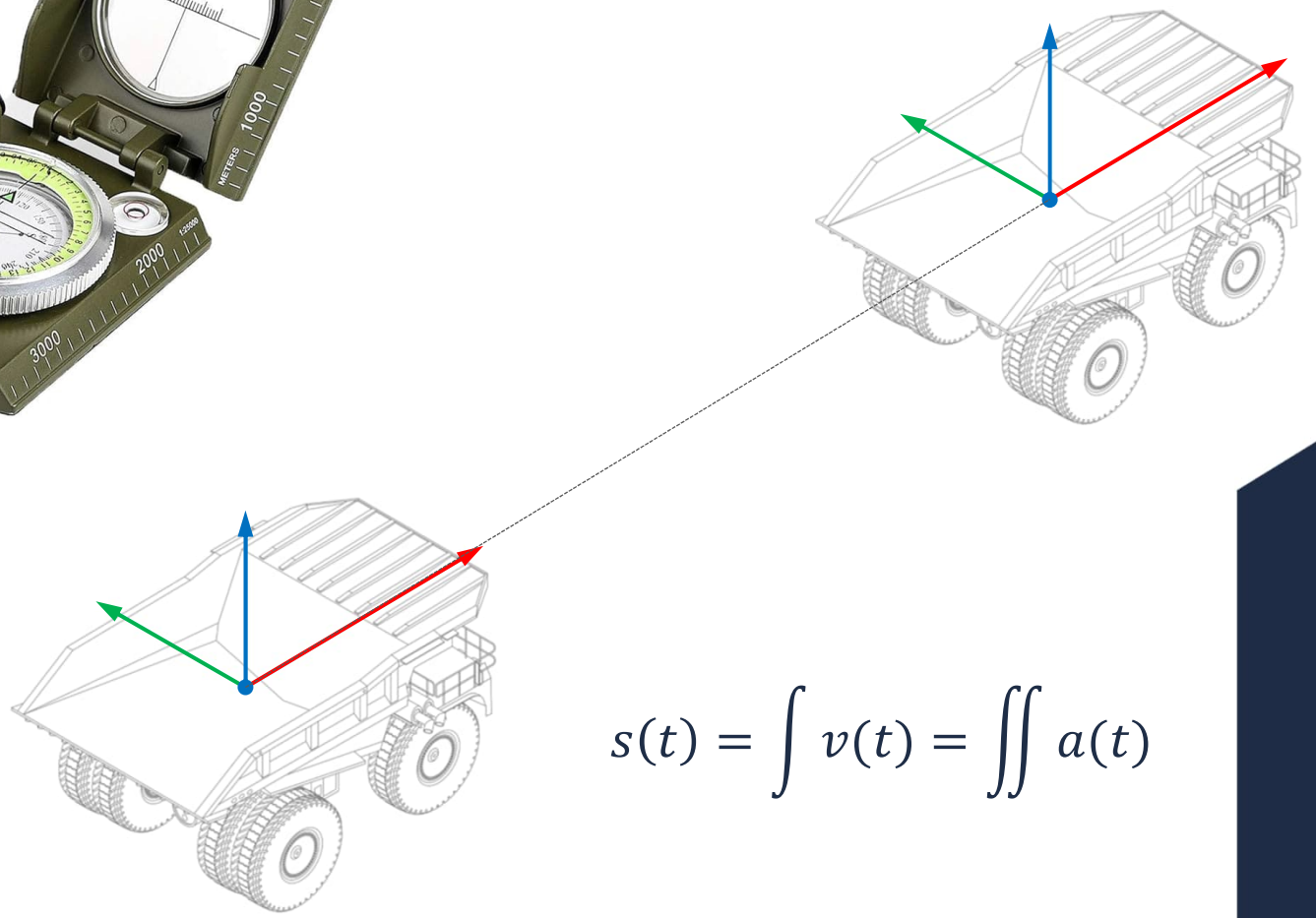


Concept



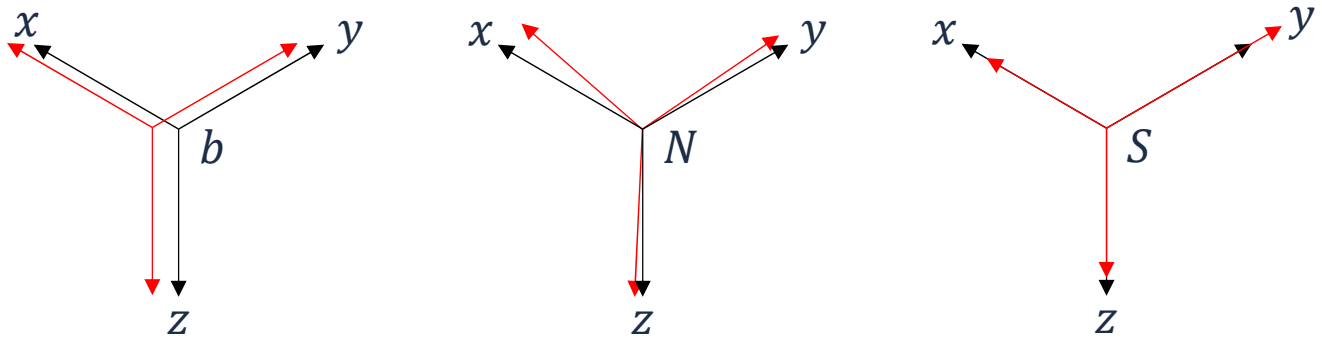


$$s(t) = \int v(t) = \iint a(t)$$

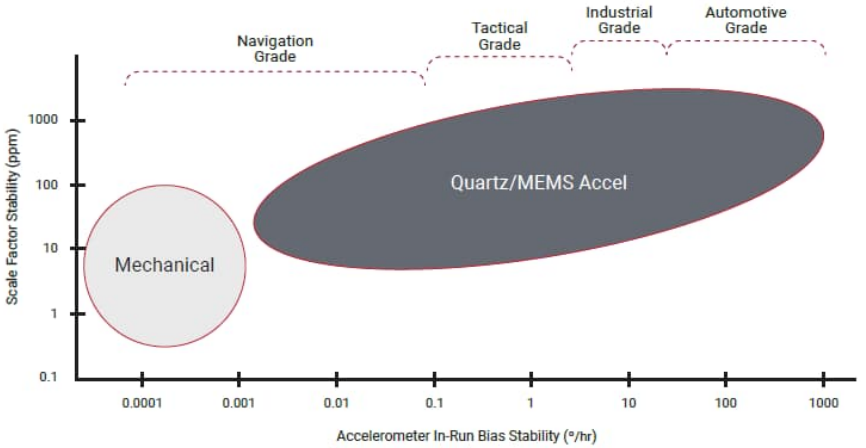
https://www.amazon.de/BIJIA-Professioneller-multifunktionaler-wasserdicht-Neigungsmesser/dp/B07NRLCSP8
iXblue presentation: Civil engineering product range

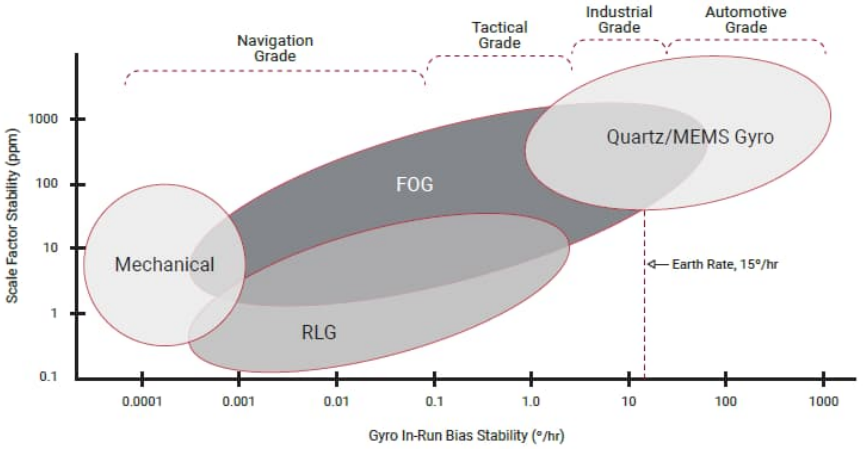
IMU Characterization

$$y_k^b = SNu_k^b + b + \varepsilon_k^b$$



y_k^b	raw data
u_k^b	true value
ε_k^b	noise
b	bias
N	non-orthogonality
S	scale factor

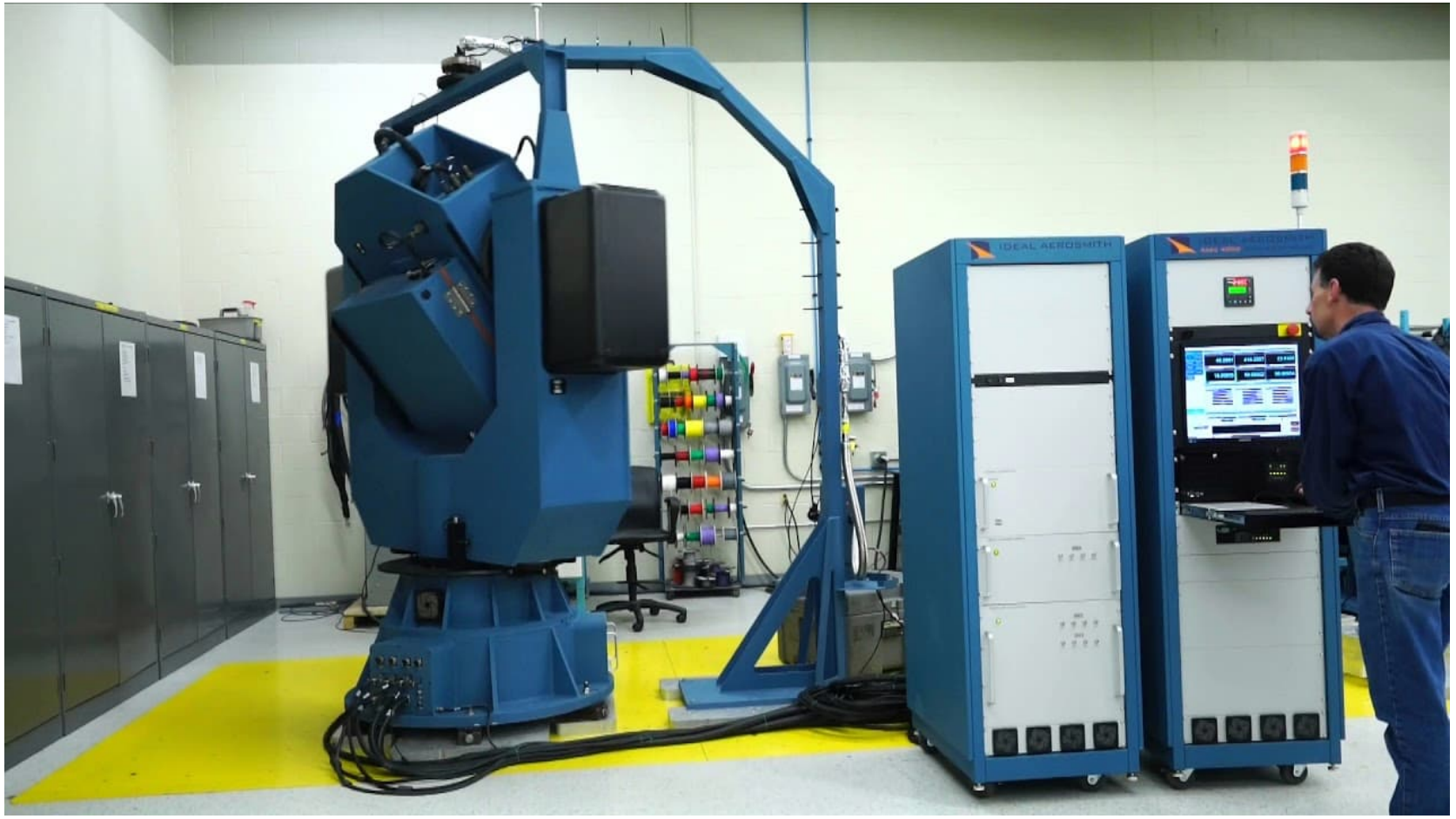




https://teslabs.com/articles/magnetometer-calibration/
https://www.vectornav.com/resources/inertial-navigation-primer/theory-of-operation/theory-inertial

IMU Calibration

Ideal Aerosmith: 3-Axis Rate Table (Model 1573VE)

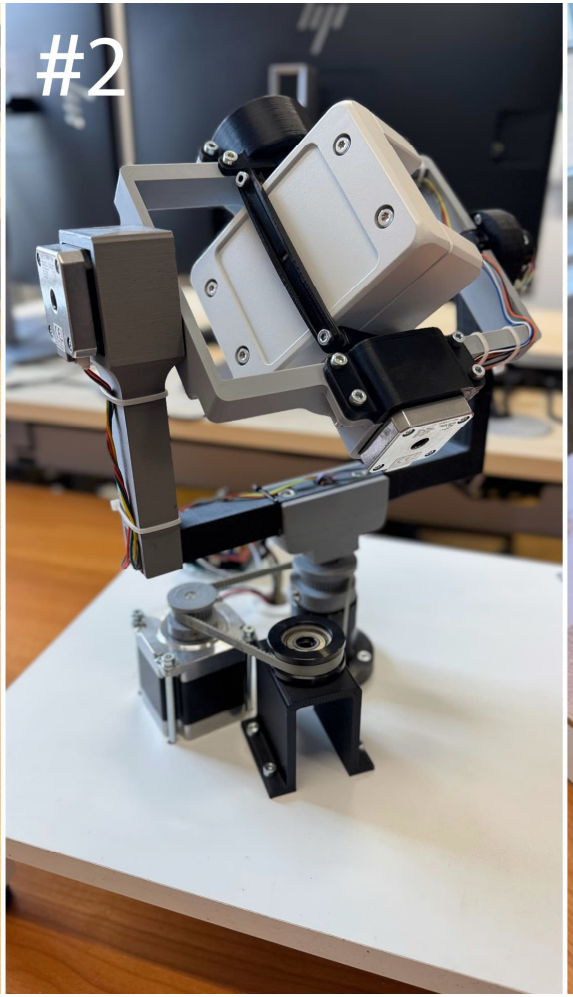


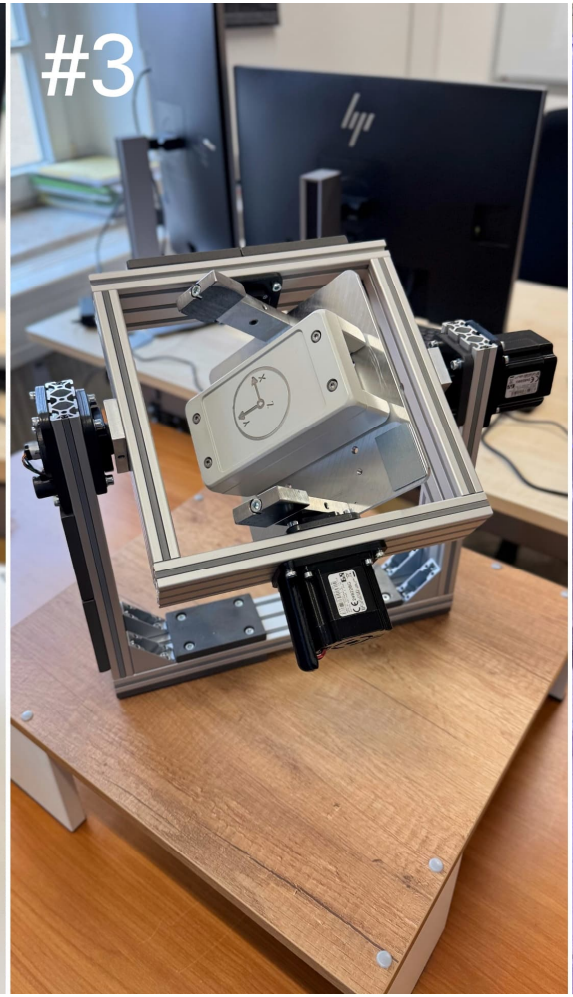
Pro:
- high accuracy

Contra:
- stationary, large-scale system
- heavy-duty construction (high mass inertia)
- high costs
- skilled personnel required

https://www.ideal-aerosmith.com/ideal-product/1573p/

Rate Tables at IMB





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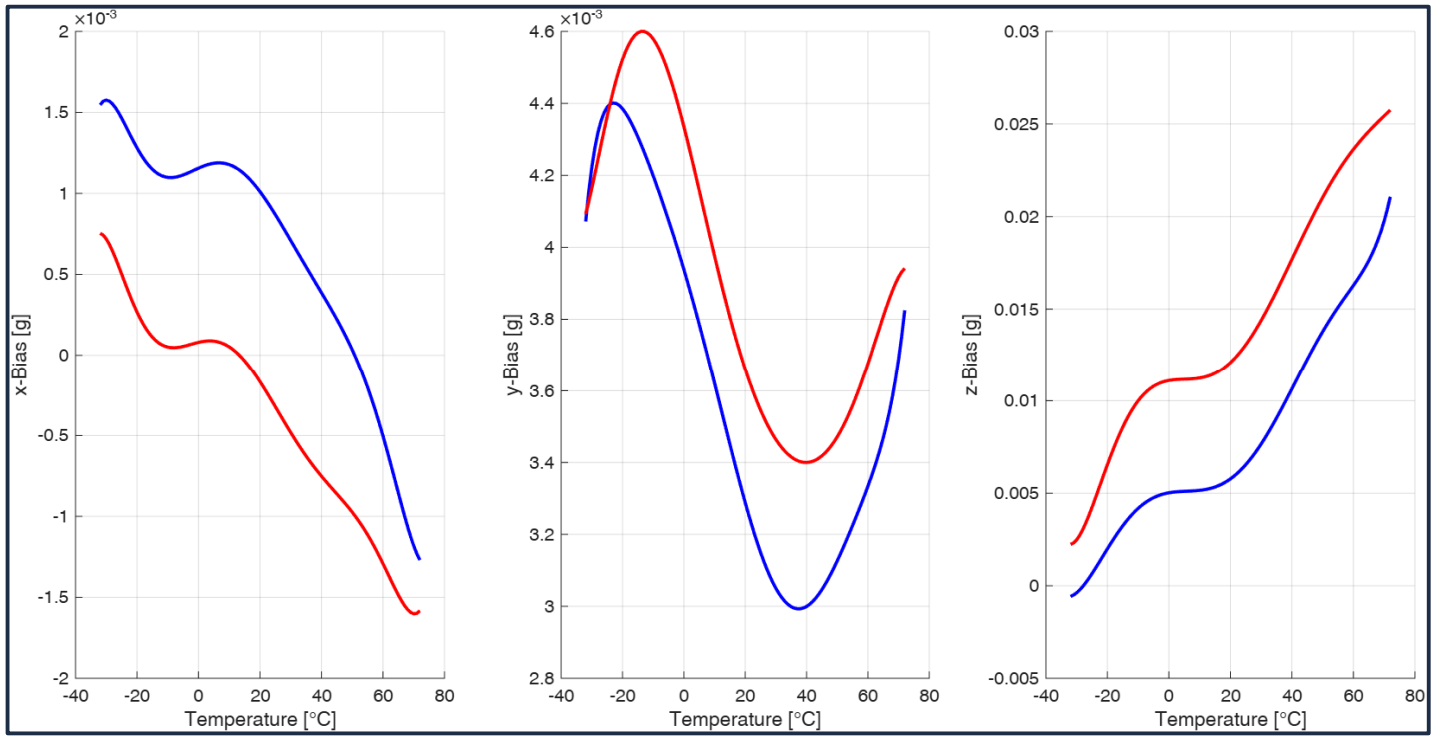
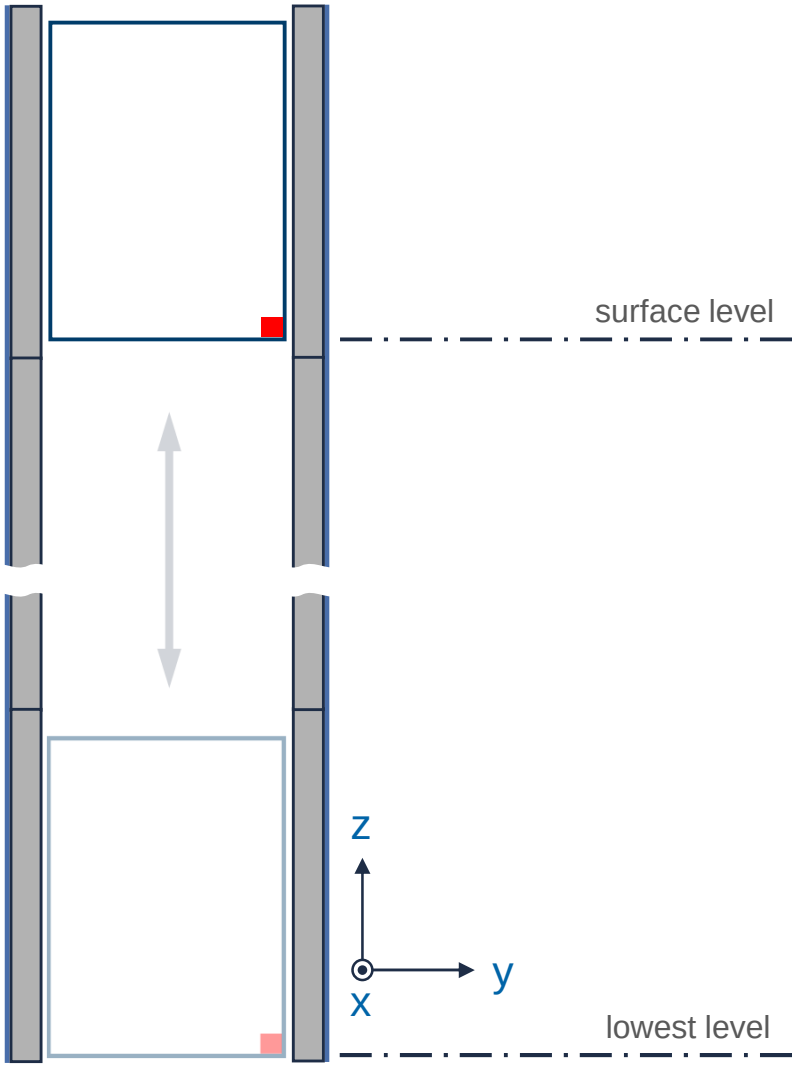
Temperature Compensation



Temperature Chamber: -40 °C … 150 °C
IMU: -40 °C … 85 °C

- non-linear behavior
- each sensor axis is different
- deviation between warm-up and cool-down phases

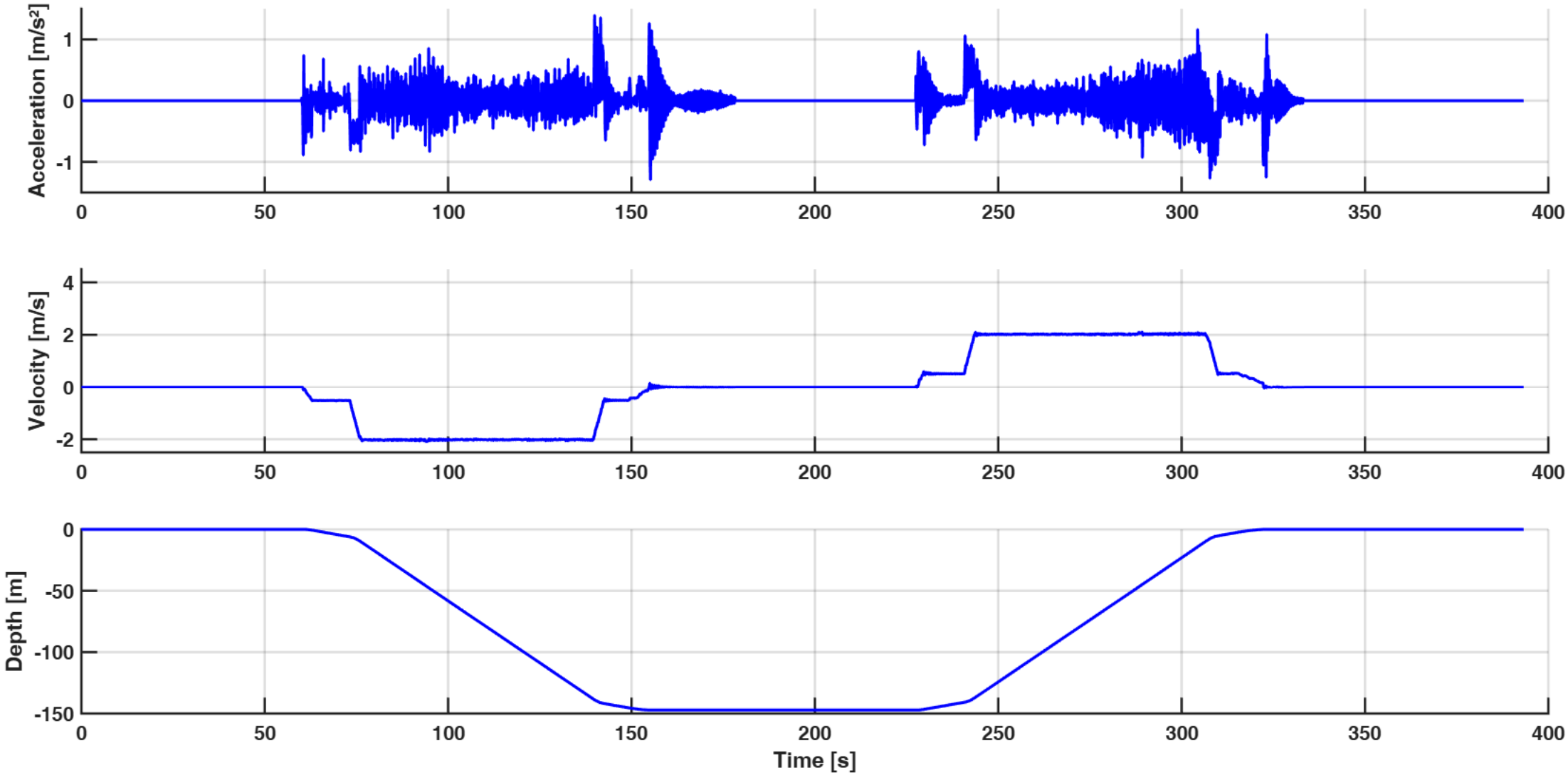
Tests in the mine shaft



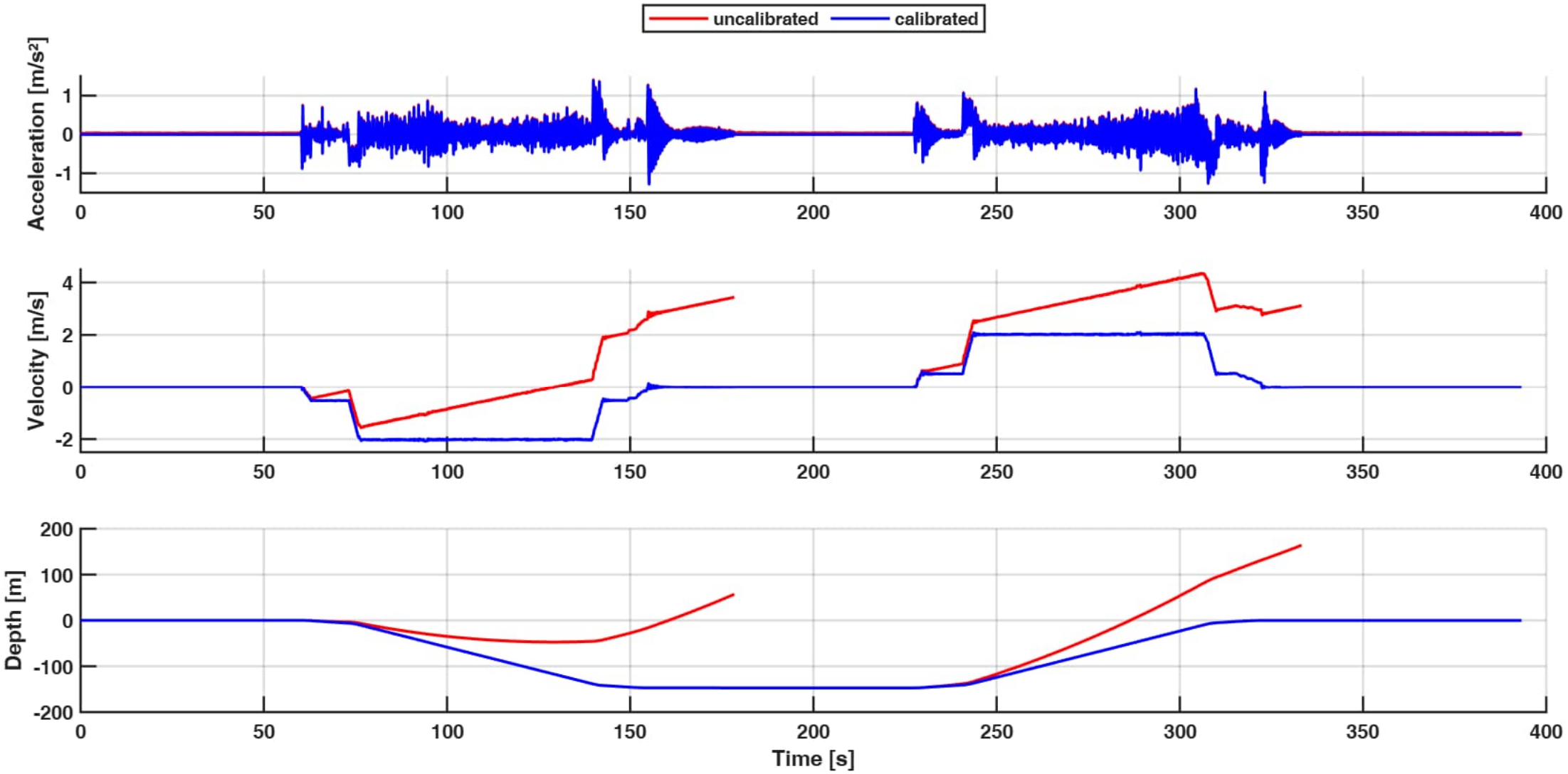
Aim:
- detection of velocity and
- distance traveled by the mine cage

Procedure:
→ start at surface level
→ ride at max. velocity to the lowest level
→ return to the surface level

INS Results


Acceleration [m/s²]
1
0
-1
0
50
100
150
200
250
300
350
400
Velocity [m/s]
4
2
0
-2
0
50
100
150
200
250
300
350
400
Depth [m]
0
-50
-100
-150
0
50
100
150
200
250
300
350
400
Time [s]

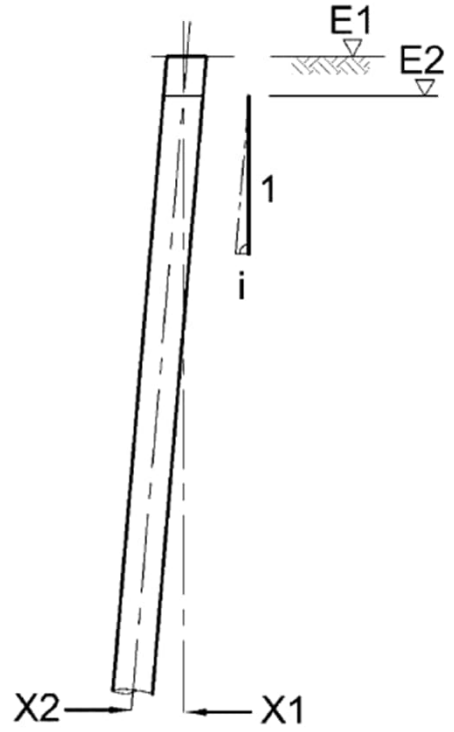
INS Results


uncalibrated
calibrated
Acceleration [m/s²]
1
0
-1
0
50
100
150
200
250
300
350
400
Velocity [m/s]
4
2
0
-2
0
50
100
150
200
250
300
350
400
Depth [m]
200
100
0
-100
-200
0
50
100
150
200
250
300
350
400
Time [s]

Tests in different mine shafts

Mine Shafts:	max. depth:	v_{max}
Forschungs- und Lehrbergwerk „Reiche Zeche“ (Freiberg)	147 m	2 m/s
Drei-Brüder-Schacht (Freiberg)	281 m	1 m/s
Versatzbergwerk Sollstedt - Osten	680 m	6 m/s
Versatzbergwerk Sollstedt - Westen	685 m	6 m/s
Versatzbergwerk Bleicherode - Schacht 1	604 m	2 m/s
Versatzbergwerk Bleicherode - Schacht 2	607 m	2 m/s
Glückauf Sondershausen - Schacht 1 Norden	660 m	4 m/s
Glückauf Sondershausen - Schacht 1 Süden	660 m	4 m/s
Glückauf Sondershausen - Schacht 5	731 m	6 m/s

Inclination Test

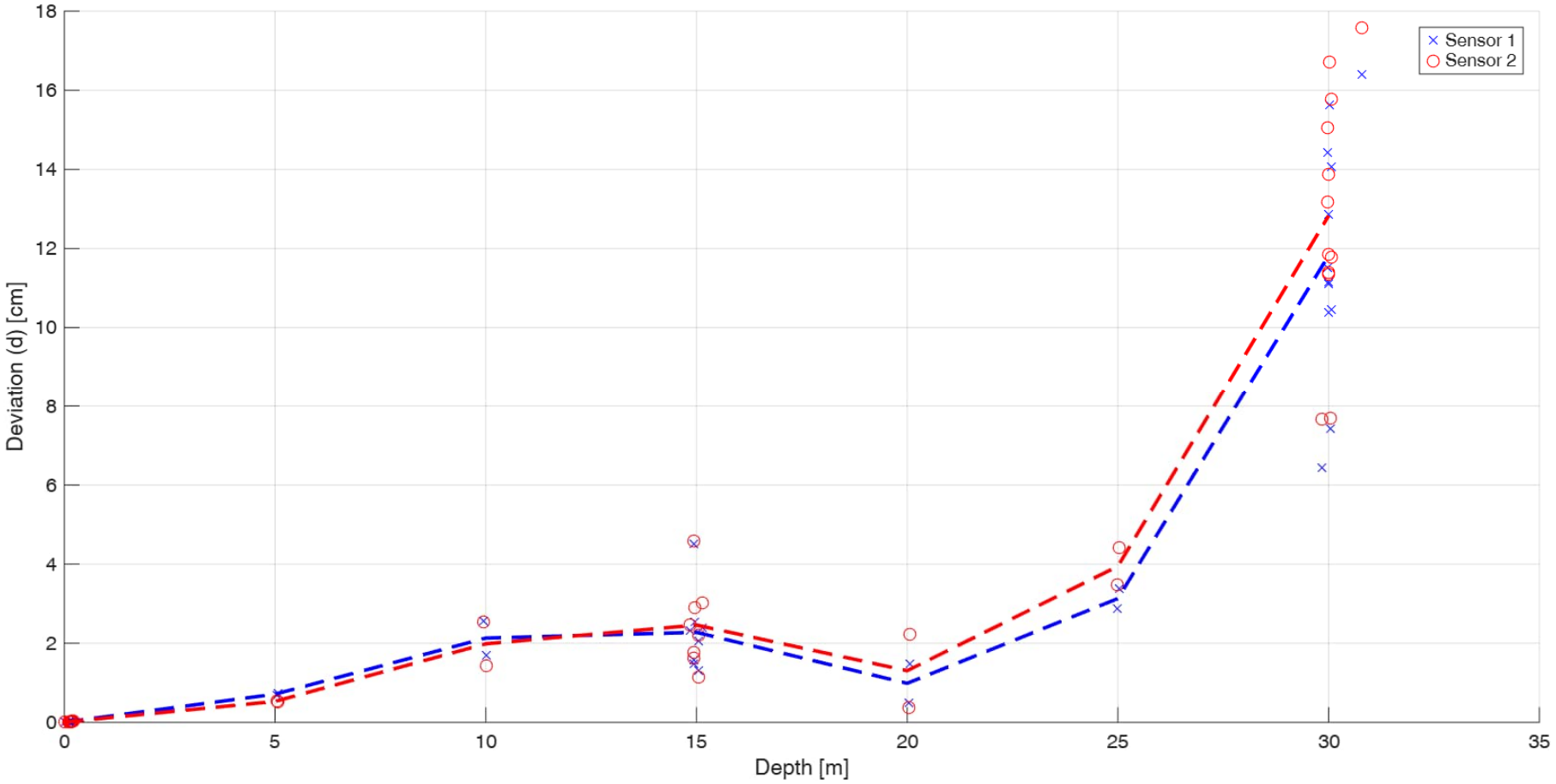


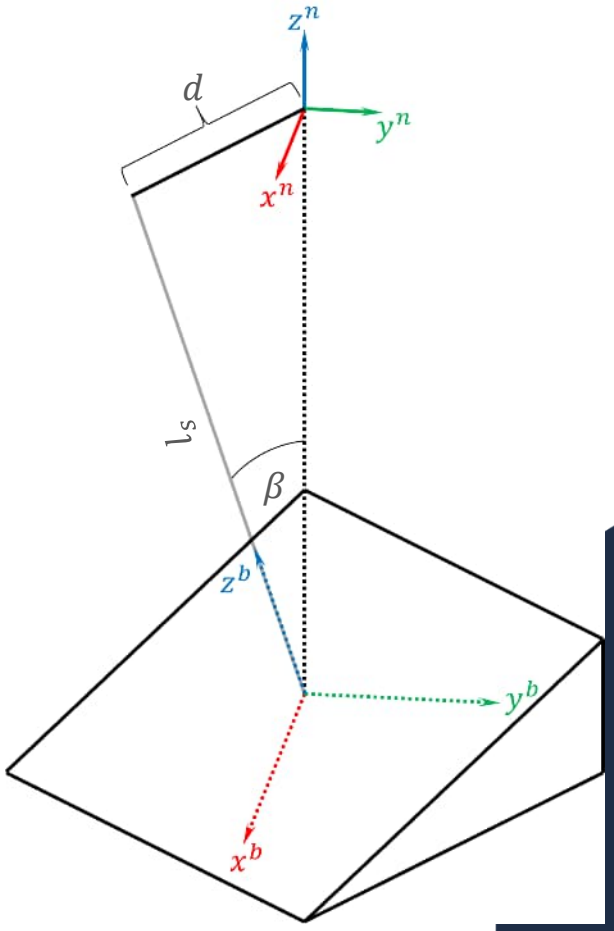
DIN EN 1536: Ausführung von Arbeiten
Spezialtiefbau – Bohrpfähle
$\Delta\theta < 0{,}8°$

a) Vertikaler Pfahl

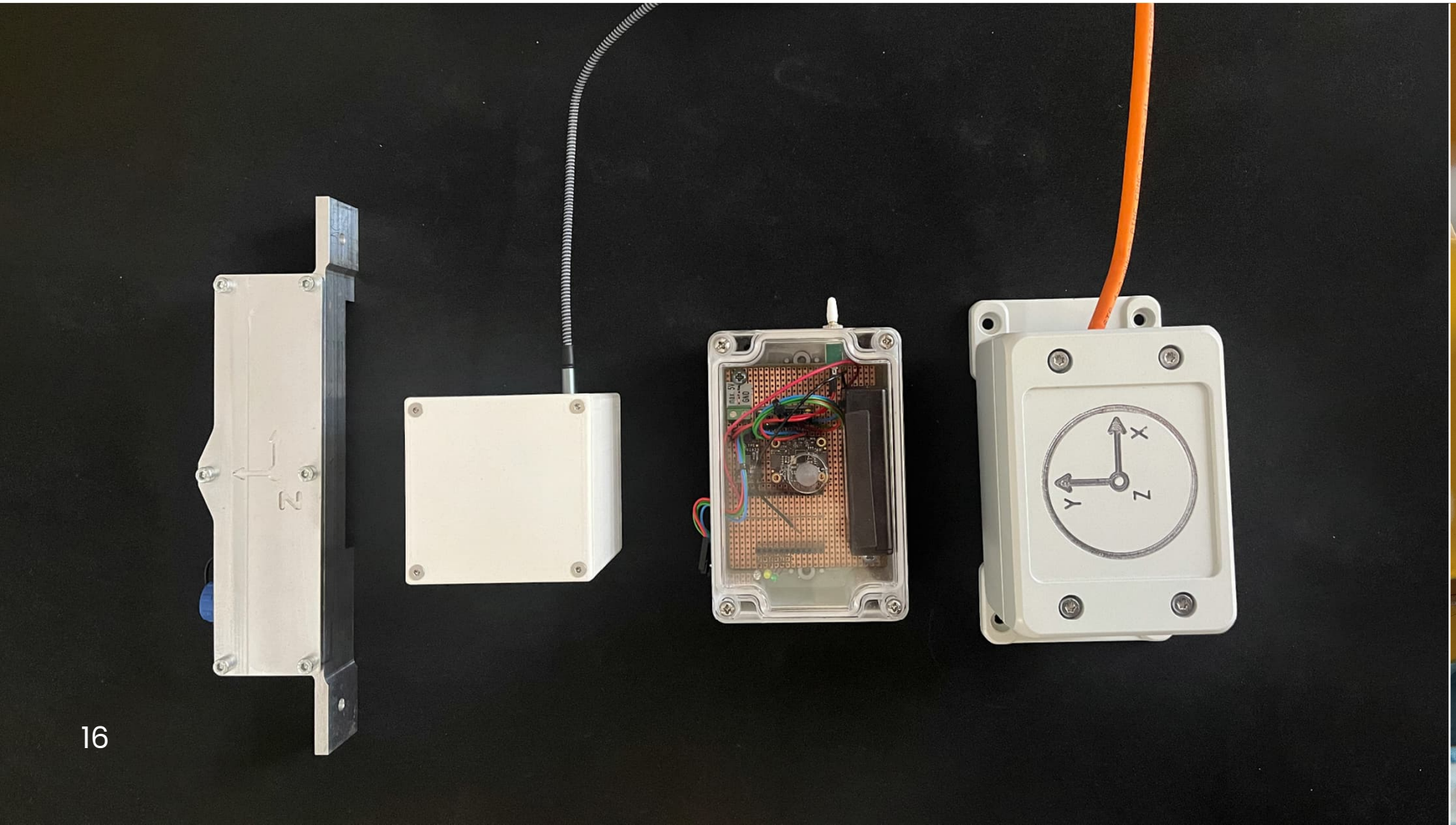
https://equipment.bauer.de/de/drehbohrgeraete
ProFound - Innovation by BAUER: No. 2 2025

Inclination Test





IMU Evolution at IMB



Deep Sea Sampling

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Krebs & Aulich

Sonderbare Elektromaschinen

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