Handheld LiDAR SLAM Guidance
From First Scan to Professional Deliverable

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Audience: GNSS-transition surveyors, BIM / architecture / indoor-scanning newcomers, dealer / sales engineer training, forestry / emergency / police / cross-industry operators.

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0 · How to Use This Guide

0.1 Who This Guide Is For

This guide is written for four kinds of readers, each coming to a handheld LiDAR SLAM scanner from a different starting point:

1. The GNSS-transition surveyor. You are fluent in RTK (real-time kinematics), GNSS constellations, total stations, and coordinate systems — but mobile SLAM technology is new to you. You want to know how the scanner perceives space and captures sptial data, not just which button to press.
2. The BIM / architecture / indoor-scanning newcomer. You need accurate point clouds for Revit, Recap, Navisworks, etc. You may never have used GNSS, and you don't want to.
3. The dealer, reseller, or sales engineer. You demo the device, train customers, and answer first-line support questions. You need a document you can teach from.
4. The cross-industry operator — forestry, emergency response, police, cultural heritage, utilities. You have a job to do and SLAM is just a tool. You need the shortest path to reliable results.

If you fit any of these, this guide is for you.

0.2 How to Read It

- Brand-new user: read 0 → 2 → 4 → 5, then the one 6 scenario that matches your first job. Skip everything else until you need it.
- Already scanned a few times: skim 2, read 3 and 5, then live in 6 and 9.
- Training other people: read 10 first, then use 2, 5, 6, and 9 as teaching blocks.

0.3 Conventions Used Throughout

Symbol Meaning

⚠ Warning -- read before acting

📓 Deep Dive -- Optional technical detail for readers who want the "why behind the why"

☑ Do -- Recommended action

✕ Don't -- Action that will predictably cause problems

0.4 A Promise and a Warning

The promise. If you read 2 and follow the 10 Golden Rules in 5, 90% of the typical scanning failures in 9 will never happen to you. The warning. This is not a replacement for hands-on practice. Read the guide, then go scan — ideally scan the same space five times, look at each result in the post-processing software, and watch how your technique changes the data. That feedback loop is what turns an operator into a professional.

0.5 Version & Feedback

This educational edition is intended to be maintained by the training owner, product owner, or field-operations team. If you find a mistake, a scenario that's missing, or a technique that works better than what's written here, tell us. This document gets better when operators push back on it.

1 · Know Your Tool — Handheld LiDAR SLAM at a Glance

Reading time: 10 minutes. The goal is to leave this chapter able to name every major part of a handheld LiDAR SLAM system and describe, in one sentence, what each sensor contributes.

1.1 What a Handheld LiDAR SLAM Scanner Is

A handheld LiDAR SLAM 3D scanner is a mobile reality-capture system designed for fast, single-person site capture. A typical system integrates, in one body or one kit:

- A high-frame-rate LiDAR for the geometric skeleton of the environment.
- An IMU (inertial measurement unit) for short-term motion sensing: pitch, roll, yaw, and acceleration.
- One or more cameras for colorization and visual features.
- Optional GNSS / RTK for an absolute global anchor when there is sufficient sky view.
- Onboard storage, battery power, and a live preview connection to a phone, tablet, or controller.

How it works: As operator walks the route, the scanner estimates its own trajectory and builds a point cloud. After the session, raw data is processed in desktop or cloud software to produce the deliverable point cloud and, on systems that support it, visualization outputs such as panoramic imagery or 3D Gaussian Splatting.

The teaching principle is universal: no single sensor solves the job alone. Reliable field work comes from understanding which sensor is strong in each environment and planning the route accordingly.

1.2 Typical System Anatomy

Key parts and what they do:

- Main sensing unit. Houses the LiDAR, IMU, cameras, processor, storage, and sometimes GNSS.
- Handle, grip, pole, backpack, or vehicle mount. This controls how stable the sensor is and how repeatable the trajectory is.
- Positioning or control-point interface. Provides a repeatable way to pick up ground control points or known targets.
- Battery system. Determines practical session length, hot-swap strategy, and cold-weather performance.

- Storage media. Holds raw data. A missing or full card/drive is a field failure, not a processing issue.
- Mobile app or controller. Provides start/stop, live preview, project setup, coordinate/RTK status, and in-field QA.

Exact part names, LEDs (light-emitting diodes), attachment order, passwords, file names, and accessories vary by product. For the MVP S1-specific version of this information, refer to the latest MVP S1 datasheet.

1.3 Key Operational Parameters — What to Look Up Before a Job

Parameters in this guide are deliberately product-neutral. Always refer to the latest datasheet for authoritative specifications. In the field, the operator needs to know these categories, even when the numbers differ by scanner:

- Recommended working distance. This is the distance range where density, noise, and feature matching are reliable.
- Absolute LiDAR range ceiling. Points may return at this range, but they should usually be treated as reference geometry, not measurement-grade evidence.
- Minimum range. Below this distance the sensor may clip, produce unstable returns, or produce color/geometry artifacts.
- Best imaging distance. The range where cameras produce useful color, visual features, and 3DGS (3D Gaussian Splatting) imagery.
- Relative accuracy. The internal self-consistency within an indidual scan.
- Absolute accuracy. Agreement with ground truth from RTK, GCP (ground control points), or other georeferencing.
- Battery endurance. The realistic session duration, including hot-swap windows.
- Environmental rating. Dust, rain, temperature, and vibration limits.

Do not memorize another scanner's numbers and apply them blindly. Use the current datasheet for the device in your hand. The original MVP S1 values are available in the latest MVP S1 datasheet.

1.4 The Software Ecosystem

Most handheld SLAM workflows use three software layers, from field to office, in order of use:

1. Mobile capture software. Live preview, start/stop, project setup, control-point acquisition, RTK status, and coverage checking.
2. Desktop or cloud post-processing software. Trajectory optimization, loop closure, RTK/GCP fusion, point-cloud export, reporting, and optional visualization outputs.

3. Vendor resource center. Firmware, installers, manuals, release notes, calibration instructions, and support files.

Before a new job, confirm that the capture app, firmware, post-processing software, and license status are all current enough for the features you intend to use.

1.5 Packing Checklist — Generic

A generic handheld SLAM kit should be checked as a system, not as loose parts:

- Scanner or sensing head.
- Handle, grip, pole, backpack, vehicle mount, or tripod adapter as required.
- Positioning plate, target adapter, or GCP pickup accessory if control points will be used.
- Batteries, charger, power bank if approved, and required cables.
- Storage media and card reader if applicable.
- Mobile device or controller with the capture app installed.
- Post-processing license/dongle/account if required.
- Cleaning cloth, protective case, rain/dust protection if approved by the manufacturer.
- Printed or offline checklists and emergency support contacts.

Missing anything? Stop before the first job. A 5-minute kit check prevents a full rescan day.

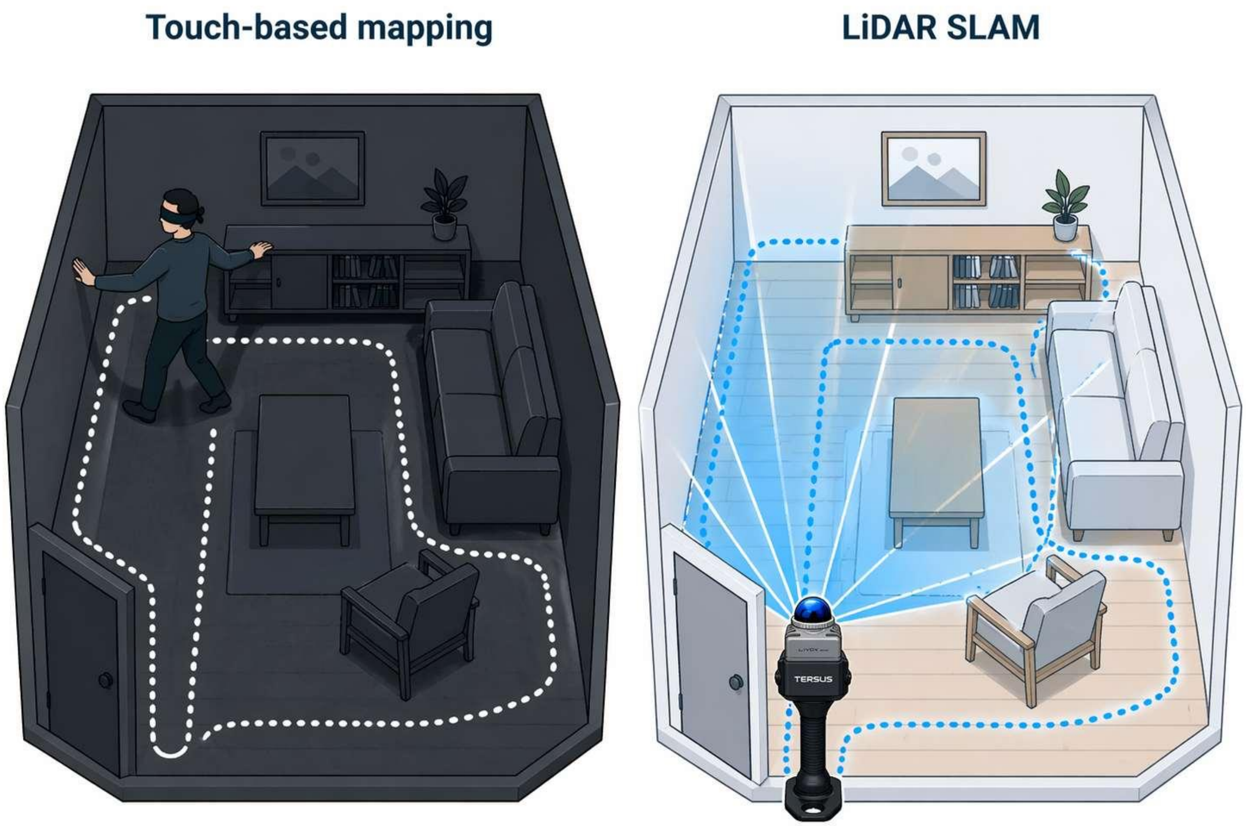
2 · Understand Before You Scan — A SLAM 10-Minute Primer

If you remember only one thing from this chapter: every rule in 5 is just a physical consequence of how SLAM works. Understand the "why" and the rules stop feeling arbitrary.

2.1 What Is SLAM?

SLAM stands for Simultaneous Localization And Mapping. It's exactly what it sounds like: the scanner figures out where it is and what the environment looks like at the same time, using only its onboard sensors. A helpful metaphor: imagine walking through a dark, unfamiliar house with your eyes closed, using only your hands. You touch a wall — that's a feature. You walk three steps forward — that's motion. You touch the same wall again on the way back — now you can close the loop and correct the drift in your mental map. SLAM does the same, but with laser beams instead of fingertips and 200,000 or more measurements per second instead of one touch at a time.

📸 [Figure 2-1: Metaphor — person with eyes closed mapping a room by touch, next to a LiDAR-based equivalent]



2.2 How the Scanner's Sensors Work Together

A handheld LiDAR SLAM scanner is a multi-sensor fusion system. No single sensor does SLAM alone; each covers the others' weaknesses.

- LiDAR → Geometric skeleton. Gives you hundreds of thousands of precise 3D points per second. Strong in shape and distance, weak in appearance.
- IMU → Instant motion. Knows, millisecond by millisecond, how the scanner is rotating and accelerating. Strong in short-term motion, drifts heavily over time if used alone.
- Dual fisheye cameras → Texture and visual features. Provide color for every point plus a visual backup when LiDAR is ambiguous (e.g., long corridors, featureless walls).
- GNSS / RTK → Global anchor. When the sky is visible, gives the SLAM engine absolute-coordinate constraints so the whole map doesn't drift.

The magic is in the fusion. A corridor where LiDAR can't tell how far you've walked is often a corridor where the cameras can see features. A tunnel where GNSS vanishes is often a tunnel where the LiDAR excels. Each weakness is covered.

2.3 SLAM's Two Engines: Front End and Back End

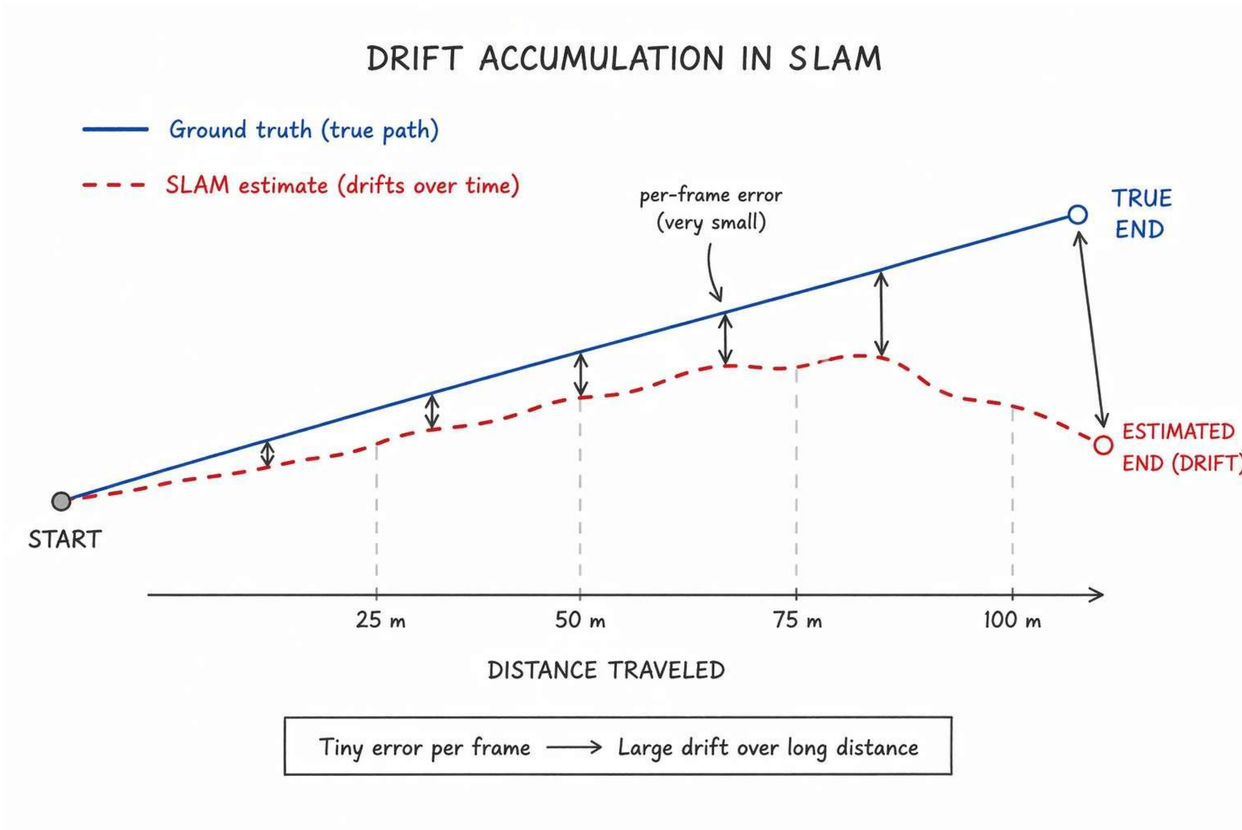
Inside the SLAM pipeline there are two jobs running at once.

- Front end (odometry). Every frame the scanner fires, the front end compares the new LiDAR + IMU + camera data with the previous frame and estimates, "how did I move in that millisecond?" Stitch enough of these together and you get a trajectory and a rolling point cloud.
- Back end (loop closure + graph optimization). The back end is watching for moments when you come back to a place you've already scanned. When it spots one, it solves a big optimization problem to pull the whole accumulated trajectory back into alignment. Imagine pulling a rubber band tight: all the small drifts get redistributed. Every frame accumulates a tiny error. Without the back end, those errors pile up. With the back end, they get erased each time you close a loop. It is precisely because of stable back end optimization algorithms that SLAM can consistently achieve survey-grade accuracy.

2.4 Why the Trajectory Drifts

Each frame's motion estimate is off by a small amount — maybe half a millimeter. Over one second that's invisible. Over a thousand frames — say, 100 meters of walking — those half-millimeters add up to several centimeters. In the worst case (long corridors, featureless spaces), drift can be much larger. This is not a bug; it is the fundamental cost of "figuring out where you are from scratch." Every SLAM system on earth has it. The mitigation strategies — loop closure, GNSS anchoring, and ground control points — are about bounding the drift, not eliminating it.

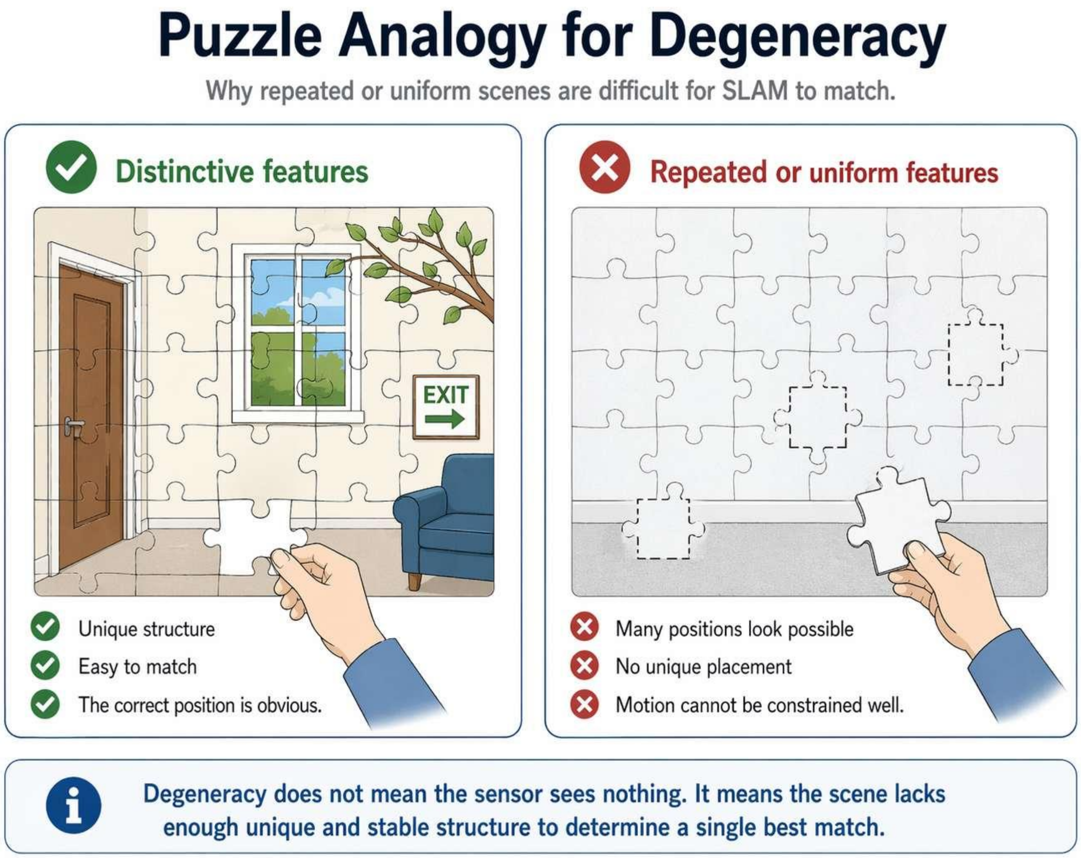
📷 [Figure 2-4: Drift accumulation diagram — true path vs. estimated path diverging over distance]



2.5 Degeneracy — The "Snow Blindness" of SLAM

In some environments, the challenge isn't that "the algorithm isn't good enough" — it's that the environment itself offers almost no usable information. We call these degenerate scenarios. A jigsaw puzzle makes for a fitting analogy. When a piece contains a door frame, a window, a tree branch, or a road sign, it's easy to place correctly — the pattern is distinctive enough to point to exactly one position. But imagine a section of the puzzle that's nothing but white walls, open sky, carpet, or repeating corridor texture. Suddenly, many pieces look nearly identical. You pick one up and find it seems to fit here — but also there, and somehow over

there too. The issue isn't that you've forgotten how to do puzzles. It's that this particular piece simply doesn't carry enough unique information to determine its one correct position.



This is precisely the situation SLAM faces in degenerate environments. It's not that the sensor "can't see" — it's that what it sees lacks the distinctiveness or stability needed to constrain the system's own motion estimate. As a result, displacement along certain directions becomes, in a very real sense, unknowable.

The most common degenerate scenes:

- Long corridor. The walls, the ceiling, the floor — they all look the same meter after meter. In one frame the scanner sees "a hallway." In the next frame the scanner sees "a hallway that is visually identical." The algorithm cannot tell if you walked half a meter forward or a meter forward. Without and external anchor, the distance along the corridor axis is literally unknowable from the data.
- Huge open space (a plaza, an arena, an empty parking lot). The nearest geometry is so far away that a 1-meter step produces a tiny change in the measured points. It's like trying to measure your progress across a desert using only distant mountains as reference — possible, but very noisy.
- Pure white walls, glass curtain walls. LiDAR either cannot get a stable return (laser passes through glass, or is absorbed by matte black) or the returns are so uniform from point to point that no single point can be matched uniquely between frames.

- Tight parallel walls (narrow alley, between two trailers). The geometry collapses into a single dimension — a tube. The algorithm is back in the corridor problem.
- Under dense foliage with wind. Every leaf is moving randomly. There are plenty of returns, but almost none of them are stable features.

What the algorithm does when starved of features. The IMU temporarily takes over. It "dead-reckons" — integrating measured accelerations and rotations to guess motion. The IMU is good for about 1 – 3 seconds before its own drift starts to dominate. Past that window, errors balloon. What the operator can do.

1. Walk closer to one wall — even in a large space, hugging one edge keeps features nearby.
2. Insert a side-loop. A short detour into a side room or around a column breaks the symmetry and gives the algorithm a geometric anchor.
3. Swing the scanner gently left-and-right while walking — increases the variety of features seen per second. (Gently! Rule 2 still applies.)
4. Outdoor: keep RTK Fixed. The global anchor replaces what local geometry cannot provide.
5. Indoor in a corridor: plant GCPs every 20 – 30 m if the job needs absolute accuracy.

> 📓 Deep Dive — "Unobservable directions". In a long corridor the motion along the corridor axis is what engineers call an unobservable degree of freedom. The math of SLAM literally has no information about that axis: a 1-meter translation and a 2-meter translation produce the same predicted observations. Adding GNSS (when outdoor), a loop closure, or a visible landmark at the end (a door, a column, anything unique) breaks the symmetry and restores observability. This is also why a "side-room dip" works so well — it adds a geometric event that is uniquely recognizable.

2.6 Loop Closure — How Drift Gets Cancelled

Loop closure is the most misunderstood concept in SLAM. A few points that matter for field work:

1. A "loop" is not just returning to the start. The scanner has to recognize that the geometry it's currently seeing is the same as something it's scanned before. That recognition requires overlap.
2. You need 5 – 10 meters of overlap with the prior trajectory. Not a single pass back through a doorway. Not "I walked past the entrance and kept going." The engine needs to match a block of frames against another block of frames, and a block is typically several meters long.

3. If there is no overlap, there is no loop. Simply stopping at your starting point and pressing Stop does not trigger a closure.
4. Once the loop is found, drift collapses. The back end solves a global optimization that pulls the entire trajectory into self-consistency. This is

why a good loop often turns an ugly-looking live preview into a clean final point cloud.

5. Large areas benefit from intermediate loops. Don't wait until the end — every 100 – 300 meters, walk a short side loop that re-enters territory you already covered.
6. the post-processing software's processing report tells you if loops were recognized. See 7.6 for how to read this.

2.7 What RTK Actually Does for the scanner

RTK is not a positioning device inside the scanner. It is a global anchor. Here's the distinction:

- When RTK is in Fixed state, each sample delivers a centimeter-level absolute position. SLAM uses this as a constraint — "at this moment, I know exactly where I am." The cumulative drift is continually reset.
- When RTK is in Float or Single state, the absolute accuracy is too low to trust. SLAM de-weights it or ignores it.
- When RTK reports Fixed but is actually wrong (the feared Pseudo-Fix), SLAM trusts it anyway — and the whole map can warp around the bad constraint. Pseudo-Fix typically happens in:
- Urban canyons.Tall buildings blocking signals, and reflecting signals (multipath).
- Under dense tree canopy
- In narrow valleys
- Under metal gantries and bridges

⚠ An indoor segment losing RTK is normal and harmless. SLAM is designed for that. A pseudo-fix outdoors, however, can produce large-scale layering that is much harder to diagnose. This is why experienced operators watch RTK status on the app throughout the run.

2.8 Why You Should Not Block the LiDAR (Explained via SLAM Principles).

A common misconception from new operators: "It's just a laser, covering it up for a second is fine." It is not. The front end matches each frame against the previous frame using overlapping geometry. If your hand covers the LiDAR for even half a second:

1. The current frame contains only your palm (a featureless, close-range mass).

2. The previous frame contained the environment.
3. There is no overlap between them that isn't also on your hand.
4. The front end either fails the match entirely (a tracking break) or matches the palm — in which case, the moment the palm moves away, the map jumps. The result, after post-processing, is one of three things: a missing section, a misaligned section that no longer connects to the rest, or a failed job. "Blocking" includes not only hands but also: the carry strap flapping up, long hair, loose clothing, a hanging lanyard, a phone held in front of the scanner, reflective signage propped against the scanner, a passenger in a vehicle standing in front of it.

☑ **Keep the LiDAR unobstructed at all times during a scan.**

✕ **Don't transfer the scanner between hands while scanning.**

✕ **Don't rest it against your chest or stomach mid-scan.**

✕ **Don't wear a hat or high collar that flops into the field of view.**

2.9 IMU and Angular Acceleration — Why Smooth Matters

The IMU in the scanner is a MEMS (micro-electo-mechanical system) device — precise, but with real limits. Two of those limits shape how you move the scanner:

- Angular acceleration (how fast you twist). Rotating your wrist suddenly, swinging the scanner around an axis, or jerking it from a holster — all produce angular accelerations that push the IMU toward its noise floor. The SLAM engine receives noisy rotation estimates, and the front end propagates that noise into the point cloud as local twist, slight tilt, or failed frame matching.
- Sudden linear acceleration (stop-and-go walking). Hard stops and hard starts excite IMU bias in ways the algorithm has to fight through. The rule is simple: SLAM doesn't mind slow. SLAM hates shake, rush, and yank.

📓 Deep Dive — Initialization phase. During the first seconds after pressing Start, the IMU is measuring gravity to calibrate roll and pitch. If the scanner is moving, gravity measurement is corrupted. This is why 2.10 matters.

2.10 The Initialization-Location Rule

How the scan starts determines how the entire session goes. This is the rule experienced operators learn first — often the hard way. During the first 10 – 30 seconds after you press Start, the system is:

- Measuring gravity via the IMU (to calibrate roll and pitch of the whole map),
- Acquiring initial LiDAR features to seed the front end,

- Taking initial camera frames to establish visual context. If any of these inputs are corrupt, the corruption propagates through the entire scan and is often unrecoverable in post-processing. Where to initialize

☑ On a stable, level surface: ground, table, bench, tripod, a closed vehicle's hood (engine off).

☑ In an environment that is itself stationary for at least 10 seconds: no crowd traffic in front of the scanner, no swaying trees framing the view, no flapping curtains in the scene.

☑ With good feature visibility: walls, furniture, built structure in the LiDAR's field of view. Where NOT to initialize

✕ On a boat, a floating dock, a ferry, a pier with motion — the IMU will measure "gravity" that isn't truly vertical, and the entire point cloud will be systematically tilted.

✕ Facing swaying trees, shrubs, tall grass, or curtains in wind — the cameras will detect "movement" and the visual module will assume you are moving, biasing the initial pose.

✕ In a crowd — moving people near the scanner will be treated as static features, and once they walk away, the map will jump.

✕ On a moving vehicle (even slowly) — same issue as the boat.

✕ Hand-held while you walk toward the start point — always place the scanner down, let it settle, press Start, wait for the Ready state, then pick it up smoothly.

⚠ A bad initialization produces a point cloud that is tilted or systematically skewed with no post-processing fix. You will have to re-scan. Invest the 15 seconds upfront.

3 · What Handheld LiDAR SLAM Can and Cannot Do — Managing Expectations

Read this chapter before you take any handheld SLAM scanner to site. A scanner used outside its envelope produces bad data and a disappointed customer.

3.1 Accuracy — Three Numbers, One Confusion

Customers routinely conflate three different accuracy figures. They are not the same thing and should not be quoted interchangeably.

- Point cloud thickness. System self-noise. How thick a measured wall appears in the point cloud. It is a property of the scanner and the processing pipeline, not the same as measurement accuracy. It tells you how crisp the cloud looks.
- Relative accuracy. Internal self-consistency. Two points in the same scan, measured in different seconds, agree with each other within the scanner's stated relative tolerance. This is what matters for questions like "is this room square?"
- Absolute accuracy. Agreement with ground truth. When the point cloud is placed in a real-world coordinate system through RTK, GCPs, targets, or other survey control, this is how close it is to survey-grade truth.

⚠ Common misuse: promoting a point-cloud thickness number as if it were measurement accuracy. It is not. A customer making a wall-to-wall measurement should quote absolute accuracy when the cloud is georeferenced, or relative accuracy when comparing features inside one scan.

💡 A note on positioning: Most handheld SLAM scanners are precise enough for many architecture, BIM, construction support (e.g. stockpile volumes), forestry, emergency mapping, and documentation workflows if the operator follows the scanner's operating envelope. The honest answer is usually: yes, if the route, control, and environment match the accuracy claim.

3.2 Distance — What You Can Scan vs. What You Should Scan

This distinction matters and is routinely muddled in sales material.

- Recommended working distance. Within this distance the point density is high, noise is lower, and the SLAM engine has enough local structure to work with. Plan routes to keep important targets inside this distance.
- Absolute LiDAR range. Points may return beyond the recommended working distance. But density drops, noise rises, and far-range returns should be treated as reference geometry, not as measurements you stake decisions on.

- Minimum range. Below the scanner's near-field limit, LiDAR has no stable return or produces unreliable geometry. Do not press the scanner against a wall expecting more detail.
- Best imaging distance. Cameras have their own sweet spot for color quality, visual features, and 3DGS reconstruction.

For low-reflectivity targets such as black surfaces, dark asphalt, or matte industrial paint, reduce the practical working distance substantially. The exact values are product-specific; use the latest datasheet and project tolerance.

3.3 What Handheld LiDAR SLAM Can Do Well

- Indoor architectural capture — rooms, corridors, floors, ceilings, MEP (mechanical, electrical, plumbing).
- Building-exterior and campus capture — façade scanning, parking lots, roads.
- Construction site progress — earthworks, steel frames, partially built volumes.
- Forestry inventory — DBH (diameter at breast height), canopy density, stand structure.
- Underground spaces — parking garages, tunnels, mines, heritage crypts.
- Cultural heritage — temples, historic buildings, archaeological sites where tripod terrestrial scanning is too slow.
- Emergency mapping — quick reality capture for incident response.
- Industrial plants and utility corridors — pipe racks, process units, and service corridors within the scanner's distance envelope.

3.4 What Handheld LiDAR SLAM Cannot — or Should Not — Be Used For

- Millimeter-grade structural deformation monitoring. Use a laser tracker, total station, or other appropriate metrology tool.
- Single-point high-precision staking. Use a GNSS RTK rover or total station.
- Airborne or wide-area topographic mapping. Use a UAV LiDAR or mobile mapping system designed for that scale.
- Underwater scanning or wet operation outside the device rating.
- Active rain, heavy snow, dense smoke, thick dust. LiDAR returns will be dominated by particles.
- Temperature, vibration, or dust/water exposure outside the device's stated operating range.

3.5 Industry-Wide Hard Limits

It helps to tell customers which constraints are physics, not product choices:

- Featureless corridors frustrate every handheld SLAM system. Intermediate loops and side rooms are the universal fix.
- Glass curtain walls, full-length mirrors, and still water surfaces produce reflection or transparency noise that commodity LiDAR cannot fully remove at capture time.
- Rain, dust, and heavy snowfall degrade LiDAR across all brands.
- Dense canopy plus deep valleys routinely produce GNSS multipath and pseudo-fix on every device.

When a customer pushes back — "but the datasheet says..." — explain where the number applies. Datasheet specifications reflect results under optimal conditions: inside the sensor range and environmental envelopewith good route-planning and control. Do not defend a number without context.

4 · Pre-Scan Setup — Getting Ready for the Field

The difference between a one-take job and a re-shoot is almost always decided here, before the scanner is turned onL.

4.1 Assembly

Order matters. Skipping steps or doing them in the wrong order is a common cause of a scan that wobbles at initialization.

1. Assemble the scanner exactly in the vendor-specified order.
2. Confirm every mechanical lock, click, clamp, or screw is fully seated.
3. Gently test for unwanted rotation or looseness before powering on.
4. Attach tripods, vehicle mounts, backpack frames, or special adapters only in the order recommended by the vendor.
5. If the scanner has a dedicated control-point plate or target pickup accessory, confirm it is rigid and repeatable before you rely on GCPs.

4.2 Lens and Sensor Hygiene

Cameras are not cosmetic. They contribute color, visual features, and sometimes tracking support.

- Before every scan, inspect all camera lenses and LiDAR windows in good light. Look for smudges, water spots, fine dust, condensation, scratches, and fingerprints.
- Use the vendor-approved cloth and cleaning method only.
- If lenses fog after moving from an air-conditioned vehicle to a hot outdoor site, wait several minutes before scanning.
- Any visible smudge can produce color banding in panoramas, visual-feature weakness, or 3DGS reconstruction artifacts.

4.3 Battery and Power

- Pre-charge batteries before the job.
- Bring enough spares for the planned scan time plus delays.
- Understand whether the product supports hot-swap, external power, or scan-while-charging, and what those modes do to battery lifespan.
- Do not improvise chargers or cables on a paid job. Power-negotiation problems are preventable.

- Plan battery changes at natural route breaks, not in the middle of a loop-closure-critical segment.

4.4 Storage Check

- Confirm formatted storage media is installed before powering on.
- Check free space before every session.
- After intensive jobs, copy data to the processing computer and verify the full copy completes before reformatting the card or drive.
- Treat incomplete data copies as data-loss events until proven otherwise.

4.5 Power On / Off

Every product has its own button sequence and LED logic. The generic rule is simple: learn it before the field day.

- Power on according to the vendor's sequence.
- Wait for the ready state before starting the scan.
- When stopping, keep the scanner still until the software confirms save completion.
- Do not power off during initialization, firmware upgrade, saving, or data transfer.

4.6 App Install & Pairing

- Install the current capture app before the job.
- Pair the phone, tablet, or controller to the scanner in the office first.
- Verify the live preview, project creation, storage status, and start/stop controls.
- For Wi-Fi-based scanners, record the SSID/password and any manual IP settings in the project kit.
- For enterprise or public-sector sites, confirm that Wi-Fi, Bluetooth, mobile data, or NTRIP connectivity is allowed.

4.7 Firmware and Software Check

- Check firmware and capture-app versions before the first scan.
- Upgrade only when you have time to follow the upgrade procedure completely.
- During an upgrade, do not exit the software, disconnect power, remove storage, or manually power off unless the vendor procedure says to.
- If a required feature such as Resume-Scan, RTK fusion, GCP pickup, or a new processing mode depends on firmware, verify the required version in advance.

4.8 CORS / NTRIP / RTK Configuration

For outdoor high-precision jobs:

- Enter the NTRIP (networked transport of RTCM via internet protocol) host, port, mountpoint, username, and password correctly.
- Confirm RTK reaches Fixed state before starting the scan, ideally in open sky for a short stabilization period.
- Check satellite count, coordinate stream, and correction age when the app provides them.
- Watch RTK status during the scan. Fixed can help; Float, Single, or pseudo-fix can hurt.

4.9 App Parameter Settings

Typical preview parameters include point size, preview point count, transparency, focus/follow mode, colorization settings, photo interval, RTK on/off, and GCP acquisition mode. Change them for the operator's field awareness, not because they magically improve bad geometry.

- Lower preview density on older phones for smoother live QA.
- Increase point size for sparse outdoor preview if needed.
- Use transparency when you need to see the trajectory through the cloud.
- Turn RTK on only when it is useful and trustworthy.
- For 3DGS-oriented jobs, shorten photo interval and plan a dedicated saturation route.

4.10 The 2-Minute Pre-Capture Checklist

Before you press Start:

- Device assembled and mechanically locked.
- All lenses and LiDAR windows clean.
- Battery level adequate, spares on hand.
- Storage inserted and free space verified.
- Firmware/software version suitable for the job.
- App/controller connected and live preview visible.
- RTK status confirmed if outdoor.
- Initialization location chosen: stable, level, stationary environment.
- Route mentally rehearsed: entry, loop points, GCPs, exit.
- Operator knows where to stand so the LiDAR is not blocked at the start.

5 · The 10 Golden Rules of Scanning

Rule 1 — Start Static, End Static

Initialize on a stable, level, stationary surface. Finish the scan with a few seconds of stillness before pressing Stop. Why: The IMU calibrates roll, pitch, and gravity direction during the first seconds. A wobbly start produces a tilted point cloud that no post-processing can fully fix. A jittery stop may corrupt the final save.

- ✅ **Ground / bench / tripod / stable table / closed vehicle hood.**
- ❌ **Boats, floating piers, moving vehicles, swaying foliage in view, crowd moving directly in front.**

Rule 2 — Lift Slowly, Move Smoothly

Never yank, twist, or rotate the scanner abruptly. High angular acceleration is the IMU's worst enemy. Wh: IMU noise scales with how fast you rotate. Flick the wrist and the algorithm sees garbage.

- ✅ **Pick the scanner up as if it were a cup full of coffee.**
- ❌ **Don't spin it to show a colleague. Don't swap hands quickly. Don't rotate your wrist to check the screen.**

Rule 3 — Walk at ~1 m/s

A steady human walking pace is the designed speed. Slower is fine; faster is not. Why: LiDAR frame rate and IMU integration are tuned for human-scale motion. Running loses detail and starves loop closure.

- ✅ **Relaxed, continuous, unhurried.**
- ❌ **Sprinting between rooms. Pausing then lurching forward.**

Rule 4 — Keep LiDAR Seeing Features

The scanner's immediate view should contain at least some walls, columns, trees, or stable geometry at all times. Why: SLAM feeds on feature matches. An empty view starves the algorithm.

- ✅ **Walk along walls rather than down the center of a large space. Sweep the scanner to pick up side rooms.**

❌ **Don't march through empty plazas with the scanner pointed at the sky. Don't stare at a featureless ceiling.**

Rule 5 — Respect the Near / Working / Absolute Range Rule

Minimum useful range is 0.3 m. Plan within 40 m of targets. Accept that 70 m is a ceiling, not a working distance. Why: See 3.2. Density and noise both depend on range and on each scanner's datasheet limits.

✅ **Plan routes so walls and key features fall within the scanner's recommended working distance.**

❌ **Don't stand in the middle of a 100 m warehouse and expect wall corners to register.**

Rule 6 — Never Obstruct the LiDAR

Any obstruction — hand, strap, hair, lanyard, jacket sleeve, phone — breaks the frame chain.

Why: See 2.8. The SLAM front end cannot match one frame to the next when one frame contains only your palm.

✅ **Keep the LiDAR aperture in free air at all times.**

❌ **Don't transfer the scanner between hands mid-scan. Don't carry it under your arm. Don't let a strap flop into view.**

Rule 7 — Open the Doors First, Then Transition Slowly

Before you press Start, walk the building once and open every door you plan to pass through. At the doorway itself, slow down and let the LiDAR see both rooms for a few seconds. Why — Part 1: opening doors in advance. A door in motion is SLAM's worst-case object. Here is why:

1. A swinging door is a large, moving, structural surface right in front of the scanner. The LiDAR sees a big flat plane occupying a significant portion of its field of view.
2. The SLAM front end is designed to match geometry between consecutive frames. When something big changes shape between frames, the algorithm has to decide: "did the scene change, or did I move?"
3. For a swinging door, both answers are partly true. The scanner is moving forward and the door is moving across its view. The algorithm can't cleanly separate the two motions — it doesn't know the door is a moving object, because it is large enough and close enough to look like part of the structure.

4. The result is that the door frame, which should be a rock-solid reference, becomes an unreliable source of features for several frames. In practice this produces: local layering on the door and surrounding walls, a small jog in the trajectory right at the threshold, and occasionally a complete tracking break that cuts the new room loose from the previous room.
5. The moving-object filter does not save you here, because the filter is designed for clearly dynamic objects (people, cars) that move independently of the structure. A door is attached to a wall, moves slowly, and has a flat geometry — it sits in the filter's blind spot. The fix is almost free: open every door before you start scanning. Walk the route you plan to scan, open every interior door to roughly 90 – 100° (fully open, against the stopper if possible), and confirm they will stay open on their own. Then go back to the initialization point and start. Why — Part 2: pause at each transition. Even with doors already open, the threshold itself is a critical moment because the geometry changes fast. Inside the old room the LiDAR sees walls, furniture, a ceiling; once through the door, it sees a completely new room's walls. The two frames share only a narrow slice of the door frame in common. Walking through at 1 m/s gives the algorithm roughly 0.5 – 1 second of common features, which is marginal. Pausing at the threshold gives the algorithm 10× more overlap frames — dozens of measurements where it can simultaneously see the old room through the door behind it and the new room ahead. This is what makes the stitch across the door reliable.

✅ Do

- Open every door before the scan begins. Walk the route, open doors, confirm they stay open, then return to init point.
- If a door has a spring or self-closer, wedge it open (a rubber doorstop, a book, a chock).
- At each doorway, pause 2 – 3 seconds with the LiDAR seeing both rooms. Turn the scanner gently left-and-right to pick up the full door frame.
- For glass doors, leave fully open — the glass itself is a LiDAR-noise source; don't try to scan through it.

❌ Don't

- Don't push through a closed door while scanning. Every time the scanner sees a door open in front of it, the algorithm takes a hit.
- Don't have a helper open doors as you approach — the helper's arm, body, and the swinging door all show up in the scan at the worst possible moment.
- Don't charge through open doors at full pace. Open + fast = better than closed + fast, but pausing is still best.
- Don't push the scanner through an opening with your body blocking the LiDAR.

Rule 8 — Close the Loop Properly

A loop needs 5 – 10 m of overlap with your prior trajectory. "Returning to the start" is not enough. Why: See 2.6. The algorithm needs a block of frames to match against another block.

☑ **Before finishing, re-enter a section you've already scanned for at least 5 – 10 m. In large areas, plant intermediate loops every 15 – 30 m.**

✕ **Don't stop at the exact start point without overlapping. Don't expect an automatic loop on a long linear corridor.**

Rule 9 — Avoid Moving Objects Around You

The algorithm has a moving-object filter, but filters are never perfect. Keep dynamic clutter out of the scan as much as possible. Why: People walking near the scanner occasionally get picked up as static features; when they leave, local jumps can appear.

☑ **Keep bystanders ≥ 20 m away. Plan routes around moving traffic. Scan forests when no one is walking the trails.**

✕ **Don't scan crowded lobbies without coordinating a quiet window.**

Rule 10 — Keep Each Scan Reasonably Sized

Long single scans without intermediate loops accumulate unrecoverable drift. When in doubt, split and resume. Why: Drift grows with distance. Loop closure is the cure; split-and-resume is the workaround when geometry doesn't allow a loop.

☑ **Plan sessions so each continuous scan can close at least one meaningful loop.**

✕ **Don't scan a 2-km linear corridor as a single session and hope.**

6 · Scenario Playbook

Each scenario in this chapter follows the same structure: Environment → SLAM risks → Recommended route → Specific actions → Image placeholder → Field checklist. You can rip any page out, print, and bring it to site.

6.1 Indoor Multi-Room & Corridors

Environment. Walls, doors, furniture, ceilings. Rich in features, but corridors are geometrically weak and doors are the silent killers of otherwise good scans.

SLAM risks:

- Long corridor degeneracy (2.5).
- Door transitions that break frame continuity (5 Rule 7).
- Swinging doors opening during the scan — a severe interference pattern (5 Rule 7, Why Part 1).
- Moving bystanders if the building is occupied.
- Mirrors, glass partitions, glossy floors reflecting LiDAR.

Pre-Scan Preparation

Before you press Start in any occupied indoor scene, do a walk-through pass with no scanner:

Open every door on the planned route to 90 – 100°. Wedge open any self-closing doors.

Open glass doors fully and leave them so you don't scan through the glass.

Turn on all the lights you can reasonably turn on (helps cameras; doesn't affect LiDAR).

Move obvious movers. Close window blinds if they're flapping in a draft. Silence a noisy fan that's making a curtain move.

Warn occupants. Ask people in rooms on your route to stay still for the next 5 – 10 minutes, or to leave.

Identify a clean initial point. A corner room with structured walls and no traffic is ideal. This walk-through typically takes 5 – 10 minutes in a small building. It saves 30 – 60 minutes of re-scanning.

Recommended route

1. Start in a corner room — maximum initial features from walls meeting at right angles.
2. Sweep each room fully before exiting. Walk a U-shape around the perimeter of each room rather than through the center — keeps features within 4 – 8 m.

3. Dwell at door frames for 2 – 3 seconds so the LiDAR captures both rooms simultaneously. Gently rotate the scanner so the door frame, the current room, and the next room all appear in the field of view.
4. For long corridors, enter side rooms as intermediate loops every 15 – 30 m. Each side room trip creates a micro-loop that bounds drift.
5. If the building has more than one corridor, end one corridor in a room that connects to the next corridor — do not back-track down the same corridor twice if you can avoid it (the reversed geometry can confuse the visual matcher in corridors with repeating patterns).
6. Return to the start room and re-enter for 5 – 10 m of overlap before stopping. Actions & tactical detail

- Distance from walls. Keep the scanner about 0.8 – 1.5 m from any single wall. Closer and you enter the minimum-range trouble zone; farther and in narrow corridors the opposite wall goes out of the high-density range.
- Scanner pitch. Tilt the scanner gently to ensure ceilings and floors are picked up. A common mistake is to carry the scanner perfectly level for the whole scan; this under-samples the ceiling.
- RTK indoors? No, turn RTK off for pure indoor work. If the scan will transition to outdoor at some point, leave RTK on but don't rely on it indoors; the algorithm is designed to gracefully accept its disappearance.
- Trailing doors. Only close a door behind you if the scan path will not return through it. Otherwise leave open so re-entry is a natural loop, not another door event.
- Mirrors. Full-length mirrors create a full-room phantom in the point cloud. If possible, temporarily cover mirrors with a sheet or a light-colored fabric. If not possible, plan to clean the phantom geometry in post.
- TV screens and glossy cabinets. Large dark glossy surfaces produce sparse returns; don't be alarmed if they show as "thin" geometry in the cloud.
- Kitchens / bathrooms. Extra care — lots of glossy tile, chrome fixtures, mirrors, glass shower doors. Walk slower here.

6.2 Stairs & Multi-Floor Buildings

Environment. Vertical transitions, often with low light in stairwells, and mirror-like handrails.

SLAM risks:

- Vertical axis challenges for pure-SLAM (few horizontal features during the climb).
- Handrails can cause reflective noise.
- Scanner posture changes (tilt as you climb).

Recommended route.

- Handheld, bottom-up for single-flight stairs. Start at ground floor, ascend slowly, stop on each landing.
- Pause for 3–5 seconds at each landing and turn the scanner 360° to pick up the stairwell geometry.
- If two stairwells exist, scan each end-to-end and connect them via the common floors.

Actions.

- Walk each flight at half normal pace.
- Keep the scanner roughly level; don't tilt severely to "look up" or "look down."
- At the top and bottom, walk one loop around the floor landing before moving on.

6.3 Large Open Spaces

Environment. Gymnasiums, warehouses, exhibition halls, empty parking lots. SLAM risks: Extreme degeneracy — most features may be far away and mostly uniform.

Recommended route.

- Walk along the walls, not the center. This keeps features < 10 m away.
- Add cross-passes through the interior when absolutely necessary, but keep them short and bracketed by wall sections.
- Close at least one internal loop per major area.

Actions.

- Consider using the backpack mode for stability on long sweeps.
- Outdoors with clear sky: keep RTK on. Indoors: GCPs help significantly.
- Reduce point density in the app to keep the preview legible.

6.4 Indoor-Outdoor Transitions

Environment. Doorways, entrance lobbies, garage exits.

SLAM risks:

- RTK state change shock — sudden jump from Fixed (outdoor) to nothing (indoor) or vice versa.
- Dramatic light change may saturate cameras for a few frames.

Recommended route.

- At every indoor/outdoor boundary, pause for 5 seconds at the threshold to let:
  - Camera exposure re-adapt.
  - LiDAR pick up of features on both sides.
  - RTK state settles before / after.
- Enter outdoor phase with RTK already Fixed if possible.
- Close a loop by re-entering the indoor space for 5 m before finishing.

6.5 Large Building Exteriors & Campuses

Environment. Façades, courtyards, parking lots, connected building volumes.

SLAM risks: Long linear sections; GNSS shadow in courtyards; tall buildings reflecting multipath signals.

Recommended route.

- Close the large outer loop first. Walk the perimeter of the whole campus before diving into interior detail.
- Then do interior / courtyard detail as branches off the main loop.
- Re-enter the main loop's path before finishing.

Actions.

- Watch the RTK status constantly. If it drops to Float near tall buildings, slow down and give the receiver time to recover.
- Plan GCPs at entrances, property corners, and any interior courtyard.

6.6 City Streets & Roads

Environment. Long linear scenes, parked vehicles, active traffic, changing buildi and trees along the right-of-way corridor. SLAM risks: Urban canyon pseudo-fix (2.7); long linear drift; moving vehicles.

Recommended route.

- Walk on one sidewalk, then cross and return on the other sidewalk — this creates a natural closed loop.
- At major intersections, do a small side-scan into each cross street (20 – 30 m in, then back).
- Break the scan at intersections if the street is long (> 200 m).

Actions.

- Turn RTK on. Watch for pseudo-fix under heavy tree canopies.
- Place GCPs at intersections if the deliverable needs absolute accuracy.
- Stay out of traffic. Sidewalk-only operation whenever possible.

6.7 Forestry

Environment. Dense features (trunks, branches) but sky obscured; GNSS often weak. SLAM risks: Canopy attenuates GNSS; pseudo-fix is common; trunks look locally similar.

Recommended route.

- Multi-loop strip pattern. Walk strips with clear overlap; close at least one loop per strip.
- Accept that RTK may spend most of the scan in Float. Plan GCPs at strip endpoints and intersections if absolute accuracy is required.
- Keep one hand free at all times for balance — uneven ground injects unwanted motion if you slip.

Actions.

- Walk slowly. Forest floor is uneven; smooth motion is harder here.
- Don't scan with the canopy directly overhead only — vary the LiDAR's angle to see trunks.

6.8 Tunnels & Underground

Environment. Zero GNSS, long linear geometry, possibly poor lighting. SLAM risks: Pure SLAM scenario. Long linear drift in tunnels. Dust and moisture.

Recommended route.

- Scan out and back. The reverse path creates natural overlap — 100% loop coverage.
- At each end, do a small loop in the surface/adit area so the entry/exit points are visible landmarks.
- In parking garages, walk a circulation pattern that closes multiple internal loops.

Actions.

- Check that the LiDAR dome is clean before entering (dust).
- Watch for drips and water on the floor — a slip is an angular-acceleration event.
- Lighting for cameras is nice-to-have; if the garage has lights, use them.

6.9 Tight Indoor Spaces

Environment. Narrow corridors, small bathrooms, storage rooms, utility closets, interior stairs. SLAM risks: Minimum-range clipping (inside the scanner's near-field limit), and cramped corridors approach geometric degeneracy from the opposite direction — too much wall.

Recommended route.

- Keep ≥ 0.5 m from walls whenever possible. If the space is narrower, accept clipping at the wall closest to the scanner and make sure the opposite wall is covered.
- Walk through slowly and re-walk once.

Actions.

- Do not press the scanner against a wall to "get more detail." The opposite effect — LiDAR has no stable return < 0.1 m.
- Corner geometry is your friend. Use corners as natural feature clusters.

6.10 Glass Curtain Walls & Water Surfaces

Environment. Modern architecture with large glass panels; waterfront or riverside scenes. SLAM risks: Glass lets the laser through, produces partial returns, and sometimes returns from the interior behind the glass — creating phantom geometry. Water reflects specularly.

Recommended route.

- When possible, scan from angles not perpendicular to the glass. Glazing returns are weakest at grazing angles, stronger at normal incidence, but the normal-incidence returns are often the ghost-layer ones.
- Scan the water surface but expect to clean the resulting noise in post.

Actions.

- In post, use the post-processing software's clipping and manual filtering to remove water-surface and glass ghosts.
- Don't blame the device — this is a physics boundary that no commodity LiDAR solves at capture time (3.6).

6.11 Low-Light & Night

Environment: Dusk, dawn, night scans, dimly lit interiors. SLAM risks: Cameras contribute less; color quality drops; 3DGS quality drops substantially.

Recommended route.

- LiDAR still works fine at night — the scanner is not light-dependent for geometry.
- Accept that color may be grayer and sometimes patchy.
- For 3DGS-oriented jobs, add portable lighting.

6.12 Cultural Heritage & Historic Interiors

Environment. Tight spaces, intricate detail, reflective surfaces (polished stone, gold leaf), low light. SLAM risks: Operator wants maximum detail; scanner limits on minimum range and density must be respected.

Recommended route.

- Multiple passes: once for overall volume, once for each detail zone.
- Accept that 3DGS capture requires yet another dedicated pass (8.10).
- Close loops frequently — heritage sites usually have enough walls and columns to support them.

Actions.

- Do not touch surfaces. Maintain ≥ 1 m from fragile features.

6.13 Ships, Docks, & Water Edges

Environment. Piers, gangways, moored vessels, shore structures. Possibly mild deck motion. SLAM risks: Initialization failure on moving platforms. IMU picks up platform motion as vehicle motion.

Recommended route.

- Initialize on the shore, not on the ship. This is non-negotiable. The entire point cloud's vertical reference depends on it.
- Board the vessel only after initialization is complete and the scanner is already tracking stable geometry.
- Accept that a moored-but-swaying vessel will produce some systematic jitter. Calm sea states are essential for measurement-grade work.
- Close loops on the shore, not on the deck.

Actions.

- If the vessel truly must be scanned while afloat, the best compromise is to initialize ashore, board gently, scan quickly, and disembark. Loops should overlap a portion of the shore walk.

7 · In-Field QA & Resume Scan

The moment to catch data problems is before you leave the site. A 10-minute QA pass on-site can save hours or days of rework.

7.1 What to Watch in the Live App

During the scan, keep one eye on the app's live preview. You are looking for:

- Coverage completeness. Are there gray zones in the preview where no points have been placed? Go back and sweep.
- Trajectory shape. Does the displayed path match your memory of the actual walk? If a loop looks broken or kinked, the algorithm is struggling.
- RTK status bar. Green (Fixed) is healthy outdoor. Yellow/Red for more than a few seconds in the open sky = investigate.
- Battery level. Plan your hot-swap window.
- Storage remaining. If TF / microSD card fills, the scan ends without warning.

7.2 When to Stop and Rescan

Stop and either re-do the problematic segment or abort the entire scan if:

- Live preview shows a gap / hole that you definitely walked through.
- Trajectory has a visible kink that doesn't match reality.
- RTK spent > 30 seconds in pseudo-fix in the open (you'll see large coordinate jumps).
- Someone walked in front of the scanner for several seconds.
- Scanner reports an anomaly; don't be a hero. A 10-minute rescan beats a 2-hour return trip.

7.3 Resume-Scan Done Right

Resume-Scan lets you pick up where a previous scan stopped. E.g., for Tersus SLAM, firmware ≥ v1.0.3. or greater is required.

Do:

- ✅ Return to a feature-rich section of the previous scan (not an empty hallway).
- ✅ Overlap at least 5 – 10 meters with the prior trajectory.
- ✅ Initialize for the resume segment exactly as you would for a fresh scan (2.10 rules apply).
- ✅ Save all resume segments to the same project folder. Don't:
- ❌ Resume with zero overlap — the segments won't stitch.

- ✕ Expect global loop closure to find a match between two separate resume projects. E.g., for Tersus SLAM cross-project loop closure is not currently supported.
- ✕ Resume at the exit of a long corridor expecting to stitch immediately. Walk back into feature-rich geometry first.

⚠ Seam zones may show slight layering. In very high-accuracy jobs, plan routes so resume seams fall on walls or details that are easy to mask or re-scan.

7.4 The 10-Second Save Ritual

When you press Stop:

1. Hold the scanner still.
2. Watch the indicator light turn yellow (saving).
3. Wait for "Save Successful" on the app.
4. Do not power off until the save confirmation appears.
5. Wait ≥ 1 minute before starting the next task. Skipping this ritual is the most common cause of corrupted files.

7.5 Ground Control Points (GCPs) — Layout & Best Practices

GCPs are the single most powerful tool for turning a "pretty good" scan into a survey-grade deliverable. They are also the most common place where a well-intentioned operator accidentally sabotages their own data. The following section is long for a reason.7.5.1 What GCPs Actually Do for Your Point Cloud

A GCP is a point with known true coordinates (typically measured by a GNSS RTK rover, a total station, or an existing survey monument). When you pick a GCP during a scan, you are telling the post-processing software: "I am, at this moment, standing exactly on the point that has coordinates (X, Y, Z)." With at least three non-collinear GCPs with known coordinates, the post-processing software can solve for the rigid-body transformation (rotation + translation) that best places the entire point cloud into the true coordinate frame. With more than three GCPs, the solver uses least-squares to also diagnose internal distortion, flag outliers, and produce per-GCP residuals that tell you how well the scan fits the real world. GCPs improve three things:

1. Absolute accuracy. The whole cloud is shifted and rotated so that known points line up with their true coordinates.
2. Tilt correction. See 9.1 Cause B — a drifted scan with tilted far-field can be pulled flat by well-distributed GCPs.

3. Accountability. Residuals give you a number to report. "Absolute RMS to GCPs: 18 mm" is a defensible statement. "Looks good to me" is not.

7.5.2 The Common-Sense Rules of Layout

Six rules cover 90% of what you need to get right. Each one has an intuitive explanation — no math required.

Rule 1 — Never lay GCPs in a straight line

Why: Three points on a straight line do not uniquely define a 3D rotation. The cloud can be pivoted around the line without any of the three residuals

changing. The solver will still give you an answer, but the answer is not unique, and the parts of the scan far from the line can swing substantially with any measurement noise. In practice. If you stand back and look at your planned GCP positions on a site map, they should form a polygon, not a line. Even a shallow triangle is dramatically better than a straight line.

✗ Don't put all five GCPs along one side of a building.

✗ Don't put all your GCPs along the centerline of a long road.

☑ If a site is linear (like a road or pipeline), zigzag the GCPs — alternate left and right of the centerline.

Rule 2 — Spread GCPs to cover the full extent of the site

Why: The solver extrapolates beyond the GCP envelope. Anything inside the envelope (the convex hull of your GCPs) is interpolated — small error. Anything outside is extrapolated — error grows with distance from the envelope. In practice.

- Push GCPs to the corners and edges of the site, not just the interior.
- If your site is a 100 m × 60 m campus, put GCPs near all four corners plus at least one or two in the middle.
- If you only cover one half of the site with GCPs, the other half will drift freely.

✗ Don't cluster GCPs at the entrance and skip the back of the site.

✗ Don't pick only in easy-to-reach locations if the easy locations are all in one zone.

☑ Every "region" of the site should have at least one GCP within or on its edge.

Rule 3 — Include vertical diversity

Why: A cloud with all GCPs on one elevation has strong horizontal constraint but weak vertical constraint. The scan can "tilt" around the horizontal plane defined by the GCPs, and the solver may not detect it. In practice.

- On multi-story buildings, place GCPs on at least two floors (ground floor + top floor minimum).
- On sites with terrain, place GCPs at different ground elevations (top of slope, bottom of slope, mid-slope).

Rule 4 — Minimum number, and how many more is "enough"

Minimum: 4 — strictly required for a robust solve (3 is mathematically enough but gives no redundancy for outlier rejection). Recommended baseline: 6 for small sites (< 50 m extent), 8 – 12 for typical building-scale jobs, 12 – 20+ for campus-scale or high-accuracy work. Think of it this way: with 4 GCPs, one bad pickup kills your solve. With 8 GCPs, one outlier is flagged and removed automatically.

Rule 5 — Place GCPs where they can actually be picked up

cleanly The positioning plate's cone requires a small clear flat area to rest the scanner on the GCP. A great GCP coordinate on an inaccessible bush-covered hillside is useless.

✅ Good GCP surfaces: paved ground, concrete pads, pavement markings, building corners that can be reached, stable man-made features.

❌ Bad GCP surfaces: soft soil (plate sinks), grass (plate rocks), sand, gravel that shifts, metal grates (uneven), loose tiles. Pro tip. If the site has few natural GCP surfaces, bring a few nail-head targets (or a painted X on a stable pavement). Place them before surveying, then pick

them up with the total station / RTK rover. They now exist as known coordinates and you can pick them up with the scanner during scanning.

Rule 6 — GCPs must be stable for the duration of the scan

A GCP that moves between "known coordinate measurement" and "scanner pickup" is worse than no GCP — it actively pulls the solve toward the wrong answer.

❌ Don't use a traffic cone that someone might kick.

❌ Don't use a piece of tape on grass.

❌ Don't use a nail-head target that's loose.

☑ **Use targets that are fixed, immovable, and visibly undisturbed throughout your survey window.**

7.5.3 How to Measure the GCPs Themselves

You cannot improve a point cloud beyond the quality of the GCPs used to constrain it. So the GCP coordinates have to be better than the SLAM deliverable target. Deliverable target GCP source expected the scanner relative accuracy only (no absolute) GCPs not strictly required Absolute accuracy ≤ 5 cm RTK rover in Fixed state, one occupation each Absolute accuracy ≤ 2 cm RTK Fixed with dual occupations, or total station Absolute accuracy ≤ 1 cm Total station with check-shots Write down which instrument measured which GCP, which session, and under what conditions.

Be wary of using previously established GCP without researching their pedigree: who set them, what methods did they use, how current are the coordinate values, and what coordinate / geodetic reference frame are the values? Mixing GCP of different pedigrees can be hazardous; you may see poor resudals and outliers. If you want to use existing GCP, you would be best advised to reobserve them, along with your new GCP.

7.5.4 Picking a GCP During the Scan — Detailed SOP

1. Approach the GCP normally — maintain scanning motion, keep LiDAR unobstructed.
2. Place the positioning plate's alignment cone exactly on the GCP mark. The scanner must be mounted on the plate; do not dismount.
3. Hold absolutely still for ~10 seconds. Your body should be motionless. Your hands should not shift. Exhale slowly and hold position. Shaking while the app acquires the GCP corrupts the pickup.
4. In the app, tap Add Control Point.
5. Wait for the confirmation — do not start moving until the app shows the GCP is captured.
6. Visually inspect that the cone did not slip, the plate did not rock, and the surrounding scanner position is as expected.
7. Resume walking smoothly toward the next target.

7.5.5 Common GCP Mistakes Resulting Symptoms

What you'll see in the final cloud: All GCPs collinear in the point cloud appear correct along the GCP line but tilts or twists away from GCPs clustered in one zone. That zone fits perfectly; the rest of the site drifts. Only one elevation Horizontal fit looks great; but the building appears to lean. Theoperator moved during pickup, or one GCP has a huge residual; it gets flagged as an outlier. The target may have shifted between the GCP survey and the scanning. One GCP may have a huge residual, maybe multiple if several shifted, or the wrong coordinates were input. Residuals can be huge at that point; and sometimes the solve fails entirely.

If the GCP is on soft ground, the residual may be small-to-medium, but the whole local area could then have a bias. Fewer than 4 GCPs, or only 3 is a poor practice: the solve proceeds without outlier protection; the answer may look fine but cannot be trusted.

7.5.6 Efficient GCP Collection Order During a Scan

Plan your route so GCPs are hit in a sequence that doesn't waste motion:

- First GCP: pick up near the start, as soon as scanning has stabilized (2 – 3 minutes in is ideal).
- Mid-scan GCPs: distribute throughout the route. If your plan has 8 GCPs and a 30-minute scan, you should be hitting roughly one every 3 – 4 minutes.
- Last GCP: pick up shortly before the final loop closure — this anchors the end of the scan.
- Don't try to do all GCPs at the beginning — the end of the scan then floats away from them.
- Don't do all GCPs at the end — the beginning of the scan has no anchor.

7.5.7 Indoor GCPs — A Few Special Tips

Most GCP guidance above assumes outdoor sites with RTK-measured targets. For indoor-only jobs:

- Survey the indoor GCPs with a total station run from exterior stations with known coordinates. Shoot at least 4 – 8 indoor points per floor.
- Or use large printed target sheets taped to walls at known surveyed positions. These become indoor GCPs.
- Indoor GCPs should include all floors if the building is multi-story (cross-floor drift is common if only one floor is anchored).
- Remember Rule 3 — indoor GCPs should span height diversity, not just floor-level positions. Wall-mounted targets at 1.5 m height are helpful.

7.5.8 A Worked Example

Scenario: 80 m × 50 m two-story office building, indoor-outdoor scan, GCP / targets with 3 cm absolute accuracy. Recommended GCP layout:

- 4 outdoor GCPs at the building's four corners (measured with RTK in Fixed state).
- 2 indoor ground-floor GCPs (from printed targets surveyed by total station): one in the lobby, one at the far end.

- 2 indoor second-floor GCPs: one near the stairs, one at the far end of the second floor.
- 1 GCP on the rooftop access if accessible (measured with RTK) — provides vertical diversity.
- Total: 9 GCPs, distributed in plan, on three elevations, with good redundancy. This layout handles the Rule 1–6 checklist cleanly: non-collinear, full-extent, vertically diverse, > 4 minimum, on stable surfaces, with room for one outlier if something goes wrong.

7.6 Reading the the Post-Processing Software Processing Report

After post-processing in the post-processing software, the report tells you:

- Was loop closure detected? If yes, it names which segments matched. If no, you know the scan was unclosed — drift is not corrected.
- Were there periods of RTK pseudo-fix? the post-processing software flags suspicious jumps in the RTK position stream.
- Any tracking breaks? These are moments where the front end lost track. Flag for inspection.
- Final absolute error estimate vs. GCPs. If GCPs were imported, the post-processing software produces per-GCP residuals.

If the report shows no recognized loop closure, the options are:

1. Rescan with better overlap (preferred).
2. Accept drift (for informal / preview deliverables).
3. Run with GCPs to pull the cloud into an absolute frame even without loop closure.

8 · From Raw Data to Deliverable — Post-Processing

Post-processing is where the scanner's raw output becomes a deliverable. This chapter covers the processing environment, the decision tree across processing modes, the role of GCPs and RTK in post, and the 3DGS capture methodology.

8.1 Processing Environment

Minimum and recommended PC specifications are product-specific, but the field rule is universal: processing is computationally heavy, especially for large loops, dense point clouds, image colorization, and 3DGS.

- Use a modern multi-core CPU.
- Use an NVIDIA/AMD GPU that meets the vendor's requirement when the software accelerates reconstruction.
- Use enough RAM for the largest expected project, not only for demo scans.
- Use SSD (solid state) storage for the active working directory.
- Keep GPU drivers current.
- Disable sleep during long processing jobs.
- Use ASCII-only paths for maximum compatibility unless your software explicitly supports non-ASCII project paths.

8.2 Installation and Licensing

Most desktop SLAM packages require an installer, license account, online license / dongle, or activation service. Treat licensing as part of job preparation.

1. Install drivers or license tools first if required.
2. Install the post-processing software.
3. Activate the license, dongle, or account.
4. Launch the software and open a sample project before the paid job.
5. Record software version, license status, and processing mode used in the project notes.

8.3 Preprocess Check

When the software provides a preprocess or integrity check, run it first. It should be used to:

- Validate raw data integrity.
- Report truncated or missing files.

- Flag tracking breaks.
- Flag suspicious RTK jumps or pseudo-fix intervals.
- Recommend a processing mode or warn that the scan needs rescan.

✅ **Always run the cheapest QA step before a long reconstruction. It finds problems before a multi-hour processing run.**

8.4 Processing Modes — Decision Tree

Different products use different names, but the logic is common.

- Standard / default mode. Use for typical mixed scenes with moderate features.
- Open/feature-poor mode. Use for plazas, empty parking lots, long straight roads, riverbanks, waterfronts, clearings, and other scenes with weak local geometry.
- Narrow/confined mode. Use for tight indoor scenes, underground parking, corridors, mines, pipe tunnels, and service galleries.

When to switch modes: if the default mode produces layering, delamination, or registration failure, select the mode that matches the geometry of the scene before assuming the scan is unrecoverable.

8.5 Importing GCPs Correctly

The most common GCP import error is a fake CSV. Renaming a .txt or .xlsx to .csv does not make it a CSV. Correct procedure:

1. Open the coordinate list in Excel or a text editor.
2. Use Save As → Comma Separated Values (.csv). Do not just rename the file.
3. Check file encoding. UTF-8 without BOM is often safest unless the software specifies otherwise.
4. Confirm column order: Point Name, X, Y, Z, or the exact project template.
5. Preview in a text editor before import. You should see comma-separated plain text, not spreadsheet binary data.

8.6 Processing Time Expectations

Processing time is nonlinear with raw data size. Typical ratios vary by product, but the trend is consistent:

- Short, well-scanned sessions process much faster than long, unclosed sessions.
- Large projects with many loops, many images, heavy GCP use, and 3DGS take substantially longer.
- Poor initial data quality can force more iterations or manual review.

Set customer expectations honestly. Over-promising a same-day deliverable on a large job is a common source of disappointment.

8.7 Output Formats & When to Use Each

Common deliverables include:

- LAS/LAZ. Survey-grade point-cloud deliverables and broad GIS/CAD/BIM support.
- PCD/PLY. Robotics, research, and open-source pipelines.
- RCP/RCS or other vendor-specific BIM formats. Autodesk and BIM integration workflows.
- Panorama images with camera poses. Texturing, 360° review, QA, and downstream visualization.
- 3DGS or web visualization packages. Client walkthroughs, marketing, and context visualization.

Always confirm the required coordinate system, units, file format, decimation, colorization, and accuracy report before processing.

8.8 3DGS — What It Is, What It Isn't, and How to

Capture for It 3DGS (3D Gaussian Splatting) is the most misunderstood feature in the current release. This section exists to get customers and operators on the same page.

8.8.1 What 3DGS Is

3DGS is a technique for reconstructing a photorealistic, renderable 3D scene from many photographs taken at different angles. Instead of storing geometry as discrete points (like a point cloud), 3DGS represents the scene as a cloud of tiny 3D Gaussian "splats" — each with position, size, orientation, color, and opacity. When you render the scene from any viewpoint, the splats blend together to produce an image that looks nearly photographic. The result is a scene you can walk through, zoom into, and render — spectacular for visualization, walkthroughs, marketing, and client presentations. 8.8.2

8.8.2 What 3DGS Is Not

- Not a measurement tool. A 3DGS reconstruction has no guarantee of centimeter-level geometric accuracy. Do not quote "< 1 cm" on a 3DGS deliverable.
- Not a "point cloud beautifier." A badly scanned point cloud does not become a good 3DGS scene by running 3DGS on it. The two outputs have different inputs and different failure modes.
- Not the same as the point cloud with color. A colored point cloud shows XYZ + RGB per point; 3DGS models appearance from multiple viewing angles and handles view-dependent effects (shine, reflection) in ways a point cloud cannot.

⚠ The two outputs have independent success criteria. A point cloud can be excellent while the 3DGS from the same scan is mediocre, or vice versa. Treat them as separate deliverables with separate capture disciplines.

8.8.3 Capture Discipline for Good 3DGS

For 3DGS to work well, the camera needs to see every important surface from multiple angles, in many photographs, under stable lighting. This is a significantly more demanding capture style than a point-cloud walk. Four principles:

1. More angles. Each target surface should be photographed from at least 3 – 4 distinct directions. Walking past a wall once, in one direction, is not enough. Orbit it.
2. More photos. Shorten the photo interval in the app (e.g., from 1 s to 0.5 s). Walk the same region multiple times.
3. Saturation-pattern routes. Instead of a single linear path, cover the scene with overlapping loops — a "weave." For a building façade, walk close, then far, then medium, then from each end.
4. Stable lighting, controlled motion. Strong shadow-to-sunlight transitions produce floaters (flying splat artifacts). Walking speed must be consistent; any motion blur degrades feature matching badly.

8.8.4 Saturation Route — How to Think About It

For point-cloud capture, you walk a route. For 3DGS capture, you walk a network of routes that together cover every surface from many angles.

8.8.5 Practical Setup for 3DGS-Included Jobs

- Plan separate time budgets for point-cloud capture and 3DGS capture. A typical scene might be 20 min for point cloud + 40 – 60 min for 3DGS.
- Use even, stable lighting. Overcast daylight is ideal; strong directional sunlight causes harsh shadow baking.
- Walk slowly — sub-1 m/s for 3DGS — and hold the scanner as steady as possible.
- Avoid scanning the same spot at very different times of day in one 3DGS project — lighting differences confuse reconstruction.

8.9 Combining Precision Tools — Decision Priorities

When the job needs maximum accuracy, combine tools in this priority order:

1. Clean scan (5, 6). No amount of post-processing can fix a fundamentally broken scan.
2. Ground Control Points (7.5). The strongest single-source accuracy improvement.

3. RTK calibration (8.5). When GCPs are unavailable and RTK was stable.
4. Processing mode choice (8.4). Matches the solver to the scene.
5. Post-process cleanup. Manual filtering for glass, water, moving objects.

9 · Failure Atlas & Recovery

This chapter is organized by what the user sees, not by what the software reports. For every visible symptom, we give: what it looks like, what typically causes it, the order in which to check, and how to fix or prevent it.

Note on error codes. the scanner's software stack is independent from other the vendor product lines; error codes and message text differ. This chapter focuses on symptom-level diagnosis that applies regardless of specific the post-processing software version strings.

9.1 Tilting / Skewing

What it looks like. Walls that should be vertical lean noticeably. Floors that should be level tip to one side. The whole point cloud feels "rotated" relative to gravity. Three root causes — each with a different fix. Cause A — IMU Calibration Issue Signature. The tilt is present from the very beginning of the scan. Even if you scanned a static section standing still on level ground, the data is still tilted.

Self-test procedure.

1. Place the scanner on a perfectly level surface (use a bubble level to verify).
2. Keep it completely static.
3. Start a 1-minute scan. Do not move the scanner at all.
4. Stop, save, import into the post-processing software.
5. In the viewer, check whether the floor plane you scanned is horizontal. If the static-scan floor is tilted, the IMU calibration is almost certainly off. Contact the vendor's technical support via your dealer or regular support channel — the fix is a remote IMU calibration, where the factory re-writes the IMU calibration parameters to the device. You do not need to ship the unit. Cause B — Drift Without Loop Closure Signature. The near-field data (early in the scan) looks fine; the far-field data (near the end) is progressively tilted. The tilt increases with distance from the start. Fix.

1. Re-scan with deliberate loop closures — don't let the scanner travel far without closing back into known territory.
2. Or add GCPs at the "tilted" end of the scan — the post-processing software's GCP calibration will rotate the point cloud into the correct frame. Cause C — Environment Is Actually Tilted Signature. The data matches the environment perfectly, but you expect it to be "level." This happens in old buildings that have settled, in construction mid-pour, in situations where the floor itself isn't flat. Fix. Reference to GCPs or RTK. Use absolute coordinates as the source of truth, not the internal geometry.

9.2 Layering / Delamination

What it looks like. Walls appear as two or more parallel sheets. Floors have a "ghost" floor above or below. Outdoor scans show the ground as two strata.

▨ Most layering is not a scanner limitation — it's a controllable cause.

Root causes, ranked by observed frequency from highest to lowest:

Root Cause A — Environmental (most common)

- RTK pseudo-fix. Urban canyon, forest canopy, narrow valley. RTK reports Fixed but the position is wrong; SLAM is fed a bad anchor, so the map warps.
- Glass / water / mirror reflections. Phantom geometry behind glass creates a second "layer."
- Dynamic objects. Moving vehicles or people briefly registered as geometry. Root Cause B — Operator Behavior
- Too-fast movement, sudden stops, wrist rotation (2.9).
- LiDAR obstruction events (2.8).
- Unstable initialization (2.10). Root Cause C — Route Planning
- No loop closure or loop with overlap < 5 m.
- Single long linear scan without intermediate loops.
- Long straight corridor without side-room branches for feature variety. Root Cause D — Device Boundary (least common)
- Extreme degenerate scenes — long tunnel + pure featureless walls + no GCPs.

Recovery Workflow

Step 1 — Switch processing modes. This fixes most layering.

- Try Open Mode first if the scene was feature-poor.
- Try Narrow Mode if the scene was tight indoor / underground.
- Re-run and inspect. Step 2 — Root-cause analysis if mode switch doesn't work.
- Inspect the processing report: were loops detected?
- Inspect the RTK log: any long pseudo-fix periods?
- Inspect the trajectory visual: are there kinks or jumps?
- Inspect the timeline: was there a period of occlusion or fast motion? Step 3 — Decide.
- Kink from fast motion or occlusion → rescan that segment (Resume-Scan).
- Pseudo-fix → rescan with RTK off, or add GCPs and disable RTK calibration in post.
- No loops found → rescan with a proper loop.
- Device edge-case → usually unfixable at that specific range; design the customer's expectation note accordingly.

💡 **Experience is the differentiator. The more data you process and the more you iterate, the faster you'll diagnose layering from a glance at the cloud. Use every failure as a learning artifact.**

9.3 Ghosting

What it looks like: Features appear in duplicate at a small offset. Often most obvious on fine details — chair legs, railings, thin walls.

Causes:

- Incomplete moving-object filtering (person / vehicle was in the scan briefly).
- Fast scanner motion in a high-vibration environment (uneven walking).
- Too close to a wall (inside the scanner's minimum useful range) — fisheye edge distortion + geometric near-range issues combine. Fix.
- For dynamic objects: filter manually in post (third-party software).
- For motion-induced ghosting: rescan at slower pace.
- For too-close ghosting: maintain ≥ 1 m from walls when possible.

9.4 Color Smearing / Misalignment

What it looks like: Color bleeds across the correct geometric boundary. A red chair has a red aura on the wall behind it.

Causes:

- Fisheye lens edge distortion when objects pass close to the camera edge of the field of view.
- Motion blur from too-fast walking.
- Incomplete multi-pass coverage — only one camera saw a surface, so colors couldn't be blended. Fix:
- Slow walking pace.
- More passes — especially for 3DGS.
- Clean lenses (4.2).

9.5 Phantom People / Figures

What it looks like. Faint silhouettes of people in the final cloud. Cause. Someone walked through the scan without being filtered out. Fix.

- ≥ 20 m distance rule for bystanders.
- Coordinate to have quiet windows to scan occupied sites.
- Filter in post-processing manually.

9.6 Glass & Water Noise

What it looks like: Spurious points behind glass (phantom room), floating noise above water. Fix: Accept it at capture. Clean manually in post-processing (the post-processing software clipping, third-party tools like CloudCompare). This is an industry-wide limitation — no commodity LiDAR solves it at capture time.

9.7 Indoor-Outdoor Color Inconsistency

What it looks like. Walls blue indoors, yellow outdoors, at a visible seam. Fix: Usually addressed at the software level. Upgrade to the latest the post-processing software and re-process. If it persists, escalate to support — most of these cases are resolved in newer processing pipelines.

9.8 Hardware Anomalies & Self-Tests

9.8.1 Physical Damage

Symptoms: Erratic power-on, scanning interruptions, abnormal LED patterns, missing LiDAR data, unusual noises. Triggers. Drops (even from waist height onto hard floor), crush events (inside a backpack with heavy equipment on top), water exposure. Resolution. Return to factory for repair. Do not attempt to open the unit — the precision alignment of the LiDAR, cameras, and IMU cannot be restored in the field.

9.8.2 IMU Calibration Anomaly

See 9.1 Cause A for the self-test. Resolution is remote IMU re-calibration with the vendor's support.

9.8.3 Incomplete Data Copy

Symptoms. Files appear on the copied destination but fail to open in the post-processing software. File size smaller than expected. the post-processing software reports missing or corrupt data. Causes. Copy interrupted (PC sleep, USB disconnect, flaky card reader). TF / microSD card bad sectors.

9.8.4 Lens Contamination

Symptoms: Panorama has obvious color patches or blurred regions. 3DGS fails or produces heavy artifacts. Some areas have missing or miscolored points. Fix: Clean with the provided cloth (4.2). If deep scratches are visible, contact support.

10 · From Novice to Certified Operator

Training the user is as important as shipping the hardware. This chapter defines a four-level competency model and the curriculum to move people up it.

10.1 The Four-Level Model

- L1 — Observer

  Can: Watch a scan being done; identify the major parts of the device; describe what a point cloud is. Time to reach: 1 hour of exposure. Validation: Verbal walk-through of the scanner parts.

- L2 — Operator

  Can: Independently run a standard indoor or mixed indoor-outdoor project from start to deliverable, on a known site, without assistance. Time to reach: ~ 2 – 3 days including practice scans. Validation: Complete an independent project on a pre-surveyed building, with GCPs, within tolerance.

- L3 — Advanced Operator

  Can: Handle complex / unusual / hybrid scenes (forestry, tunnels, ships, heritage). Diagnose tilting and layering visually and recover most jobs with mode switches and route planning. Use 3DGS capture discipline. Time to reach: ~ 2 – 4 weeks with varied project exposure. Validation: Complete a project in each of: tunnel/underground, forestry, and multi-building campus, with successful deliverables.

- L4 — Expert Operator Can: Teach L1 – L3. Diagnose root cause of any failure from scan data and processing report. Write project SOPs. Represent the organization in customer-facing technical discussions. Time to reach: ~ 6 – 12 months with active teaching and failure-debugging experience. Validation: Train at least two operators to L2 certification. Publish at least two internal post-mortems of project failures and their root causes.

10.2 Per-Level Curriculum

L1 Curriculum (1 hour)

- Read 0, 1.
- Watch a scan.
- Review this guide's conventions.

L2 Curriculum (2 – 3 days)

- Day 1 morning: 0 – 3. Assembly drills, first dry scan.

- Day 1 afternoon: First live scan, supervised. Review in the post-processing software together.
- Day 2 morning: 4, 5, 7. Repeat a known space three times with different routes; compare results.
- Day 2 afternoon: Two 6 scenarios (pick the ones most relevant to the operator's future work). GCP pickup drill.
- Day 3: Independent project on a pre-surveyed site. Deliverable review against known truth. L3 Curriculum (2 – 4 weeks)
- One complex project per week from 6. Include:
  - Tunnel or deeply underground space.
  - Forestry or canopy-heavy site.
  - Multi-building campus with indoor-outdoor transitions.
  - Heritage / detail-intensive site OR a water-edge scenario.
- For each project: execute, review deliverable, identify at least one mistake in your own work, and document it.
- Read 8.4 and 8.10 deeply. Practice 3DGS capture on a simple scene. L4 Curriculum (ongoing)
- Teach one L1-to-L2 cohort under supervision of an existing L4.
- Conduct two "failure deep dives" on real client data, identify root causes, document corrective procedures.
- Contribute at least one improvement or scenario playbook back to the internal training system.

10.3 Practical Training Projects — A Suggested List

For an organization standing up a handheld LiDAR SLAM training program, these practical projects build capability in order:

1. Single-floor office suite (baseline indoor).
2. Multi-floor office building (stairs + floors).
3. Small campus (indoor-outdoor transitions + exterior loop).
4. Underground parking garage (pure SLAM).
5. Forestry plot (GNSS-weak + uneven terrain).
6. Linear road / tunnel (out-and-back loop discipline).
7. Heritage interior with 3DGS deliverable (capture discipline + post-processing).
8. Layering recovery drill — take a deliberately bad scan (fast motion, occlusion) and recover as far as possible with mode switching and root-cause analysis.

Appendix A1 · Field Checklists

A1.1 Two-Minute Pre-Capture Checklist

- Device assembled and mechanically locked.
- Lenses and LiDAR windows clean.
- Battery level adequate; spares on hand.
- Storage inserted; free space verified.
- Firmware/software version suitable for required features.
- App/controller connected; live preview visible.
- RTK status confirmed if outdoor.
- Initialization location chosen: stable, level, stationary, feature-rich.
- Route rehearsed: entry, loop points, GCPs, exit.
- Doors opened, wedges placed, and occupants warned if indoor.
- Operator position checked so the LiDAR is unobstructed at start.

A1.2 Route Planning Checklist

- Does every major segment have a loop closure or an out-and-back overlap?
- Are long corridors broken by side rooms, side loops, or control points?
- Are large open spaces scanned along edges before cross-passes?
- Are indoor/outdoor thresholds treated as pause points?
- Are glass, mirrors, water, rain, dust, traffic, and crowds accounted for?
- Are scan sizes reasonable, or should the job be split and resumed?

A1.3 Ground Control Checklist

- GCPs are not collinear.
- GCPs cover the full site extent.
- GCPs include vertical diversity when the site has floors, stairs, slopes, or roofs.
- At least four GCPs are available; six or more are preferred for small sites, and more for campus-scale or high-accuracy work.
- Every GCP is on a stable, accessible, clean pickup surface.
- GCP coordinates were measured with an instrument whose accuracy exceeds the deliverable target.
- GCP pickup order distributes anchors across the whole scan, not only at the beginning or end.

A1.4 Stop / Rescan Decision Checklist

Stop and rescan or resume the problematic segment if:

- Live preview shows a gap or hole that you definitely walked through.
- Trajectory has a visible kink that does not match reality.
- RTK status shows suspicious jumps or pseudo-fix.
- Someone or something blocked the LiDAR for several seconds.
- A door was opened in front of the scanner during a critical transition.
- The scanner reports an anomaly.

A1.5 Ten-Second Save Ritual

1. Hold the scanner still.
2. Press Stop only when you can keep it steady.
3. Watch the saving indicator.
4. Wait for save confirmation.
5. Do not power off or start the next task until the save completes.

Appendix A2 · Recommended Learning Resources

A2.1 General Practice

- Scan the same space five times. Change your route each time. Compare the five results in the post-processing software. Nothing teaches operating discipline faster than watching your own mistakes show up in the cloud.
- Keep a failure journal. Every time a scan fails or disappoints, write down what you saw, what caused it, and what you did to recover. Re-read after 10 entries.
- Shadow another operator. Watch how someone with more experience holds the scanner, paces themselves, pauses at doors, handles RTK pop-ups, and decides when to stop.

A2.2 General Technical Background

For operators who want to deepen their understanding of the underlying technology, the following topics are worth self-study in any technical textbook, course, or vendor-neutral training material:

- Handheld SLAM surveys.
- Loop-closure detection.
- LiDAR + IMU tightly coupled fusion.
- RTK GNSS fundamentals.
- Ground control and coordinate systems.
- 3D Gaussian Splatting.

These are the academic and industry common-knowledge underpinnings of any handheld SLAM system. Understanding them will make every scenario in 6 easier to plan, and every failure in 9 easier to diagnose.