NDT Trends.
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The Next Generation of NDT

Innovation, Intelligence & Sustainability

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One measurement plan, all parts: how VGSTUDIO MAX takes the repetition out of CT series inspection



A Heartful Thanks to all the Contributors

This edition of NDT Trends has been enriched by the knowledge, experience, and perspectives shared by our contributors. Through your articles, interviews, and insights, you help OnestopNDT bring meaningful conversations to the global NDT community. Your support adds depth to every edition and strengthens our mission of promoting learning, innovation, and industry growth. We sincerely value your contribution and thank you for being part of this journey.

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ONE STOP NDT

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About OnestopNDT

OnestopNDT is a global digital platform built exclusively for the Non-Destructive Testing industry. We connect professionals, companies, manufacturers, training institutes, and decision-makers through industry-focused content, visibility, knowledge sharing, and professional engagement.



SOME THINGS IN NDT CAN'T BE ~~Googled~~.

That's why we created **NDT Talks** —a monthly panel where real experts share insights you won't find online.





Seeing what we cannot reach

Picture yourself in a Shanghai metro tunnel at night. The concrete arches overhead, damp in places, darker where water has found a way in. You cannot cut a core sample here. You cannot close the line for a week. Yet someone needs to know whether this wall is still as strong as the day it was poured.

Our research paper in this issue tackles that. Using hyperspectral imaging and a deep neural network, the team mapped concrete strength on Shanghai Metro Line 12. Healthy lining averaged about 47.6 MPa. Spalled areas dropped to about 33 MPa. Then the authors did something I admire. They listed where their method can fail, including dust and poor lighting.

That honesty is the thread of this issue. Every method has an edge, and our cover story looks at what each technique cannot see, and how skilled teams combine them to cover the gaps.

The same thinking runs through our application note. Xnovo detects metallic inclusions just a few voxels in size at production speed. Hexagon applies one CT measurement plan across an entire batch. Rail Labs looks beyond individual defects to patterns across the Indian Railways network.

But sharper tools are only half the story. Xnovo relies on domain experts to review false positives and missed calls. Rail Labs wants AI grounded in engineering reality.

That is why I remain optimistic: technology keeps advancing, but human judgement matters more than ever.

So tell me: where does your favorite method go blind, and what do you use to cover the gap? Write to us.

Until December,

Santosh Gavankar
Editor-in-Chief

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Insights in Focus

Top Stories Shaping the NDT Industry



NEWS I

DÜRR NDT Raises the Bar for Mounting and Protecting Flexible X-ray Detectors



Image Source - @DurrNDT

DÜRR NDT has introduced newly developed mounting and protective covers for its D-DR 1025B NDT and D-DR 1043B NDT bendable digital X-ray detectors. Designed for demanding industrial inspection environments, the updated covers provide improved detector protection and more versatile mounting options while retaining the flexibility and image quality of the existing detector models.

The new design offers multiple ways to secure the detectors to inspection objects. Depending on the application, inspectors can use magnets, tension straps or rubber fasteners to position the detectors. These mounting options are intended to simplify setup and provide reliable attachment during inspections, including work in hard-to-reach locations.

Flexible Mounting and Improved Durability

The protective covers are designed to preserve the detectors' lightweight construction, portability and bending capability. This allows the D-DR 1025B NDT and D-DR 1043B NDT to conform to curved surfaces while maintaining their digital radiographic imaging performance.

Durability was another key consideration in the development. The covers are manufactured from Cordura® fabric, which provides resistance to mechanical stress, abrasion, dirt and impacts associated with routine field operations. By protecting the detector surface during use, the covers are intended to reduce wear and help extend service life.

Detector Specifications and Imaging Software

Both detector models feature a 99 µm pixel pitch and a maximum basic spatial resolution (SRb) of 100 µm, supporting demanding weld inspections on pipes and other curved objects.

The models differ in their active imaging areas:

- D-DR 1025B NDT: 97 × 249 mm
- D-DR 1043B NDT: 97 × 427 mm

The detectors operate with DÜRR NDT's D-Tect X X-ray inspection software. The software provides image analysis tools designed to support fast and precise evaluation of digital radiographic images.

The updated mounting and protective solution expands the practical usability of DÜRR NDT's bendable detector range in industrial environments. By combining flexible positioning, durable protection and established imaging capabilities, the company aims to support reliable digital radiography inspections in demanding field conditions.

NEWS II

DGIST Develops Screw-Lens Ultrasonic Transducer for High-Resolution Semiconductor

Image Source - @DurrNDT

Researchers at Daegu Gyeongbuk Institute of Science and Technology (DGIST), South Korea, have developed a screw-lens-focused ultrasonic transducer designed to improve the detection of micro-defects inside semiconductor chips. The technology reduces internal ultrasonic noise by introducing a threaded structure on the side surface of the transducer lens, enabling clearer imaging without increasing the sensor's overall size.

The research was led by Professor Chang Jin Ho from DGIST's Department of Electrical, Electronic and Computer Science. The development could support non-destructive testing (NDT) of high-reliability power semiconductors used in electric vehicles and aerospace applications, where detecting microscopic defects is critical to component performance and reliability.

Screw-Lens Design Addresses Internal Ultrasonic Noise

Ultrasonic testing is widely used to inspect semiconductor components for internal defects such as micro-cracks and voids without damaging the devices. Compared with optical inspection and X-ray methods, ultrasound offers strong penetration capabilities for examining internal structures.

Industrial semiconductor inspection systems commonly use a water-column transmission technique, also known as the waterfall method. However, limitations on sensor size can make it difficult to improve image quality by simply increasing the dimensions of the lens. In compact sensors, ultrasonic waves can reflect and interfere within the lens, generating edge noise that obscures fine internal features.

To address this issue, the DGIST team drew inspiration from the angled, sound-absorbing structures used in anechoic chambers. Researchers machined slanted, screw-thread-shaped grooves into the outer side surface of the ultrasonic lens. When ultrasonic waves reach these inclined surfaces, they scatter in multiple directions rather than reflecting back and converging to produce unwanted noise.

Computer simulations helped the team identify suitable design parameters for the threaded structure, including a thread height of 500 µm and an inclination angle of 30 degrees. According to the research team, these specifications provide effective noise suppression while remaining practical to manufacture.

The design does not require changes to the sensor's overall dimensions or internal core components. Instead, the modification is made to the lens's outer surface, potentially allowing the technology to be integrated into existing compact industrial inspection equipment.

Micro-defects Visualised in Automotive Power Modules

The researchers tested the developed transducer on automotive power semiconductor modules. The new design enabled clearer visualisation of internal microstructures and defects that were difficult to distinguish using conventional ultrasonic sensors because of internal noise.

The inspection revealed fine metal wires approximately one-quarter the thickness of a human hair, along with microscopic bubbles. The resulting image clarity was reported to be comparable to that of conventional computed tomography (CT) imaging.

The development is particularly relevant to power semiconductor inspection, as these components must withstand high operating voltages and temperatures in applications such as electric vehicles and aerospace systems.

Potential for High-Frequency Ultrasonic Inspection

Professor Chang Jin Ho said the research addresses a major challenge in designing ultrasonic sensors for industrial inspection by reducing internal lens noise through a modification to the lens geometry. He added that the approach could establish a foundation for mass-producing ultra-high-frequency ultrasonic transducers operating at 100 MHz or higher.

The team plans to conduct further testing in collaboration with semiconductor manufacturers to evaluate the technology against defects encountered in actual manufacturing processes. These studies are expected to help advance NDT systems designed around industrial inspection requirements. The research was supported by programmes from South Korea's Ministry of Science and ICT (MSIT), the National Research Foundation of Korea and the Institute of Information & Communications Technology Planning & Evaluation (IITP). DGIST postdoctoral researcher Kang Sungwoo and integrated master's-Ph.D. student Park Hyunkyu participated as co-first authors. The findings were published in the international journal NDT & E International.



NEWS III

MuRay Raises €7 Million to Commercialise Muon-Beam Inspection Technology



Image Source - @tech.eu

Hamburg-based technology company MuRay has raised €7 million (approximately US$7.8 million) to commercialise its muon-beam imaging technology, which is designed to inspect the interiors of dense industrial components using non-destructive testing (NDT).

The company's technology uses a controlled, laser-driven muon beam to generate 3D images of an object's internal structure. Unlike conventional X-ray imaging, which can face limitations when inspecting thick or dense materials, muons can penetrate substantial thicknesses of metals, ceramics and composites while maintaining high imaging resolution.

Muons are subatomic particles similar to electrons but more than 200 times heavier. They occur naturally in the upper atmosphere through cosmic-ray interactions and can also be produced artificially using particle accelerators.

DESY Spinout Secures Funding for Accelerator Development

MuRay was spun out of the German accelerator research centre Deutsches Elektronen-Synchrotron (DESY). The newly raised funding will support the development of a portable, laser-based particle accelerator approximately the size of a shipping container.

The company plans to offer non-destructive imaging and inspection services to engineers working in metal additive manufacturing, space, aerospace, defence and energy. Initial services are expected to begin in early 2027.

According to MuRay, its technology can reduce inspection times from hours to minutes, potentially allowing manufacturers to identify internal defects while components are still on the production line. The system is also designed to map material composition alongside density, helping distinguish between materials that may appear similar under conventional X-ray imaging. The company further claims that its approach can achieve these results at a lower radiation dose.

The €7 million funding comprises equal contributions from private and public sources, including a grant from the European Union's Horizon Europe programme.

MuRay is working with DESY and the German Space Agency at DLR, while also partnering with laser technology company Caelora to develop the system. The company has already modelled the inspection of a rocket engine in collaboration with DLR and plans to conduct its first real-world engine assessment in 2027.

For its first industrial customers, MuRay intends to use DESY's existing electron beam in Hamburg alongside its own imaging system. It expects to transition to its own full-scale laser-driven accelerator in 2029.

Recruitment and Technology Development

MuRay is recruiting physicists and engineers in Hamburg as it works towards developing the technology. The company aims to increase its workforce to 25 employees by the end of the year.

The development programme includes building a laser-plasma accelerator capable of producing muons on demand, detectors that can measure the particle flux at high speeds, and AI algorithms to reconstruct the resulting images.

“Defects that manufacturers can’t see keep parts out of service for longer than they should be.”

-Dr Kristjan Põder, co-founder and co-CEO of MuRay

Dr Andi Hektor, co-founder and co-CEO of MuRay, said, “X-rays reach their limit at a few centimetres of steel, yet much of modern industry, from reusable rockets to gas turbines, is built from metal far thicker than that. Active muon imaging lets manufacturers see inside those large, dense components.”

Dr Kristjan Põder, co-founder and co-CEO of MuRay, added, “Defects that manufacturers can’t see keep parts out of service for longer than they should be. Our technology helps them find those defects and get components back into service faster. This funding will help us continue proving the physics whilst delivering our first service to industrial customers.”



Image Source - @firstmomentum.vc

NEWS IV

ROSEN to Assess 221 km of Gas Pipelines in Lithuania Using Non-Intrusive Technology



Sources - @Inspenet

ROSEN will deploy its Non-Intrusive Pipeline Assessment (NIPA) service across approximately 221 kilometres of gas pipelines operated by Amber Grid, Lithuania’s gas transmission system operator. The three-year contract is intended to improve pipeline integrity assessments for assets that cannot accommodate conventional in-line inspection tools, without interrupting gas transmission.

Announced by ROSEN on August 27, 2026, and confirmed by Amber Grid the following day, the agreement expands the use of non-intrusive assessment techniques to support pipeline integrity management. The programme combines external field measurements, historical operating information and data analysis to help identify areas requiring further investigation.

Combining Field Measurements and Pipeline Integrity Data

ROSEN’s NIPA service integrates construction and operating records, magnetic surveys, cathodic protection data and geographic information systems (GIS). Combining these sources provides a broader view of pipeline conditions and helps operators assess potential integrity concerns along a pipeline route.

The service uses the combined datasets to identify areas of interest and prioritise excavations and non-destructive testing (NDT) inspections. Field verification and integrity management planning are also included in the offering.

The approach is particularly relevant to pipelines where conventional in-line inspection (ILI) is restricted by infrastructure or operating limitations. Such constraints can include diameter changes, bends, valves, the absence of launching and receiving facilities, or other conditions that prevent the passage of inspection tools.

Assessing Pipelines Without Conventional In-Line Inspection

A key element of NIPA is large stand-off magnetometry (LSM), which uses above-ground magnetic measurements to help assess selected pipeline integrity concerns. The technique can support investigations of indications associated with mechanical stresses and geometric anomalies in buried pipelines.

In a technical case study, ROSEN described using above-ground magnetic measurements and comparing their locations with previous records to investigate potential pipeline movement. This illustrates an application of the technology, rather than a reported finding from the Amber Grid programme.

By combining external measurements with available asset information, operators can develop a more informed picture of pipeline condition and determine where additional examination may be warranted.

Data Analytics and Artificial Intelligence in Integrity Assessment

The programme is supported by ROSEN’s Integrity Data Warehouse, which the company says contains information from more than 26,000 in-line inspections conducted worldwide.

This historical data resource supports the development, validation and interpretation of models assisted by artificial intelligence (AI).

Historical inspection data can provide context for assessing indications, but conclusions about individual pipeline sections must also account for the available asset records, survey conditions and verification findings. The aim is to translate the information collected into practical priorities for further inspection and integrity management.

Field verification and NDT inspections can provide additional evidence for evaluating indications and determining whether maintenance or further assessment is required.

Amber Grid Expands Its Experience with NIPA

Amber Grid Chief Executive Officer Nemunas Biknius said the operator had tested the technology in the previous year before expanding its application through the new contract. The three-year programme represents a broader deployment of the approach across the operator's gas transmission network. It is intended to help Amber Grid assess pipeline sections that are difficult to inspect using conventional internal inspection tools while supporting decisions on asset integrity.

Results from the 221-kilometre programme, including confirmed defects, specific inspection findings or quantified reductions in pipeline risk, have not yet been reported. The effectiveness of the programme will therefore be assessed through its verified findings and the maintenance or integrity decisions they support.
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Image Source - @pipeliner.com



Cover Story

Every method has a blind spot, and that is where the work begins

Why no single technique is enough, and how skilled teams combine them.



Cover Story

On January 10, 1954, a de Havilland Comet, one of the first jet airliners in passenger service, broke apart in the air near Elba, Italy. On April 8, a second Comet was lost near Naples. Investigators at the Royal Aircraft Establishment in the UK then tried something bold. They put a complete fuselage in a water tank and pressurized it again and again, to copy flight after flight.

The fuselage failed after 1,830 tank cycles, on top of 1,230 pressurized flights it had already flown. The crack started at the corner of a squarish window. Investigators tied the Elba crash to fatigue near the aircraft's automatic direction finder (ADF) windows. Fatigue is damage that builds up when a structure is loaded and unloaded many times.

One detail still teaches. An earlier test fuselage had been proof-tested to twice the working pressure. That overload cold-worked the window corners and made them tougher. The test piece lasted about 16,000 cycles. Production aircraft began cracking at about 1,000, according to the FAA. The test did not match the real part.

Nobody had looked for this crack, in this place, in this way.

The same lesson, 34 years later

On April 28, 1988, Aloha Airlines Flight 243, a Boeing 737-200, was flying at 24,000 feet over Hawaii. About 18 feet of the upper fuselage, behind the front door, tore away. One flight attendant was lost. The crew landed the aircraft safely on Maui.

The US National Transportation Safety Board (NTSB) did not blame one instrument. It named "the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage." The failed part was a lap joint, where two sheets of skin overlap. Disbonding means the glue between them had let go, and fatigue cracks had grown where the sheets were joined. Inspections existed. The damage was still not found. That is the uncomfortable truth behind this whole field. A method can be sound, and the inspector skilled, and the flaw can still go unseen.

Where each method goes blind

Every technique reads the world through one kind of physics. Each physics has a shadow.

- **Ultrasonic testing (UT)** sends sound into a part. It is strong for volumetric flaws, but a crack tilted away from the beam can reflect sound off in the wrong direction. It also needs good coupling and a workable surface.
- **Radiographic testing (RT)** uses X-rays or gamma rays. It finds voids well. It can miss a planar flaw, like a tight crack, that runs parallel to the beam. It also brings radiation safety limits.
- **Eddy current testing (ET)** uses magnetic fields to disturb currents in a conductor, much like ripples changing around a rock in a pond. It works only on conductive materials, and mostly near the surface. Lift-off, the gap between probe and part, can change the signal.
- **Magnetic particle testing (MT)** works only on ferromagnetic materials.
- **Liquid penetrant testing (PT)** finds only flaws open to the surface. Smeared or peened surfaces can close a crack's mouth.
- **Visual testing (VT)** depends on light, access, and the eyes behind it.

None of these is a weakness of the people. They are the honest edges of each method.

What probability of detection really says

Engineers describe a method's skill with probability of detection (POD). ASTM E2862 defines POD as the fraction of flaws of a given size that are expected to be found, given that they exist.

Reports often quote a single number, called a90/95. It is the flaw size found 90% of the time, with 95% statistical confidence. Read it slowly. At that size, one flaw in 10 is still missed. Smaller flaws are missed more often.

Two cautions follow. First, a POD number belongs to one setup: one material, probe, procedure, and team. Change any of them and the curve moves. This is the Comet test lesson in new clothes. A demonstration only counts if it matches the job. Good ones use realistic samples, with real flaws, in real conditions, and they include the people who will do the work. A clean result on a polished test block says little about a rough, corroded surface in the field.

Second, POD says nothing about false calls, which are signals that turn out not to be flaws. A team can raise its detection rate by calling every doubtful signal. Then it pays in teardowns, delays, and a slow loss of trust in the findings. Detection and false calls pull against each other. Setting the balance is a judgment about risk, not a button on the instrument.

How skilled teams combine methods

The best teams do not start with a favorite tool. They start with the damage they fear. What kind of flaw is it? How big, and where? Which way does it run? What is the material, and what is the surface like?

Then they pick methods whose blind spots do not overlap. A tight crack that radiography may miss can show up under ultrasound. A surface-breaking crack found by eddy current or penetrant testing can then be sized by ultrasound. In welds, one phased array ultrasonic technique may find and characterize flaws while another, time-of-flight diffraction (TOFD), sizes them from the signals at a crack's tips. Eddy current testing is widely used to look for cracks around fastener holes in aircraft skins, exactly the kind of site that matters in a lap joint.

Combining methods is not about doing more testing. It is about removing the places where one method alone could be blind. A pipe weld, a turbine blade, and an aircraft skin each call for a different mix. The skill lies in knowing which mix fits which part, and in writing down why, so the next inspector can follow the reasoning and challenge it.

Judgment is part of the instrument

Codes and procedures give the frame. ASME BPVC Section V, ISO 9712 personnel certification, and written procedures all matter. But a Level III still has to ask the hard question: what are we afraid of, and will this method see it?

New tools make that question more important. Automation, robots, and AI can scan more area and sort more data than any person. They also bring new blind spots. A model only knows what it was trained on. A good reader asks what data it saw, what it never saw, and who reviews what it gets wrong.

The Comet and Aloha stories are about aircraft, but they are also about a habit of mind. Do not trust the instrument alone. Know where it goes dark, and then go look there some other way.

Key takeaways

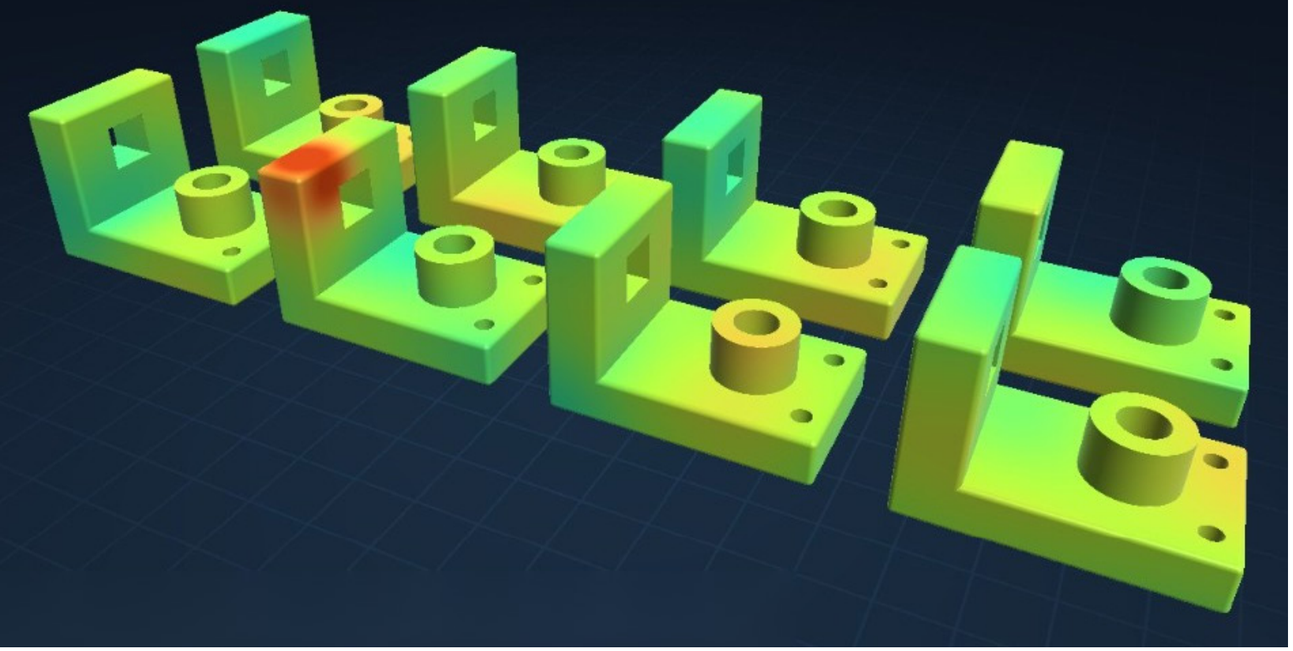
- Start from the flaw you fear, not the tool you own.
- Every method has a physical blind spot. Learn it by name.
- A POD number holds only for the setup that produced it.
- Detection and false calls trade off. Set the balance on purpose.
- Combine methods so their blind spots do not overlap.

Editor's note: The Comet and Aloha 243 investigations remind us that a missed flaw is rarely one person's failure. It is usually a gap between what a method can see and what the job demands. If you have a story of a blind spot you found, or one that found you, write to us at www.onestopndt.com/submit-your-article. We would like to hear it.

Sources

- NTSB investigation page, Aloha Airlines Flight 243 (DCA88MA054)
- FAA Lessons Learned, de Havilland DH-106 Comet 1
- ASTM E2862-23, Probability of Detection Analysis for Hit/Miss Data





One measurement plan, all parts: how VGSTUDIO MAX takes the repetition out of CT series inspection

HEXAGON



Jan Gräser
Product Manager VG Product Line, Hexagon Manufacturing Intelligence

With multipart groups in VGSTUDIO MAX, you define a coordinate measurement plan once and apply it to the CT scans of an entire batch in a single scene. This can cut the time spent on inspection preparation and project set-up by up to 50%. Spotting deviations across the entire batch earlier means producing less scrap and wasting less material.

Industrial CT lets you measure the internal and external geometry of complex components without contact. In series inspection, however, the bottleneck is rarely the scan itself. It lies in what comes afterwards.

Anyone who has ever inspected a production batch knows the routine. Load the first scan, build or import the measurement plan, calculate, save. Open the next file and start all over again. Keep every geometry element, every GD&T feature and every tolerance consistent by hand — across ten, twenty or more parts. Every repetition costs time, and every manual step is a potential source of error.

Are you rebuilding the same measurement plan for every scan? This is exactly the loop that Hexagon is now breaking.

Measuring many parts — as easy as measuring one

With version 2026.2, VGSTUDIO MAX introduces a completely new concept for handling coordinate measurement objects (CM objects) in multipart projects. You combine several scans of similar components into a multipart group. From that moment on, all supported objects are synchronised automatically across the entire group.

You then inspect and evaluate all parts at the same time — exactly as you would with a single part. Add a geometry element to one part and it appears on every other part in the group. Change a feature, and the change is transferred to all linked counterparts and calculated.

Think of it as copy and paste for measurements — only faster, consistent, and fully automated. No manual synchronising. No juggling files. Every part is measured according to exactly the same rules.

Multipart groups are available in all editions of VGSTUDIO MAX.

Three steps from scan to batch report

1. **Group the parts.** Select the volumes in the Scene Tree, choose “Group objects,” and activate the “Multipart group” option. Your pre-alignment is retained. A dedicated contextual “Multipart” tab appears in the ribbon with all the relevant functions. Adding more parts later? Move them into the existing group — they are synchronised immediately.
2. **Set up measurements once.** Import a measurement template or create your plan on a single part — geometry elements, GD&T feature, dimensions. Every CM object you add or change is transferred to all linked parts. Still refining the plan? Deactivate “Auto-update CM objects” and calculate the entire group in one step with “Update CM objects” once your plan is finalised. Parts without a surface determination are covered too: before the calculation, “Determine surface for all parts” performs an advanced surface determination for every part that needs one.
3. **Inspect and report.** The CM overview shows the geometry elements and GD&T features of all parts in the group in one table. You open it from the “Multipart” tab or by double-clicking the group in the Scene Tree, and you can link, unlink, or restore objects directly in the table. Compare deviations across the batch, then create a project report for the entire group — including the CM overview. Working with very large projects? “Export all parts as projects” saves each part as a project of its own in a separate subfolder — ready to open even on systems with less computing power.

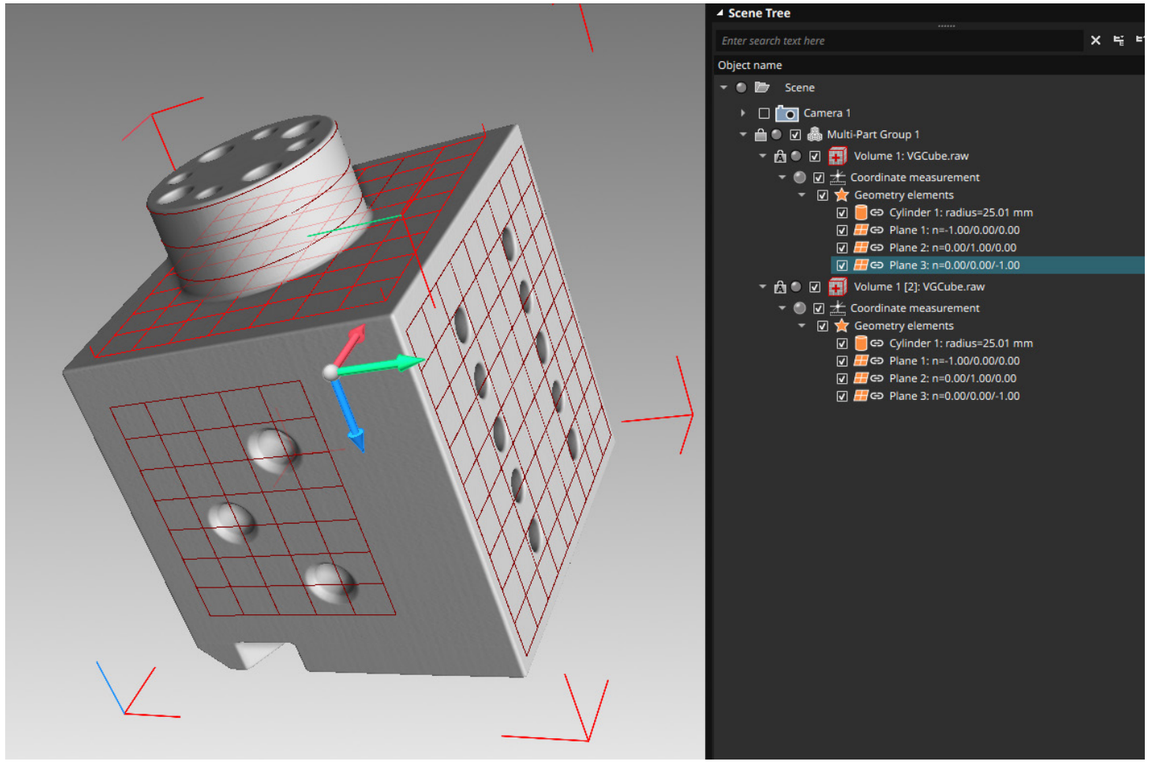
Real parts are not identical

One measurement plan for all parts works brilliantly — until one part behaves differently. Multipart groups are built for exactly this reality and adapt to your parts, not the other way round.

To change an object on a single part only, unlink it by clicking the chain icon. Changes then apply to that part alone. Clicking the chain icon again restores the object from its counterpart in the group. If you remove an unlinked object, it becomes a placeholder: it shows you that the object still exists on the other parts and brings it back with one click when needed.

Dependencies are taken into account as well. If a new feature refers to a geometry element that is missing on one part, that part receives a placeholder instead of a faulty feature. Typical causes of part-to-part variation in injection moulding can be mapped directly to three strategies:

All three strategies can be combined in a single project — with several multipart groups in one scene.



In sync across all parts: In the Scene Tree, both volumes in the multipart group carry identical, linked geometry elements.

Cause	Effect on the part	Strategy in VGSTUDIO MAX
Defect in the tool steel or a faulty slide	Local deviation in one area of the part	**Unlink the affected objects**
Cavity cooling	Warpage or shrinkage of an individual part	**Handle the part outside the multipart group**
Systematic deviation between moulds	One measurement strategy does not suit all parts	**Create a second multipart group for parts from that mould**

Use case: 20 housings, one report

Take a plastics processor producing a batch of 20 injection-moulded housings. The quality team scans several samples to check them for warpage, shrinkage, and dimensional deviations.

The conventional way, the team sets up the same measurements for every scan, switches between many files and keeps everything consistent by hand. With multipart groups, the team loads all the scanned parts into one project and defines the measurements once. VGSTUDIO MAX applies them automatically to every sample.

The team compares the parts instantly, spots deviations across the entire batch, and produces an informative report for the complete production run. The key questions are answered faster: Are these parts OK? Are they drifting out of tolerance? Do you need to adjust the process?

Equipment innovation that pays off in sustainability

A CT system is a significant investment in equipment, energy, and qualified staff. Its value depends on how much usable insight you gain from every hour of scanning. Multipart groups increase this return on the software side — without changing the hardware.

The most sustainable part is the one you don't have to scrap. CT inspection is non-destructive, so every sample inspected remains intact. Multipart groups add the series perspective: because all parts are measured with the same plan in one scene, dimensional deviations, warpage, or shrinkage become visible across a batch while they are still developing. You spot the trend early, adjust the injection moulding process faster, and produce fewer parts that end up as scrap or rework.

The workflow also makes better use of existing equipment:

- **More parts per scan.** Scan a complete tray of parts in one pass, split it into separate volumes, and evaluate them together in a multipart group.
- **Less repeated work.** One measurement plan replaces many manual set-ups. Your metrology experts spend their time on decisions, not on copying.
- **Leaner projects for existing hardware.** Exporting each part as a project of its own keeps files manageable — even on workstations with less computing power.

Here, efficiency and sustainability point in the same direction. Fewer repeated steps, less scrap, and faster process corrections mean more quality from every scan, every part, and every kilogram of material.

What metrology teams gain

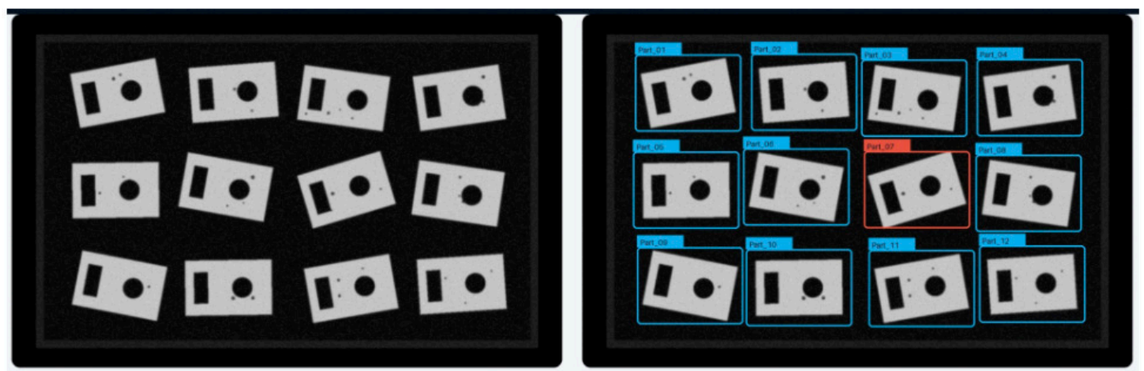
- **Less manual work.** You no longer synchronise or update CM objects by hand. Everything stays aligned automatically — cutting inspection preparation and project set-up by 30 to 50% and eliminating the errors that repetitive steps bring with them.
- **Consistent quality every time.** Every part is measured according to exactly the same rules. No human variation between scans.
- **Complex projects, one scene.** You manage multiple scans, parts, and groups in a single scene. Less file juggling, a clearer overview.
- **Quick to learn.** An intuitive, interactive interface replaces complex macro logic. New users become productive quickly.
- **Clearer reports.** Multipart groups are treated as a unit of their own — with their own handling and their own reporting. Your documentation becomes clearer and your results look more professional.
- **Made for series production.** Whether you inspect 1 part or 50 — your workflow stays the same.

The result is a change of perspective: you inspect the batch, not the part. Fewer steps. Fewer errors. Faster decisions.

Availability

Multipart groups for coordinate measurement are available in all editions of VGSTUDIO MAX from version 2026.2. Step-by-step video tutorials guide you from your first group to your first batch report. A free evaluation licence lets you test multipart measurements on your own scans.

Know More



One scan: twelve parts on a tray

One multipart group: twelve named volumes, ready to measure

One scan, twelve parts: A complete tray is split into twelve named volumes and evaluated together in a multipart group. (Illustration)

Application Note

Inline 3D Inspection for Battery Production

Reliable defect detection at production speed

xnovotech — a RAITH company

Executive Summary

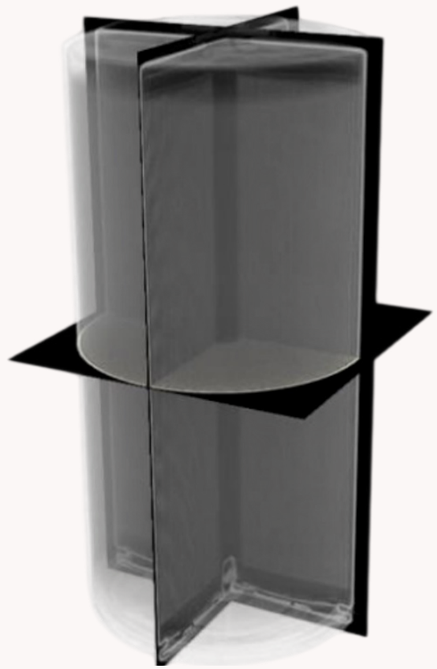
Battery manufacturers increasingly rely on 3D X-ray computed tomography (3D-CT) to inspect internal cell structures without destructive sampling. Beyond dimensional measurements and anode–cathode overhang analysis, one of the most demanding applications is the detection of small metallic inclusions and other safety- and function-relevant indications at production cycle time.

Xnovo's XNspect is a highly configurable, harware-agnostic 3D-CT battery inspection solution that combines advanced analytical image processing, proprietary anomaly detection and production-system integration. It enables highly sensitive inclusion detection while keeping CT processing and data handling within the factory environment, with inspection outputs tailored to production and quality workflows.

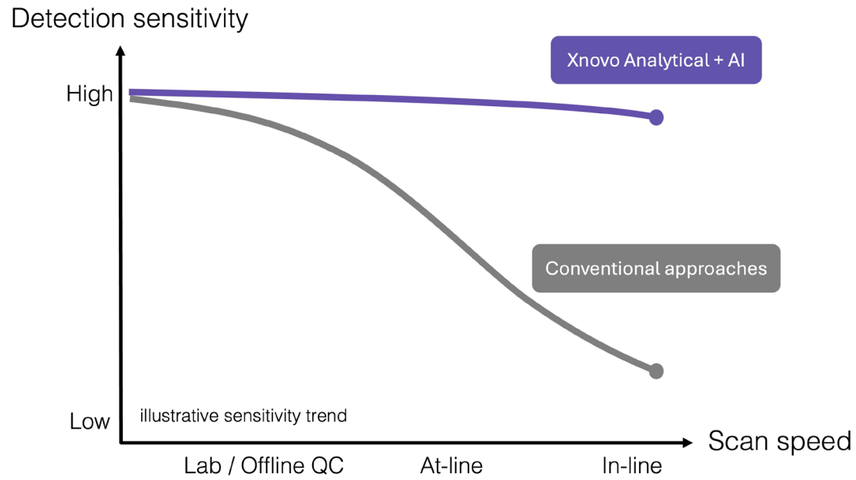
The Production Inspection Challenge

3D-CT provides a detailed view inside a battery cell, but production changes the inspection problem. Shorter scan times can increase image noise and artefacts, while the inspection system must remain sensitive to very small defects. An analysis method that performs well on high-quality laboratory scans may not deliver the same results on data acquired under production constraints.

For production inspection, the goal is not simply to make CT images look cleaner. The analysis must extract relevant information from the available data, distinguish safety- and function-relevant indications from imaging artefacts, and provide consistent OK/NOK decision support within the required cycle time.



Cylindrical battery 3D-CT



Laboratory / Offline QC
Long cycle time
High image quality
High defect contrast

At-line
Shorter cycle time
More noise & artifacts
Lower defect contrast

In-line
Fast cycle time
Challenging data
Harder defect detection

Speed vs. image quality

Short cycle times reduce signal-to-noise ratio and contrast resolution

Small critical defects

Metallic inclusions can occupy only a few voxels in the CT volume making reliable detection challenging

Context-dependence

Local cell structures and imaging artefacts can make the same type of indication easier to detect in some regions than in others

Limited training data

Real defects are rare, new defect types may appear over time, and detailed annotation is costly and time consuming for AI development

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The Xnovo Solution: Multi-Stage Analytical and AI Inspection

XNspect addresses the inspection challenge through a multi-stage analysis architecture. Instead of relying on a single algorithm, the workflow combines complementary analytical and AI -based methods:

- **Advanced analytical detection**

Analytical processing provides the foundation for efficient and robust evaluation of CT data.

- **Ultra-fast 3D classification**

Optimized 3D convolutional classification to evaluate candidate regions at production speed.

- **Anomaly detection for unknown indications**

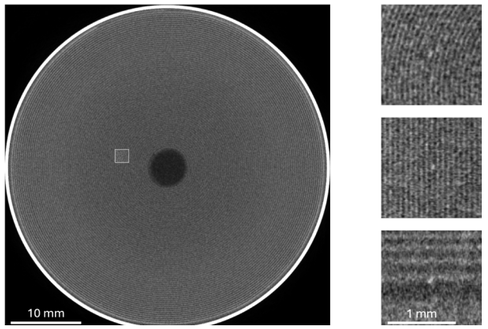
An anomaly detection network complements supervised classification by identifying regions that behave differently from normal cell structure. This is important when new or rare defect types appear, or when only a limited set of reference examples is available during initial deployment.

- **Decision logic and false-positive reduction**

The system combines outputs from the analytical, classification, and anomaly-detection stages into structured inspection results.

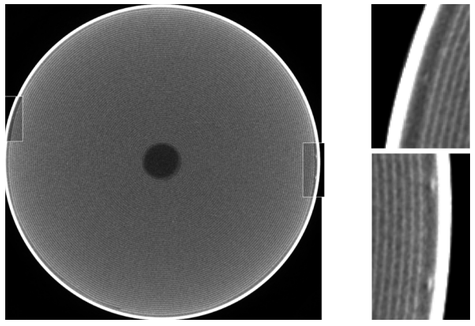
Challenging Defect Cases

Battery-cell inspection presents different challenges depending on the defect, its size, and its location:



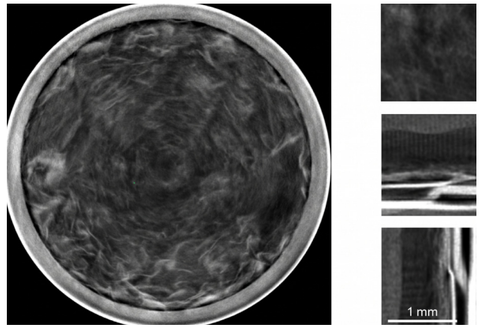
Jelly roll – small inclusion

Accurately detect critical, few-voxel inclusions that are difficult to distinguish from background variations.



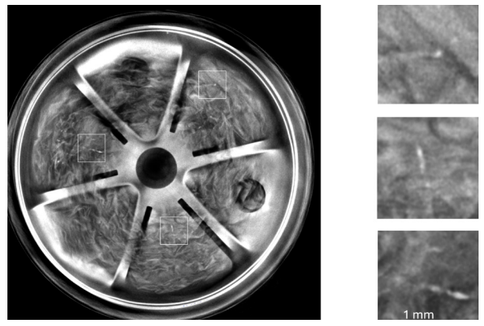
Battery can – beam hardening

The housing region is dominated by imaging artefacts from the high-density steel casing



Battery tab – weld micro-spatter

Distinguish real inclusions from harmless process structures to prevent compliant cells from being falsely scrapped.



Conductor – complex structures

Folded or overlapping conductor structures can mask small indications. Analysis must consider the local image context.

Deployment Architecture

XNspect is designed to support different deployment scenarios, from at-line sample inspection to in-line integration with production systems. The appropriate configuration depends on the CT infrastructure, target cycle time, inspection requirements, and factory interfaces:

- **Factory-local processing**

CT reconstruction, analysis & data storage can remain within the factory network, without an external cloud dependency. This supports data-security requirements and keeps sensitive production data under the manufacturer's control.

- **In-line and at-line deployment**

Integrate with existing CT infrastructure for production inspection or sample-based quality assurance.

- **Production-system connectivity**

Exchange inspection results with PLCs, manufacturing systems and quality tools through supported interfaces, including OPC UA and Q-DAS. Results can also be provided as human-readable images and PDF reports.

- **Scalable processing**

Allocate workloads across CPU/GPU resources to meet target throughput and cycle-time requirements.

- **Traceability and review**

Configure results, images, reports and scan references to support quality documentation, review and traceability.

Feasibility to Production

XNspect brings automated inclusion detection directly into the battery manufacturing environment. Connected to on-site CT infrastructure, it analyses inspection data locally or on an edge computing cluster.

Inspection results can feed directly into production and quality systems through OPC UA and SPC interfaces such as Q-DAS, alongside images and PDF reports for human review. Compression and storage can be configured after analysis to suit operational and traceability requirements.

A structured implementation approach allows manufacturers to start with available data and scale toward production integration step by step:

Phase 1: Feasibility

Objective: Establish detection capability on available CT data

Customer provides:
- Scanned cells (any CT format)

Xnovo delivers:
- Quantified detection capability

Phase 2: Integration

Objective: Demonstrate the analysis workflow at cycle time

Customer provides:
- Access to CT infrastructure

Xnovo delivers:
- Real-time algorithm processing

Phase 3: Production

Objective: Validate the complete inspection workflow

Customer provides:
- Dedicated line for validation

Xnovo delivers:
- Validated in-line/at-line 3D-CT inspection system

Practical Training and Refinement Workflow

Real defects may be infrequent, new cases can emerge over time, and detailed 3D annotation can require substantial effort. XNspect supports a practical development workflow in which available CT data and representative defect examples can be used to build, evaluate, and refine inspection capability:

- **Collect representative CT data**

Use existing production-quality scans, engineered reference samples, or a combination of both.

- **Apply simple annotation**

Mark relevant indications with simple point or region annotations rather than voxel -level segmentation.

- **Train and evaluate models**

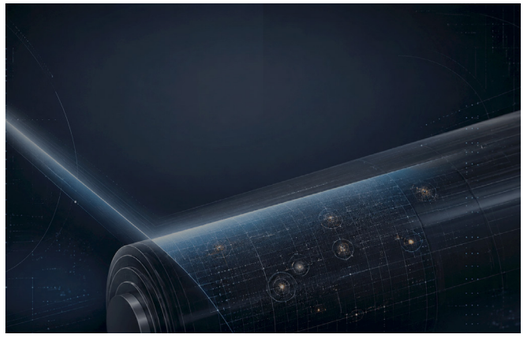
The analyses are configured for the target cell type, CT data quality, and inspection specification.

- **Review results**

False positives, missed indications, and unclear cases are reviewed by domain experts.

- **Refine for production**

Models and decision logic are iteratively improved until the workflow meets agreed sensitivity, false positive, and throughput targets.



The workflow is designed to build useful inspection capability from the data a factory can realistically provide, rather than requiring a perfect training dataset before development can begin. It can be adapted, fine-tuned, and retrained as cell designs and manufacturing conditions evolve. The result is an inspection capability integrated into the manufacturer's own production workflow.

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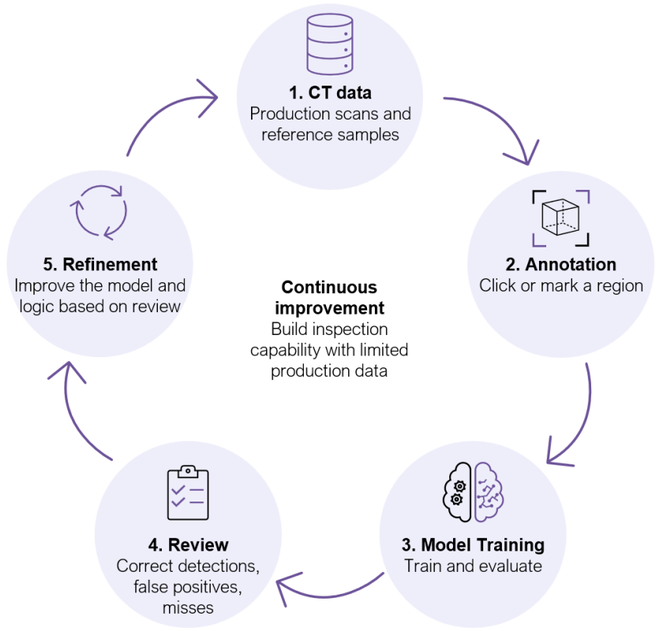
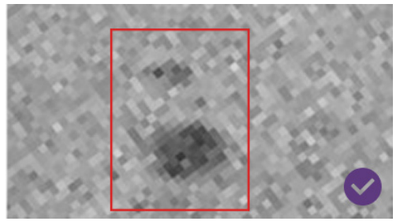


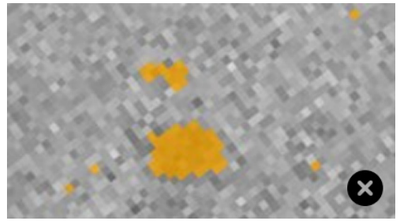
Point or region annotation

Click or mark the indication



Pixel-level segmentation

Detailed boundary labelling



Refinement feeds back into annotation and model development as needed. New production data can enter the workflow over time.

Application Value

By combining analytical processing, AI, imaging expertise, and production software engineering, XNspect helps battery manufacturers assess how 3D-CT can support practical quality assurance under production constraints.

Data Security

All reconstruction, analysis, and data storage remain strictly within your factory network.

Reliable detection of small indications

Support the detection and classification of small indications that can be difficult to distinguish in noisy CT data.

Production-speed inspection

Process 3D-CT data into structured inspection outputs within the processing time requirements.

Better discrimination and fewer unnecessary rejects

Combine analytical and AI-based information to help distinguish relevant defects from production-related artefacts.

Practical model development

Build inspection capability using representative data and simple point or region annotations, without requiring detailed voxel-level segmentation for every training example.

Adaptation as production evolves

Review results and refine the inspection workflow as additional data, new defect examples, and changing production requirements become available.

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WHY

Particle Detection in Production

Generic Inspection Analysis:
- Anode Cathode Overhang
- Delamination, Buckling
- Geometric Measurements
- + many others

WHAT

XNspect - Xnovo Advanced Analytical & AI Inspection:

- Superior detection of small inclusions
- Factory-local processing
- Integration with production and quality systems
- Customer-controlled model refinement

HOW

In-line:

CT → XNspect → MFG System
Frequency: every n-th cell

At-line:

CT → XNspect → Quality System

Conclusion

Production-speed 3D-CT battery inspection is a systems challenge. Scanner performance, image quality, analysis algorithms, computing infrastructure, review workflows, and factory integration all contribute to the final inspection result.

XNspect combines analytical processing, 3D AI, iterative review, and production integration to support reliable battery - cell inspection under realistic cycle-time constraints.

De-risk your inspection upgrade by starting with a feasibility assessment. We will evaluate detection capability on your representative CT data and identify the exact requirements for in-line integration.

Contact the Xnovo team today to discuss your cell format, target cycle times, and production requirements.

Know More

Reimagining Railway Inspection:

Where Physics Meets AI for a Safer and More Sustainable Rail Network

India is building one of the world's most ambitious railway networks, with safety, reliability and efficiency becoming increasingly important as the network continues to evolve. As railway infrastructure expands and trains operate at higher frequencies, the ability to inspect, understand and predict infrastructure condition is becoming just as important as the ability to build it.

At Rail Labs, we believe the next generation of railway safety will not be defined simply by faster inspection. It will be defined by smarter inspection.

Rail Labs is an IIT Madras-incubated company associated with the Centre for Railway Research and the Centre for Non-Destructive Evaluation. Operating at the intersection of engineering, railway infrastructure and emerging technologies, we are working towards reimagining how railway assets are inspected, assessed and maintained.

Our approach is built around a simple idea: combining the fundamental understanding of physics with the intelligence of artificial intelligence and non-destructive testing (NDT) to fundamentally rethink railway inspection.

This philosophy is at the heart of ARISTA, our autonomous track inspection initiative.

Moving Beyond Conventional Inspection

Railway inspection has traditionally been a highly specialised activity, dependent on periodic assessments, specialised equipment and the experience of trained personnel. These methods remain essential, but the scale and complexity of modern railway networks demand a new approach.

The question is no longer simply:

- **"Is there a defect?"**

The more important questions are:

- **"What is changing?"**
- **"How significant is that change?"**
- **"Where is the asset heading in the future?"**

And perhaps most importantly:

- **"Can we identify a developing condition before it becomes a safety concern?"**

This is where we see the greatest opportunity for innovation.

ARISTA is being developed around the concept of moving railway inspection from a largely periodic activity towards a more **continuous, intelligent and data-driven understanding of asset condition.**

The objective is not to replace the expertise of railway engineers or inspectors. Instead, it is to augment that expertise with technology capable of processing large volumes of information and identifying patterns that may otherwise be difficult to recognise.



Physics Meets Artificial Intelligence

At the core of our thinking is the combination of two very different strengths.

Physics provides an understanding of how railway assets behave.

Artificial intelligence provides the ability to process and interpret large quantities of information.

When these capabilities are brought together, we believe they can create a completely new layer of intelligence for railway inspection.

The physical world does not behave randomly. Rail, wheels, structures and other railway assets respond to loads, forces, environmental conditions and operational stresses according to fundamental physical principles.

The challenge is that these interactions can be complex and difficult to interpret at the scale of an entire railway network.

AI can help us identify relationships, trends and changes within this complexity. NDT provides another critical dimension: the ability to understand the condition of an asset without compromising its continued use.

This combination opens the door to a new philosophy of inspection—one where inspection is not merely about finding what has already happened, but about developing an increasingly intelligent understanding of what may happen next.

ARISTA: Rethinking Track Inspection

ARISTA is our effort to bring this philosophy into the railway environment.

Rather than looking at inspection as an isolated event, we envision an ecosystem where railway assets can increasingly be understood through the information they generate over time.

This changes the role of an inspection system.

It becomes more than a machine that collects information.

It becomes a tool that helps engineers understand condition, identify change and make better decisions.

Our long-term vision is to make railway inspection increasingly autonomous, scalable and intelligent while keeping safety and engineering principles at the centre of the system.

We are deliberately taking a phased approach to this development. Railway safety cannot be treated like a conventional technology deployment. Any system operating in such a critical environment must demonstrate reliability, repeatability and engineering credibility.

That is why our work focuses not only on artificial intelligence, but also on the physical understanding of railway infrastructure and the principles of NDT.

The intelligence must always remain grounded in engineering reality.

From Detection to Decision Support

One of the biggest opportunities in railway technology is the transition from detection to decision support.

A conventional inspection workflow may produce a large amount of information. The real challenge begins afterwards: interpreting that information, identifying what matters and determining what action should be taken.

As railway networks become larger, manually processing every piece of information becomes increasingly difficult. This is where intelligent systems can make a significant difference.

The future of railway inspection should enable engineers to focus their attention where it matters most.

Instead of treating every kilometre or every observation equally, intelligent inspection can help create a clearer picture of asset condition and highlight areas that require closer engineering attention.

This has the potential to improve not only safety but also productivity.

The goal is not to generate more data.

The goal is to generate more useful intelligence from the data that already exists.

Sustainability Is Also About Efficiency

When we talk about sustainability in the railway industry, the conversation often focuses on energy consumption, electrification or environmentally frendly materials.

These are undoubtedly important.

However, sustainability also has another dimension: **using infrastructure and resources more intelligently.** Better inspection can contribute to this objective.



If railway assets can be understood more accurately, maintenance activities can become more targeted. Engineering resources can be directed towards areas of genuine concern rather than being distributed uniformly.

This can help reduce unnecessary interventions, improve asset utilisation and potentially extend the useful life of infrastructure.

For one of the world's largest railway networks, even small improvements in how assets are inspected and maintained can have a significant cumulative impact.

This is why we see intelligent NDT not only as a safety technology, but also as a sustainability enabler.

Building for the Scale of Indian Railways

India presents a unique challenge—and an equally unique opportunity.

The scale of Indian Railways means that technologies developed for the network cannot simply be designed for laboratory conditions. They need to be capable of operating within a highly diverse and demanding environment.

Different routes, operating conditions, traffic patterns, infrastructure characteristics and maintenance practices create enormous complexity.

Technology therefore needs to be **robust, scalable and practical.**

At Rail Labs, this principle influences how we approach product development.

Our objective is not to build technology merely because it is technically possible.

Our objective is to build technology that can eventually create measurable value for the railway ecosystem.

We believe that innovation becomes meaningful only when it can move from a controlled environment into the real world.

Creating a New Culture of Preventive Safety

The larger opportunity goes beyond any individual inspection system.

We believe India has the opportunity to build a new culture of preventive railway safety—one where technology continuously supports engineers in understanding infrastructure condition.

This requires a change in mindset.

Inspection should not be viewed only as a compliance activity.

It should become an integral part of the railway's intelligence layer.

NDT can play a central role in this transformation because it allows infrastructure to be evaluated without interrupting its fundamental purpose. When combined with AI and engineering knowledge, it can become an important foundation for more predictive and informed maintenance practices.

This is the direction in which we believe the industry is heading.

An Indian Approach to Global Railway Challenges

At Rail Labs, our ambition extends beyond developing individual products.

We want to contribute to the development of technologies that demonstrate that some of the world's most complex railway challenges can be addressed through innovation emerging from India.

Indian Railways provides an extraordinary environment for solving these problems at scale.

The challenges are significant, but so is the opportunity.

ARISTA represents one part of our larger vision: to bring together engineering, NDT and AI to create a new generation of railway inspection capabilities.

We are still on this journey, and there is considerable work ahead.

But our belief is clear.

The future of railway safety will not be built only by inspecting infrastructure better. It will be built by understanding infrastructure better.

And that requires bringing together the physical world of engineering with the intelligence of modern computing.

As railways around the world move towards greater automation, higher capacity and smarter asset management, inspection systems will need to evolve alongside them.

For India, this is more than an opportunity to adopt new technology.

It is an opportunity to redefine what railway inspection can become.

At Rail Labs, we are working towards that future—quietly, carefully and with one objective at the centre of everything we do:

to make railways safer through intelligent, engineering-led innovation.

Know More



Sumit Anand
Co-founder & Chief Operating Officer
Rail Labs Pvt. Ltd.

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Your next customer is searching through AI agents.
We make sure they find *You*.

We Put Your NDT Business In Front Of Them At Exactly The Right Moment.

WHAT WE DO

Rank Higher On Google
Show Up In Ai Results
Reach Local Markets

12GRIDS

Research Paper

Automated nondestructive evaluation of compressive strength of underground lining structure using hyperspectral imaging and deep neural networks

Changsong Wang, Mingliang Zhou, Le Zhang, Hongwei Huang

Abstract

Evaluation of compressive strength in underground lining structures is critical for ensuring structural integrity and safety. Traditional assessment methods are often destructive, time-consuming, and impractical in confined environments such as tunnels and utility corridors. This study introduces an automated, nondestructive approach to visualize and estimate the compressive strength of underground concrete lining using hyperspectral imaging (HSI) combined with deep neural network (DNN) models. High-dimensional spectral data of concrete lining are assembled and trained to develop two DNN-based regression models, namely the Mono-Spectrum Deep Neural Regressor (MS-DNR) and the Segmented-Spectrum Deep Neural Regressor (SegS_DNR). Utilizing the SegS_DNR model, two-dimensional (2D) compressive strength distribution heatmaps were generated for visualization and assessment of strength variations. The SegS_DNR model demonstrated excellent predictive performance, achieving a coefficient of determination (R2p) of 0.925 and a Residual Prediction Deviation (RPD) of 5.28 on the testing set for compressive strength estimation. The idea is further validated in site by investigating the capability of identifying the defect regions of the tunnel concrete lining, namely the cracked, spalling, and leaking areas, and demonstrated promising performance in comparison with experienced inspectors on site. This approach offers a contact-free technique for automated structural health monitoring, contributing to safer and more sustainable underground maintenance practices.

1. Introduction

With acceleration of the urbanization and increasing utilization of the underground spaces, underground engineering projects such as subway tunnels, highway tunnels, and utility corridors have rapidly developed worldwide (No and Association, 2000; Li et al., 2015; Huang et al., 2022; Xia et al., 2022; Yu et al., 2023). Concrete structures are widely adopted in these underground settings due to their cost-effectiveness and stability (Putra, 2021; Antoniou et al., 2023; Wei et al., 2025). As a key indicator of structural performance, the compressive strength of concrete is susceptible to deterioration under complex underground conditions, such as water seepage (Huang et al., 2020; Wang, 2021) and stress concentration (Boulekbache et al., 2012). Such deterioration, if unaddressed, can compromise the structural integrity and may lead to catastrophic failures such as tunnel collapses (Huang et al., 2024b; Zhang et al., 2024c; Wang et al., 2025). Thus, the automated and nondestructive assessment of compressive strength is critical for informed lifecycle management and maintenance decisions in underground infrastructures (Zhao et al., 2021b, 2023; Zhou et al., 2021; Du et al., 2023), aiming to ensure operational safety and prevent such failures.

Conventional destructive methods for compressive strength evaluation of concrete lining, including coring and pull-off testing, are often impractical in confined underground environments, as they may damage the structure and require considerable time and labor (Ebead and Younis, 2019; Ali-Benyahia et al., 2023). Nondestructive testing (NDT) methods have therefore become essential in civil infrastructure maintenance and inspection (Pucinotti, 2015; Rashid and Waqas, 2017; Wang et al., 2023a; Zhang et al., 2024a, 2024d). Hyperspectral imaging (HSI) has recently emerged as a promising NDT approach, offering high spatial and spectral resolution to capture detailed reflectance characteristics of materials (Ptacek et al., 2021; Song et al., 2023; Huang et al., 2024a). However, the high dimensionality and complexity of HSI data impose greater demands on data processing and analysis, necessitating the integration of advanced analytical techniques and models to fully exploit its latent information. This study aims to develop an innovative NDT method for concrete compressive strength by integrating HSI with deep learning (DL). Additionally, it seeks to achieve visualization of the strength distribution and analyze the characteristics of structural strength degradation. Compared to existing methods, the main contributions of this study are as follows:

- Apply HSI technology to the NDT of concrete compressive strength. By capturing the reflective properties of concrete across multiple spectral bands, it extracts rich spectral and spatial information to achieve high-precision predictions of concrete compressive strength.
- Develop spatial distribution mapping techniques for compressive strength. These techniques can intuitively display the distribution of compressive strength across different regions of concrete structures, aiding in identification of the potential weak points and damaged areas.
- Obtain visualized strength results and degradation characteristics in typical defect and damage areas within concrete structures. This not only verifies the practicality and reliability of the methods but also provides strong support for their application in real-world engineering projects.

2. Related work

To gain a comprehensive understanding of the existing methods for testing the compressive strength of concrete structures and their limitations, Table 1 categorizes and summarizes traditional destructive testing methods, current NDT methods, and machine learning (ML) prediction methods. As shown in Table 1, destructive testing approaches, while capable of delivering precise data, exhibit strong invasiveness, potentially harming existing structures, and are time-consuming and laborious. For example, core extraction testing requires drilling cylindrical samples from the concrete structure, damaging the structure, and conducting tests in laboratory (Saleh et al., 2022; Xu and Li, 2018). Conversely, pull-out testing is used to measure the surface adhesion of concrete, indirectly reflecting compressive strength; however, its results are influenced by various factors, including aggregate properties, the location of rebar, and procedural variations, and its accuracy is relatively limited (Ramos et al., 2012).

NDT provides safer alternatives for concrete compressive strength assessment. Common methods like ultrasonic testing, GPR and rebound hammer employ distinct physical principles: ultrasonic waves detect internal propagation patterns (Komloset al., 1996; Del Rıo et al., 2004), GPR uses electromagnetic waves for defect identification (Lai et al., 2009; Tosti and Ferrante, 2020), while rebound hammers measure surface hardness. However, these methods face inherent limitations, as ultrasonic accuracy depends on material homogeneity, GPR suffers from resolution-depth tradeoffs, and rebound hammers are prone to surface/environmental interference. Crucially, none can generate spatial visualization of strength distribution or precisely characterize structural degradation in complex underground environments. This highlights the need for advanced visualization technologies to enable automated, precise strength assessment in underground concrete structures.

HSI, as an advanced NDT technology, has garnered widespread attention in the inspection of concrete structures in recent years. As illustrated in Fig. 1, HSI captures the reflective properties of materials across multiple continuous spectral bands, providing rich spectral and spatial information that enables in-depth analysis of the chemical composition and physical state of concrete (Short et al., 2001; Bonifazi et al., 2018; Kim and Cho, 2018). Compared to traditional NDT methods,

HSI boasts high spatial and spectral resolution, enabling the capture of detailed spectral information on the concrete surface at a microscopic level, which aids in identifying minute changes and defects within the material (Song et al., 2023). For example, hyperspectral technology can evaluate and identify concrete properties in various structural components through the reflected radiation of concrete in the visible-near infrared and short wave infrared (VI-NIR and SWIR) (Shaban, 2013; Oliveira Santos et al., 2019). Additionally, the non-invasive nature of HSI makes it an ideal tool for real-time monitoring at construction sites, as it does not cause any physical damage to the concrete structures. Furthermore, HSI can estimate the physicomechanical properties of concrete through qualitative analysis of material composition. By integrating chemical analysis methods, HSI can identify and quantify the distribution and content of components such as cement, moisture, and rebar, thereby inferring the trends in compressive strength variations (Bonifazi et al., 2018; Ptacek et al., 2021). However, application of the HSI to detection of the compressive strength of concrete structures also faces challenges, as most current research remains confined to laboratory testing and is difficult to apply in complex engineering projects. Thus, the challenge is how to efficiently handle and analyze HSI data, fully utilize its rich information and visual technologies, and perform machine vision-based assessments of compressive strength within engineering structures.

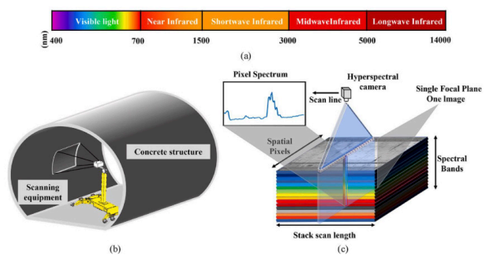

Fig. 1. The operating principle of hyperspectral imaging: (a) Spectral wavelength classification, (b) scanning equipment, and (c) hyper-spectral data structure.

With advancement of computational capabilities and development of big data technologies, application of ML and DL methods in NDT has been increasingly widespread, particularly demonstrating significant potential in predicting the compressive strength of concrete (Günaydın et al., 2023; Phoon and Zhang, 2023; Alavi et al., 2024; Buddika et al., 2024). Beyond strength prediction, DL techniques, especially Convolutional Neural Networks (CNNs), are also being successfully applied for automated detection and quantification of various structural defects in tunnels, such as water leakage and cracks (Zhao et al., 2021a; Zhang et al., 2022; Ma et al., 2025a, 2025b). These methods leverage various types of data, including concrete mix proportions, physicochemical properties, environmental conditions, and sensor acquired data, enabling automatic feature extraction and capturing complex nonlinear relationships within concrete materials, thereby enhancing the accuracy and reliability of predictions. Traditional ML algorithms, such as Support Vector Machines (SVM), Random Forests (RF), and K-Nearest Neighbors (KNN), have been widely applied in prediction of the concrete compressive strength (Chun et al., 2020; Chen et al., 2021; Li et al., 2022; Zhang et al., 2024b). In recent years, DL methods, particularly CNNs and deep neural networks (DNNs) have demonstrated higher accuracy and robustness in predicting concrete compressive strength, owing to their powerful automatic feature extraction capabilities and advantages in handling high-dimensional data (Zhao and Du, 2016; Zhong et al., 2017; Wang et al., 2023b). These models are capable of automatically learning meaningful features from complex input data, thereby reducing the dependence on manual feature engineering (Deng et al., 2018; Zeng et al., 2022; Zhang et al., 2025).

Through above innovative works, this study fills the research gap in application of the HSI for concrete compressive strength detection and visualization. It provides an automated, nondestructive visual detection technology, offering new technical means and theoretical foundations for the maintenance and life-cycle management of underground infrastructure.

3. Datasets acquisition and processing

In this study, hyperspectral datasets from in situ tunnel concrete linings were obtained, and various DL algorithms were developed to identify compressive strength. The performance of these models was compared and analyzed. Finally, the constructed DL models were applied in engineering practice to validate their effectiveness.

3.1. Compressive strength and spectral data acquisition

In this study, data are collected from two sections: the Shanghai Metro Line 12 and the Qingdao Metro Line 8, as illustrated in Fig. 2b. Both are operational metro tunnels constructed using slurry shield tunnelling methods with prefabricated reinforced concrete segmental linings, with a design concrete strength grade of C55. The former crosses the Huangpu River, primarily traversing soft alluvial and marine deposits typical of the region (e.g. layers of clay, silty clay, and sand). The latter traverses Jiaozhou Bay, encountering challenging geological conditions including marine sediments, weathered rock, and fault fracture zones. Groundwater and complex weak strata in these subaqueous environments contribute to concrete challenging issues for lining such as water leakage, spalling, and cracking, which poses significant risks to metro operations and public safety. The long-term operational exposure to these challenging environments, coupled with factors like numerous segment joints, potential installation stresses, and gradual material degradation, can still lead to the occurrence of such defects over elapsed time, necessitating reliable condition assessment.

An information acquisition system is developed to scan and obtain high-quality hyperspectral images of underground concrete structures, as shown in Fig. 2a.

Table 1 - Research methods for concrete compressive strength detection.

Method	Testing	Strength	Limitation	Source
Traditional destructive testing method	Core sampling	Providing accurate compressive strength data	Highly invasive, may damage structures, time-consuming and labor-intensive	Saleh et al. (2022), Xu and Li (2018)
	Pull-off test	Providing accurate compressive strength data compressive strength	Affected by multiple factors, limited accuracy	Ramos et al. (2012)
Current NDT method	Ultrasonic testing	Assessing internal state and compressive strength	Highly affected by material uniformity and construction quality	Komlos et al. (1996)
	Ground penetrating radar (GPR)	Detecting internal defects and structural characteristics	Limited resolution and difficult to visualize compressive strength	Lai et al. (2009)
	Rebound hammer test	Estimating surface compressive strength	Low accuracy, affected by surface treatment	Alwash et al. (2017)

The hyperspectral image acquisition system primarily consists of a hyperspectral camera, tripod, halogen light source, computer, reflectance calibration plate, and rebound hammer. The chosen hyperspectral camera, a domestically developed pushbroom near-infrared imaging spectrometer, model FigSpec FS-27 (Hangzhou CHNSpec Technology Co., Ltd., Hangzhou, China), employing an InGaAs sensor, captures 1280 × 1280 pixels spectral images within the 900–1700 nm spectral range (1024 bands, 6.5 nm spectral resolution) and saves them as 1024-bit hyperspectral image cubes. The illumination is provided by a halogen light source (FG-1000W, 400–1700 nm), offering a full-spectrum light source. The hyperspectral camera is mounted on a tripod and connected to the acquisition software terminal via a data cable, which is used to set camera parameters and capture hyperspectral images. A standard reflectance plate is placed above the detection area to facilitate reflectance calibration of the hyperspectral images. This calibration plate has been calibrated in the laboratory to a known reflectivity curve.

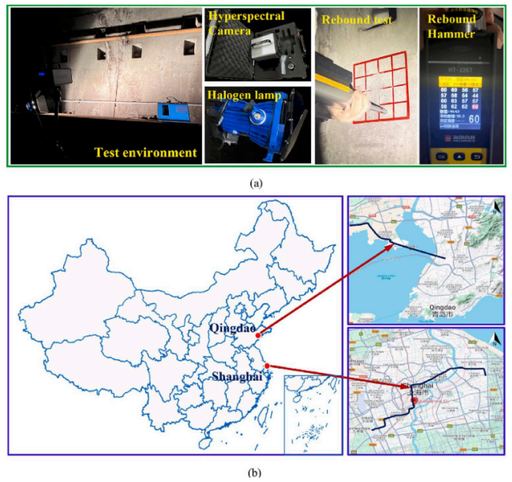

Fig. 2. Geographical location and sampling environment of the study area: (a) Schematic diagram of data collection, and (b) map of the study area's geographical location.

To ensure high-quality and consistent HSI of the tunnel linings, the camera distance and exposure time are adjusted based on the calibration plate readings before the formal image capture. Adjustments continue until the detected reflected light intensity from the plate reaches approximately 60 % of the saturation level. This target helps to optimize the signal-to-noise ratio and ensure measurements are made within the linear response range of the sensor, thereby stabilizing the data against minor illumination fluctuations and preventing data-deficient pixels caused by insufficient or excessive illumination. This 60 % target was monitored by observing the peak raw digital number (DN) values which are directly proportional to the light intensity received by the sensor elements—from the white reflectance plate in the live data feed provided by the camera's acquisition software. This ensures that the signal is strong yet well below the sensor's saturation limit (the FigSpec FS-27 employs a 12-bit sensor, with a maximum DN of 4095, thus the target was approximately 2457 DN).

As illustrated in Fig. 2a, a high-precision digital rebound hammer (Model HT225T, ZBLScien Technology Co., Ltd., Beijing, China), featuring direct digital display of rebound values, estimated strength, and compliance with C805/C805M-13a (2013), is employed in situ to determine the compressive strength of the tunnel lining surface. The measurement points were strategically distributed along the tunnel's longitudinal axis at 5-m intervals, covering critical structural zones (e.g. vault, sidewalls, and invert) and diverse surface conditions, including intact areas, cracks, spalling, and water seepage regions, to characterize the lining's mechanical behavior under varying states. The points were selected using a standard 4 × 4 grid arrangement combined with the following criteria: (1) prioritizing representative coverage of both normal and deteriorated surface conditions, and (2) introducing one random validation point between every ten primary grid points for cross-verification of data consistency. This hybrid approach ensured systematic coverage of the surveyed area while capturing the heterogeneity of tunnel lining performance. While hyperspectral images of the tunnel surface were acquired, rebound values were simultaneously recorded at each designated sampling point. To account for the influence of carbonation on the surface properties, three additional random points were chosen within the measurement region to quantify carbonation depth. The average of these three measurements, denoted as dm, was adopted as the representative carbonation depth for the site.

According to C805/C805M-13a (2013), the following equation is applied to convert the raw rebound measurements into standardized compressive strength values:

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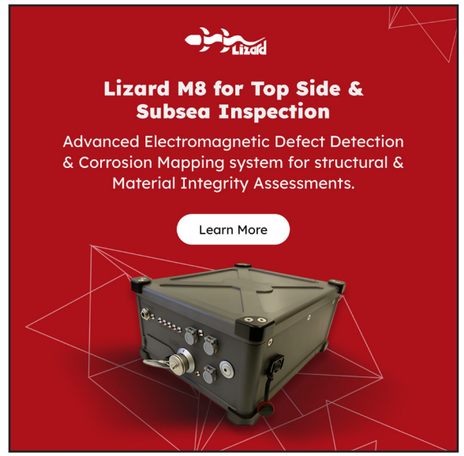
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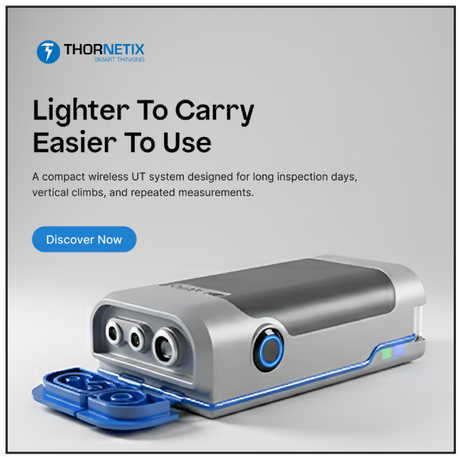
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