SURF CON INSPECT

WHITE PAPER

How In-Line 3D inspection works: setup and the operator's role

SurfConInspect White Paper
Series 5/10

About Us

WHO WE ARE

SurfConInspect (SCI) is a European project funded by the Research Fund for Coal and Steel (RFCS). Our consortium brings together leading steel producers, research institutes, technology developers and innovation experts.

The partners combine industrial expertise, academic knowledge and advanced digital solutions to transform the way steel quality is controlled.

OUR MISSION

The steel industry faces increasing pressure to become more sustainable, efficient and competitive—key goals of the European Green Deal.
Our mission is to enable zero-defect manufacturing in flat steel production by:

- Detecting surface defects earlier and more accurately.
- Reducing waste and improving resource efficiency.
- Supporting operators with advanced visualization tools.
- Providing real-time control actions directly in production lines.

MAIN ACTIVITIES

- Industrial trials in tin-plate and automotive steel production.
- Development of AI-based inspection methods.
- Application of AR for real-time operator support.
- Creation of open datasets to enhance research and industrial collaboration.
- Dissemination of results to industry, research and society through events, publications and digital platforms.

EXPECTED RESULTS

- Zero-defect production through optimized inspection and control.
- Reduced waste and energy consumption, contributing to the
  European Green Deal.
- Higher competitiveness for European steel producers.
- Transferable technologies with potential applications beyond the steel sector.
- Improved working conditions, with operators supported by innovative visualization and decision-making tools.

Executive Summary

The shift from two-dimensional to three-dimensional inspection in flat steel production is not simply a matter of installing a more advanced sensor. It changes the very logic of inspection. A conventional 2D system records how the strip surface appears under a given illumination setup. A 3D system records how that surface is physically shaped in space. This distinction is decisive in pickling-line environments, where wet physical influences, reflectivity changes, and local optical ambiguity can make a visually prominent event irrelevant and a visually modest one highly critical. SurfConInspect was built around this exact industrial problem: if the defect attribute that drives downstream risk is geometric rather than optical, then the inspection chain must begin with geometry. That is why the project adopted a combined 2D/3D configuration at RAS and used height information as the basis for more reliable decisions on topographic defects.

This white paper explains how an in-line 3D inspection system works at production scale, but it does so from the perspective that matters most in steelmaking: not abstract instrumentation theory, but the practical chain from measurement to intervention. The SurfConInspect installation at the RAS pickling line provides a particularly strong reference case because it combines full-width topographic sensing, conventional optical imaging, real-time quality processing, and operator-facing decision support within one continuous production environment. What follows, therefore, is not just a description of a sensor principle. It is the story of how a measurement architecture becomes an operational tool for reducing avoidable downstream failures while preserving yield.

The intended audience for this paper is broad. It includes line operators and technicians who work directly with inspection systems and must interpret their outputs in real time. It includes plant managers and production supervisors responsible for the operational performance of pickling lines and who must evaluate the practical benefits and constraints of advanced inspection technology. And it includes quality engineers and system integrators involved in the specification, installation, and commissioning of inspection systems who require a clear understanding of how three-dimensional sensing integrates with existing process infrastructure.

The industrial reference point for this paper is the installation commissioned at the RAS pickling line, where SurfConInspect validates what the project describes as the world's first combined 2D/3D surface inspection system for flat steel production. That installation is important not because it is novel in a generic sense, but because it was designed to answer a very specific industrial need: to detect topographic defects with a reliability high enough to support in-coil decisions at production speed. The project documentation frames this as a step beyond conventional inspection practice, especially in the pickling environment, where 3D sensing offers a way to overcome the classification uncertainty created by wet influences and visually ambiguous defect patterns.

The inspection task on a pickling line: an operational overview

A pickling line is a continuous production facility in which hot-rolled steel coils are unwound, chemically treated to remove the layer of iron oxide scale formed during hot rolling, rinsed, dried, and rewound into finished coils ready for subsequent processing. The chemical treatment—typically involving hydrochloric or sulfuric acid at controlled concentrations and temperatures—is effective at dissolving the oxide layer but also reveals the underlying steel surface in its full condition, including any defects originating in upstream processes such as casting or hot rolling that were previously hidden beneath the scale. This moment of surface revelation makes the pickling line the first point in the production chain at which a comprehensive assessment of strip surface quality becomes possible, and therefore the most strategically important location for surface inspection.

The inspection task at pickling is demanding because every technical variable is industrially stretched at the same time. In the SurfConInspect reference setup the real challenge is not to prove that 3D sensing works in principle, but that it works without slowing the line, fragmenting the workflow, or creating blind zones in exactly the operating window where pickling-line decisions have to be made.

Beyond the purely technical requirements of coverage and speed, the inspection system must operate reliably within the environmental conditions of the pickling line. These conditions include the presence of water, acid aerosols, and steam in the inspection zone, which affect both the optical properties of the measurement target and the long-term integrity of the sensor hardware. They include vibrations transmitted through the line structure from motors, rollers, and the strip itself, which can perturb the spatial stability of the sensor mounting and introduce noise into the measurement signal. And they include temperature variations—both gradual changes associated with the line warming up during operation and more rapid fluctuations caused by the cooling effect of rinsing water—which affect the mechanical stability of precision optical components.

The inspection system must therefore be understood not as a laboratory instrument deployed in an industrial setting, but as an industrial system designed from the outset for continuous operation in a hostile environment. Every aspect of its design—from the choice of measurement principle to the mechanical integration of sensor heads, from the selection of illumination sources to the architecture of the data processing chain—must reflect this operational reality. The SurfConInspect installation at RAS represents one of the most complete implementations of this principle in the European flat steel industry, combining three-dimensional topographic measurement with conventional two-dimensional imaging in a configuration that provides simultaneous coverage of both strip surfaces across the full production width.

From image to height map: the measurement principle

Two-dimensional inspection systems capture images. Three-dimensional inspection systems capture height maps. This distinction, while simple to state, has profound consequences for what can be detected, what can be measured, and how the results can be used. Understanding why height measurement is fundamentally different from image capture—and why this difference matters for the detection of topographic defects—is the starting point for understanding how a three-dimensional inspection system works and why it is configured the way it is.

In a two-dimensional imaging system, a camera records the intensity of light reflected from the strip surface at each point within its field of view. The resulting image is a two-dimensional map of brightness values, in which variations in intensity correspond to variations in the way the surface reflects light under the specific illumination conditions used. This map can reveal many types of surface anomaly—stains, changes in surface texture, colour variations, residual scale—because all of these affect the reflective properties of the surface and therefore appear as contrast variations in the image. What it cannot reveal is the three-dimensional structure of the surface, because a camera image does not contain depth information. Two points at different heights appear at the same position in the image if they have the same brightness, and two points at the same height appear differently if one reflects light more strongly than the other. Height and brightness are completely independent quantities, and a camera measures only one of them.

Three-dimensional inspection solves a problem that conventional imaging cannot solve because it measures a different physical quantity. A 2D camera captures reflected light intensity. Laser triangulation captures position in space. In the RAS setup, a projected laser line is observed under a defined triangulation angle, and the lateral displacement of that line is converted into a height value. Repeated profile after profile, this creates not an image in the ordinary sense, but a continuous height field of the moving strip. This is the critical distinction for topographic defects. A dent, an abrasion groove, or a shell-related discontinuity becomes measurable as a geometric event with depth, elevation, lateral extent, and position. In project terms, that is what makes the later stages of quality processing possible: the defect is no longer inferred from contrast; it is described numerically in physically meaningful terms.

As the strip moves continuously past the sensor at production speed, successive laser line profiles are acquired and stacked to build a two-dimensional height map of the strip surface—a dense matrix of height values in which each element corresponds to a specific point on the strip, characterised by its position along the strip length, its position across the strip width, and its height relative to a defined reference plane. This height map is the primary output of the three-dimensional inspection system, and it is from this map that all subsequent defect detection and characterisation operations are performed. A dent appears in the height map as a localised negative feature—a region where height values are lower than the surrounding surface. An abrasion appears as an elongated region of reduced height, potentially flanked by ridges of elevated material. A shell defect appears as a thin region of slightly reduced height extending over a larger area. Each defect type has a characteristic signature in the height map that reflects its three-dimensional geometry, and this signature can be quantified in terms of depth, width, length, and profile shape, independently of the illumination conditions under which the measurement was made.

Physical configuration of the sensor system

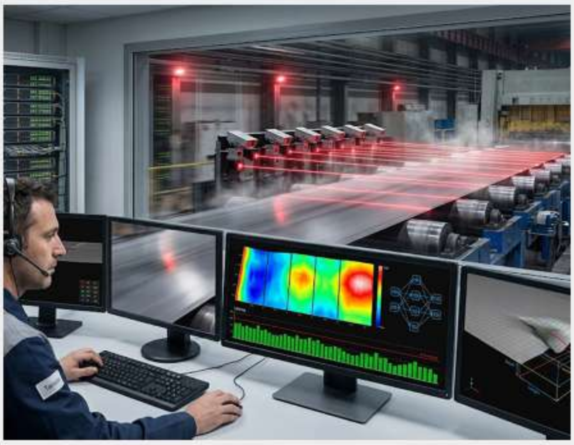
The practical implementation of laser triangulation for full-width, both-surface inspection of a steel strip at pickling-line speeds requires a sensor configuration that goes considerably beyond a single laser source and camera. The sensor architecture adopted at RAS reflects a practical compromise between field of view, spatial resolution, and robustness. Illumination choice is not a secondary engineering detail in pickling-line inspection. It is part of the reliability strategy. The project documentation shows that wet physical influences create serious ambiguity for conventional inspection, and one of the advantages of the 3D approach at RAS is precisely that the topographic view is far less vulnerable to this class of disturbance. The selected laser-triangulation setup therefore has to be understood as an industrial response to a hostile optical environment rather than as a mere metrology preference. In the SurfConInspect logic, the goal is not to create a beautiful surface map. It is to extract the defect attribute that remains discriminative when the surface is wet, reflective, or otherwise optically unstable.

The three sensor units for each surface are mounted on a common mechanical frame positioned transversely across the strip at a defined distance determined by the working range and sensitivity of the triangulation arrangement. For the upper surface, this frame is suspended above the strip. For the lower surface, an equivalent frame is mounted below the strip between the support rollers that carry the strip through the inspection zone. Both frames are mechanically isolated from the line structure to reduce the transmission of vibration from rollers and drives to the sensor optics. Environmental enclosures protect the optical components from direct exposure to acid aerosols and water spray, while maintaining optical access to the strip surface through precision windows that are designed to be easily cleaned and replaced without disturbing the sensor alignment.defect discrimination becomes more reliable, and classification can better reflect the actual severity of the defect rather than its visual representation.

The synchronisation of the six sensor units—three per surface—is a critical aspect of the system configuration. All units must acquire data simultaneously, and the timing of acquisition must be synchronised with the strip speed so that successive height profiles are spaced at a consistent longitudinal interval along the strip. This synchronisation is achieved through a combination of encoder signals derived from the drive system of the pickling line—which provide a direct measurement of strip displacement—and a central acquisition controller that triggers the lasers and cameras at the appropriate intervals. The encoder-based triggering ensures that the longitudinal sampling density of the height map remains constant regardless of variations in strip speed, which are common during the start and stop of coil sequences and during speed adjustments made by the operator in response to process conditions.

Data acquisition and real-time processing

Once 3D inspection moves from laboratory demonstration to full-width in-line deployment, data handling becomes part of the quality problem. The SurfConInspect architecture addresses this through a distributed real-time processing concept in which measurement data are transformed into quality information quickly enough to support control actions on the line. In project language, the SCI framework is designed to communicate with production measurement systems, synchronise in-coil positions, process multiple quality models in parallel, generate quality events, and translate those events into actions either for the operator or directly for the process. This is the hidden discipline behind the sensor hardware: no matter how accurate the height measurement is, it becomes operationally valuable only if the processing chain can keep pace with the strip.



Real-time processing of this data stream requires a dedicated computing architecture in which multiple processing units operate in parallel, each responsible for a defined zone of the strip width, and the outputs of these parallel processing paths are combined into a coherent, full-width height map that is continuously updated as the strip advances. The fundamental processing steps performed on the raw camera images include the extraction of the laser line position from each profile—a subpixel localisation operation that determines the lateral centroid of the bright line with a precision exceeding the pixel pitch of the camera sensor—and the conversion of this position into a height value through the triangulation calibration model. Additional steps compensate for systematic variations across the field of view, correct for the effects of strip vibration in the out-of-plane direction, and remove low-frequency height variations associated with global strip geometry rather than localised surface features.

The height map is where 3D measurement becomes industrial judgement. From that map, each defect candidate can be expressed through measurable geometric attributes such as depth, elevation, lateral extent, longitudinal extent, and position relative to the strip edge. This is consistent with the project's own findings on criticality: when RAS analysed 24 documented coil-break cases, the decisive variables were not visual prominence but depth, elevation, size, and edge position. The same analysis showed that 96% of the relevant defects had measurable height or depth information and were recognised in the 3D channel, while around 90% were located close to the strip edge. Those findings give the operator interface and the quality model a much stronger footing than image-based intuition alone. They allow the system to rank risk on the basis of mechanics rather than appearance.

In steelmaking, latency is not a software metric; it is a process constraint. The project requirements make this explicit. For the automated cutting use case, the control result must be produced and submitted to the operator within 10 seconds, while quality events and recommendations are expected in real time. This requirement is what ties the entire chain together: data collection, clustering, quality processing, event generation, and operator-facing action cannot be treated as loosely coupled functions. They form one time-critical loop. The practical meaning is simple: a defect report that arrives after the strip section has passed the last meaningful intervention point may still be informative, but it is no longer operational control.

Integration of the 3D and 2D inspection channels

The combined 2D/3D architecture at RAS reflects a mature inspection philosophy: one sensing modality cannot solve the whole surface-quality problem. The 3D channel is indispensable for topographic defects because it provides direct access to geometry. The 2D channel remains indispensable for non-topographic conditions, including scale-related issues and purely optical anomalies with no measurable height signature. This is already built into the project logic. Use case 1 relies on the 3D system for heavy-defect handling, while use case 2 uses the additional 2D channel to support speed control based on scale affection, where large-area aggregation matters more than individual topographic events. The result is not sensor redundancy. It is functional complementarity.

The two-dimensional channel in the combined system uses high-resolution line-scan cameras operating with brightfield or darkfield illumination, configured to capture the full width of the strip at sampling rates consistent with the production speed. These cameras provide a detailed optical image of the strip surface that is sensitive to contrast variations caused by stains, residual scale, surface discolorations, and other anomalies that affect the reflective properties of the surface without introducing measurable height variations. For the detection of non-topographic defects the two-dimensional channel remains essential, because no amount of height measurement sensitivity can detect a surface condition that has no geometric expression.

The three-dimensional channel, as described in the preceding sections, provides the height map from which topographic defects are detected and characterised geometrically. For the specific defect types most relevant to the automated cutting control use case the three-dimensional channel offers a capability that the two-dimensional channel cannot replicate: the ability to assess defect severity from measurable physical parameters rather than from visual appearance. A dent that appears as an ambiguous feature in a brightfield image—too similar to a water droplet reflection or a minor surface texture variation to be classified with confidence—appears as an unambiguous negative feature in the height map, with a depth value that can be directly compared against a severity threshold defined in physical units.

The integration of the two channels within a single processing framework requires that data from both be spatially registered—that is, that each point in the height map corresponds to the same physical location on the strip as the corresponding point in the two-dimensional image, so that geometric attributes derived from the height data and visual attributes derived from the image can be combined into a joint defect representation. This spatial registration is achieved through a calibration procedure that establishes the geometric relationship between the fields of view of the 3D and 2D sensors, and through the encoder-based synchronisation system that ensures both channels sample the strip at consistent longitudinal positions. The result is a composite inspection output in which each detected event can be described simultaneously by its geometric profile and by its visual appearance, enabling classification approaches that exploit both sources of information.

The operator station: information architecture and display

The physical inspection hardware and the data processing chain described in the preceding sections generate a continuous stream of defect events, each characterised by its position, type, and geometric severity. The operational value of this information depends entirely on how it is presented to the operator and on the time available for interpretation and response. In the SurfConInspect framework, the operator station is not conceived as a passive display terminal but as an active component of the quality control chain—the point at which automated inspection outputs are translated into human decisions that directly affect the process.

In operational terms, the operator station is where measurement becomes judgement. At RAS, the documented setup already reflects a hybrid inspection culture: the inspector supervises the coil in a dedicated inspection area, uses a mirror system, and receives additional information from the inspection system for top and bottom surfaces via two large monitors. This matters because the 3D system is not replacing the operator with a black box. It is changing the quality of the evidence available to the operator. Height and depth information give access to defect relevance in a way a purely visual system cannot, but the operator still remains part of the decision loop in cases where context and experience matter. The station should therefore be described not merely as a display terminal, but as the decision interface of the pickling-line quality-control chain.

On the primary display, detected defect events are represented as coloured markers whose position corresponds to the physical location of the defect on the strip—both in the longitudinal direction, expressed as distance from the coil head, and in the transverse direction, expressed as distance from one or both strip edges. The colour coding of the markers conveys defect class and severity, using a scheme in which the visual prominence of the marker is proportional to the operational urgency of the event: minor events that fall below the threshold for automatic intervention appear as small, low-contrast indicators, while events that exceed critical thresholds are displayed as large, high-contrast markers that stand out immediately within the operator's visual field.

The value of displaying depth, edge distance, and extent is not that these are sophisticated metrics. It is that they correspond to the physical variables that determine whether a topographic defect is tolerable or dangerous. The wider project evidence on dents, abrasions, and shells makes this especially clear. A dent can be visually unremarkable but mechanically severe; an abrasion may look modest in 2D while showing a pronounced 3D profile; a shell may appear shallow at pickling yet become unstable under later thickness reduction. Presenting the operator with quantitative geometry therefore shortens the distance between inspection result and sound industrial judgement. This combination of geometric data and visual representation allows the operator to verify the automated classification, assess the plausibility of the severity assessment, and form an independent judgement about the appropriate response in cases where the automated system has generated an alert without triggering an automatic intervention.

The design of the operator display reflects a careful balance between information richness and cognitive manageability. A display that presents every detected event with equal visual weight would rapidly overwhelm the operator's attention in production environments where dozens of minor events may be generated per coil. A display that presents only the most severe events would deprive the operator of context that is sometimes essential for distinguishing between isolated anomalies and systematic patterns indicating a process problem. The approach adopted in SurfConInspect uses a hierarchical presentation model in which the primary display prioritises the most operationally urgent events, while secondary displays and historical records provide access to the full dataset for operators who wish to investigate the broader distribution of surface quality across the coil.

Automated alerts and the role of audible signals

In a pickling-line operating environment, the operator cannot maintain continuous visual attention on the inspection display. The physical demands of operating a high-speed continuous processing line—monitoring strip tension, adjusting acid concentrations, supervising coil changes, communicating with upstream and downstream facilities—require the operator's visual and cognitive attention to be distributed across multiple tasks and multiple displays simultaneously. An inspection system that relies exclusively on visual alerts to communicate the detection of critical events is therefore inherently limited in its ability to ensure rapid operator response, because the alert may not be perceived if the operator's visual attention is directed elsewhere at the moment it appears.

Audible alerting is one of those seemingly simple interface features that becomes decisive in real production. The project documentation confirms that, in the industrial RAS setup, the inspection system can emit an acoustic signal in the inspection area when a heavy defect is detected. This is not a convenience function. It is recognition of how attention actually works on a pickling line. Operators do not watch one display continuously; they divide attention across the process. A well-designed acoustic signal therefore acts as an attention-capture mechanism, while the visual interface acts as the interpretation layer. Framed this way, audible alerting is not an accessory to the inspection system. It is part of the human factors engineering that makes fast intervention possible.

The audible alert system is tightly integrated with the visual display. When an audible alert is triggered, the corresponding event is simultaneously highlighted on the primary display map with maximum visual prominence, so that when the operator does redirect visual attention to the display, the relevant event is immediately identifiable without requiring a search through the defect record. The combination of audible and visual alerting therefore addresses two complementary aspects of the human-machine interface challenge in high-speed inspection environments: the problem of capturing the operator's attention when a critical event occurs, and the problem of directing that attention efficiently to the relevant information once it has been captured.

The threshold settings that determine when an audible alert is triggered are configurable and are adjusted during the commissioning and fine-tuning phase to reflect the specific process conditions and quality requirements of the line. Setting thresholds too low generates frequent alerts for events that do not require immediate action, leading to habituation effects in which operators begin to discount audible signals as background noise. Setting thresholds too high risks missing events that, while individually below the critical threshold, contribute to a pattern that warrants attention. Finding the appropriate balance is an empirical process that draws on the accumulated knowledge of the inspection system engineers, the quality engineers responsible for defining acceptance criteria, and the operators who use the system in daily production.

In-Line cutting options and operator intervention

The real industrial value of 3D inspection at pickling is that it can support defect removal before downstream failure occurs. At RAS, the operator's documented intervention options already reflect the geometry-sensitive logic of the process: near-edge defects can be removed by edge cutting with electrical scissors, defects at the beginning or end of the coil can be cut out with inline shears, and centre defects may require coil splitting. The SurfConInspect software requirements formalise this further by defining operator recommendations such as edge cut-out, coil splitting, scrap at the beginning or end, or no immediate action when downstream handling is more appropriate. The system is therefore not built around a binary "cut/no cut" philosophy. It is built around a menu of physically and economically distinct interventions matched to defect severity and location.

The decision to cut is one of the most consequential quality interventions available to the operator or to the automated control system. A cut made unnecessarily—because a defect was classified as critical when it was actually tolerable—generates scrap material and reduces coil yield. A cut not made when it should have been—because a critical defect was missed or underclassified—allows the defective material to progress to downstream processing, where it may cause a coil break or a customer claim. The economic consequences of both types of error are significant, and the design of the cutting decision logic in SurfConInspect reflects a careful analysis of the relative costs of false positives and false negatives in the specific context of tin-plate and automotive-grade steel production.

SurfConInspect distinguishes between automated supervisory control and human supervisory control. The SCI framework is intended to generate in-coil control actions both for operators and directly for process systems, while the use-case logic at the pickling line allows quality processors and the online quality supervisor to produce real-time recommendations for the human inspector. This distinction is strategically important. Some events are clear enough to justify strongly automated action paths. Others remain context-dependent and benefit from operator review. For a steel plant, that is often the right balance: automation where time and repeatability are decisive, human judgement where production context still matters.

The practical implementation of in-line cutting involves several operational considerations that are not immediately obvious from a purely technical description of the capability. The cutting station must be triggered with sufficient lead time to allow the mechanical cutting mechanism to be positioned and activated before the defect section reaches the cutting point, which means that the inspection system must detect and classify the defect far enough upstream of the cutting station to allow for this preparation time.

Operator training and system acceptance

The introduction of an advanced inspection system into an operational pickling line is not simply a technical installation project. It is also an organisational change that affects the daily working practices of the operators, the quality engineers, and the maintenance personnel who interact with the system. The success of the installation—in the sense of whether the system delivers the quality improvements it is designed to enable—depends as much on how well the human dimension of this change is managed as on how correctly the technical components are configured and calibrated.

Operator training for a 3D system cannot be limited to interface familiarisation. It also has to address a deeper cognitive shift: moving from visual heuristics to geometric reasoning. The project's own evidence explains why this matters. Many experienced operators have learned to infer severity from how a defect looks in a conventional image. Yet SurfConInspect repeatedly shows cases where the decisive information lies elsewhere. Critical events may appear visually modest, while visually noisy events may prove non-critical once height data are available. Training must therefore help operators understand not only how to use the station, but why depth, edge distance, and profile shape are more reliable predictors of downstream risk than image contrast alone. Acceptance grows when the system's logic becomes intelligible.

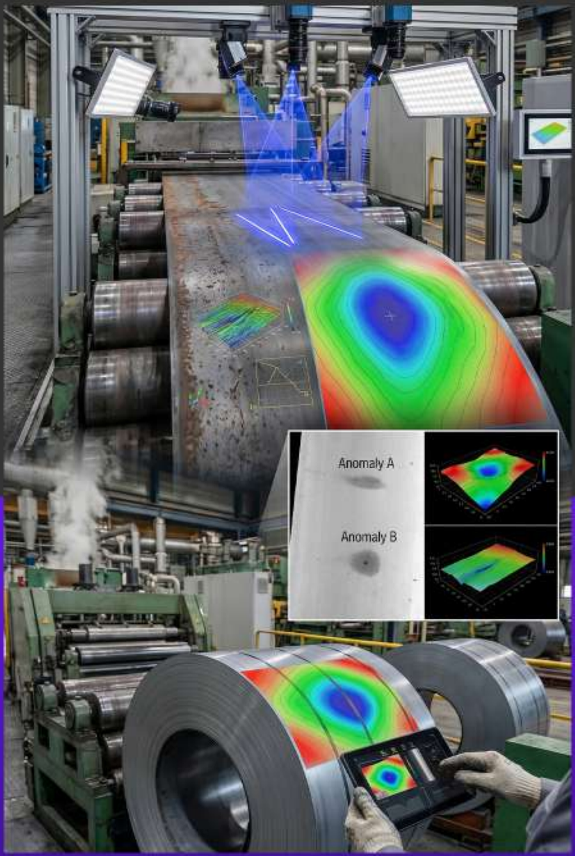
The first training dimension is familiarisation with the inspection display and its information architecture—understanding what the various elements of the map display represent, how to interpret the colour coding of defect markers, how to access detailed defect records, and how to navigate between the primary display and the historical record. This dimension of training is primarily procedural and can be addressed through structured instruction and supervised practice during the commissioning phase of the system.

The second dimension is more conceptual and more demanding: developing an understanding of the relationship between the geometric attributes reported by the inspection system and the physical severity of the corresponding defect in terms of its likely downstream impact. An operator who understands why a dent with a depth of 0.8 mm near the strip edge is more critical than a visually similar feature of the same depth in the strip centre is better equipped to make sound judgements in borderline cases where the automated system has generated an alert without triggering an automatic intervention. This understanding cannot be transmitted through procedural instruction alone. It requires an investment in conceptual education, and it develops progressively through experience with the system in operation.

The third dimension concerns the acceptance of the system's outputs as a reliable basis for decision-making. Operators who have worked with conventional two-dimensional inspection systems for years have developed a set of intuitions and heuristics about what constitutes a critical defect, based on their experience of how visual features in the inspection image correlate with downstream outcomes. A three-dimensional inspection system may challenge some of these intuitions—generating critical alerts for events that appear visually unremarkable, while assigning low severity to events that have a visually prominent appearance—and this challenge can initially be experienced as a source of confusion or distrust. Managing this transition requires active communication between the inspection system engineers, the quality engineering team, and the operators, with a particular emphasis on transparency about the reasoning behind the severity assessment logic and on the accumulation of case evidence that demonstrates the reliability of the system's judgements over time.

Conclusions

Taken together, the elements described in this paper amount to more than an upgraded inspection station. They define a new operational model for surface quality control in flat steel production. The sensor layer captures topography and appearance with complementary channels. The processing layer converts raw measurement into quality events. The decision layer supports cutting, speed adaptation, and downstream handling. The operator interface turns those decisions into timely action. And the broader project perspective extends that logic further, toward recoiling-line support and XR-based visualisation of quality information directly on the coil. This is the real narrative of SurfConInspect: inspection ceases to be a passive after-the-fact observation and becomes an active, process-integrated capability for protecting yield, avoiding downstream crises, and making operator decisions more objective under industrial time pressure.



The physical configuration of the sensor system—with multiple laser triangulation units covering the full strip width on both surfaces, mechanically isolated from the line structure and protected from the environmental effects of the pickling process—establishes the foundation for reliable, continuous measurement at production speed. The real-time data processing chain translates the raw sensor output into a continuous height map from which defect events are detected and characterised with quantitative geometric precision. The integration of the three-dimensional channel with conventional two-dimensional imaging provides complementary sensitivity to topographic and non-topographic surface conditions, addressing the full range of quality-relevant anomalies encountered in pickling-line environments.

The operator station and its information architecture—combining a real-time map display, audible alert signals, and access to detailed defect records—establish the interface through which inspection results are translated into operational decisions. The in-line cutting capability, supported by both automated and human supervisory control, provides the means by which critical defects can be removed from the production stream before they cause failures at downstream processing stages. And the training and acceptance process through which operators develop the conceptual understanding and operational trust required to use the system effectively completes the chain from measurement to action.

The implementation of in-line 3D inspection at the RAS pickling line is not the endpoint of this development trajectory—it is its most advanced reference point to date. The principles established here, from sensor architecture through decision latency to operator interface design, provide the foundation on which the quality processor architecture, the online quality supervisor, and the augmented reality interface described in subsequent papers of this series can be understood in their operational context. Each of those extensions deepens the same fundamental argument: in flat steel production, measurement is only as valuable as the action it enables. A 3D inspection system that captures geometry, communicates it clearly, and translates it into in-time intervention is not merely a better sensor. It is a different approach to quality—one grounded in physics, oriented toward prevention, and scaled for the industrial realities of high-speed pickling-line production.

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