MIPAR
Image Analysis Software

Automating Weld Dimensional Analysis through AI-Driven Image Processing

In manufacturing sectors where safety and reliability are essential, welding inspection is a critical component of production. Welds are structural elements whose performance depends heavily on geometry. In practice, weld dimensions are used to assess quality, directly influencing load-bearing capacity, fatigue life, and long-term reliability. Even minor deviations in critical weld dimensions can compromise structural integrity, making dimensional evaluation a key aspect of quality control.

Weld dimensional assessment is guided by internationally recognized standards. ISO standards such as ISO 5817 and ISO 17639, as well as AWS D1.1 from the American Welding Society, define permissible limits [1-3]. These standards ensure that weld geometry aligns with the structural requirements of the application, providing a framework for both design compliance and safety assurance.

Advances in image processing, microscopy, and artificial intelligence (AI) are transforming welding analysis into a fully automated, data-driven workflow. These technologies enable faster, more consistent, and more precise evaluation of weld geometry and defects. AI-driven image analysis further enhances weld inspection by automating dimensional measurements, defect detection, and quality evaluation.

Challenges in Traditional Weld Inspection

Historically, weld inspection has been a manual process, relying on skilled operators to measure critical features such as throat thickness, leg length, penetration depth, reinforcement height, root penetration and opening, and weld profile geometry (Figure 1). In many cases, internal weld features must also be assessed to verify fusion quality and detect discontinuities that are not visible externally. This often requires cross-sectional analysis, achieved through destructive testing or high-resolution microscopy. Polished weld cross-sections reveal fusion boundaries, penetration depth, and internal defects, providing a detailed view of the weld's structural performance. However, manual inspection is time-consuming, subject to operator variability, and prone to inconsistencies. In high-volume industries such as automotive manufacturing or pressure vessel production, these limitations can significantly impact productivity and quality assurance.

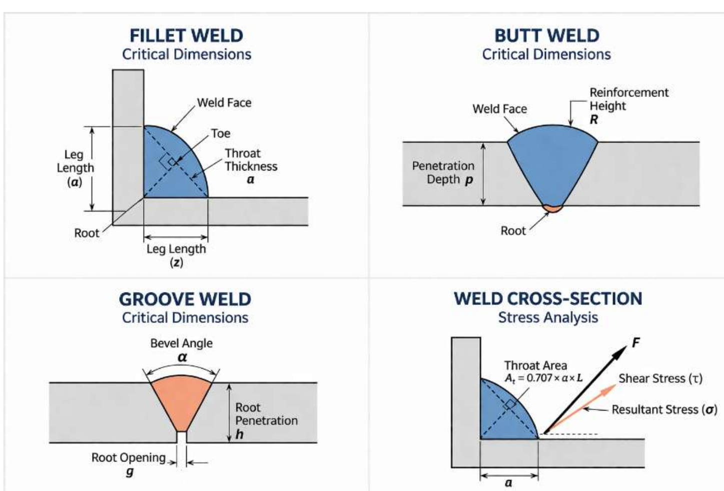


Figure 1. Key weld dimensions, including leg length, throat thickness, penetration depth, and reinforcement height, used to evaluate weld geometry and structural performance.

AI-Driven Weld Analysis and Automated Dimensional Measurements

Advances in AI image analysis, combined with imaging technologies, have transformed weld inspection into an automated process. Digital microscopes can now capture high-resolution images of welds, which are then processed using image analysis algorithms. This enables precise detection of regions of interest such as weld contours, toes, faces, root regions, heat-affected zones, and internal fusion boundaries (Figure 2).

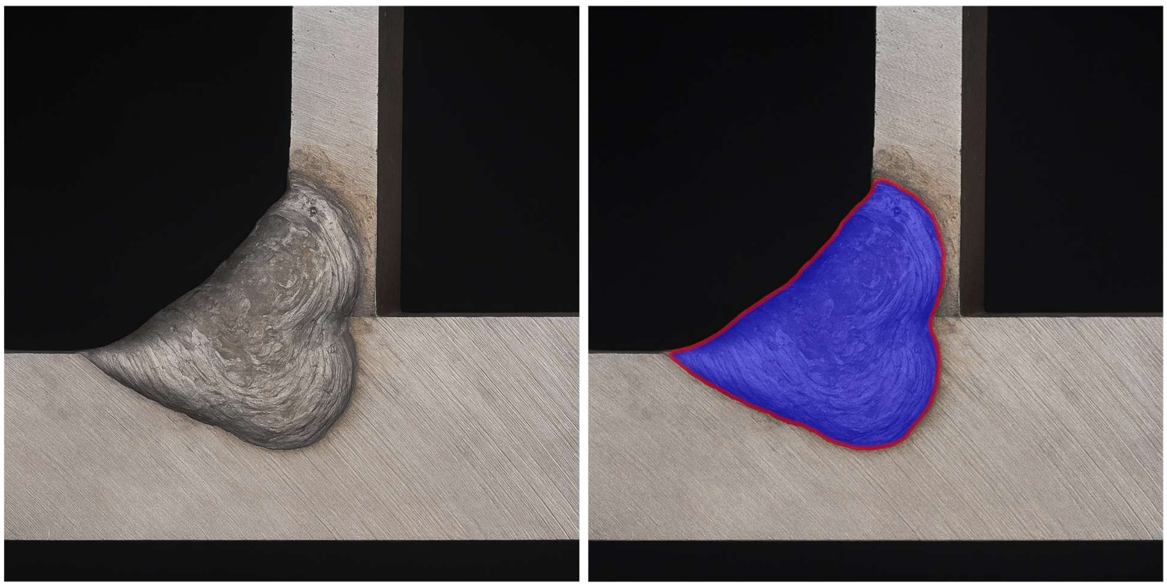
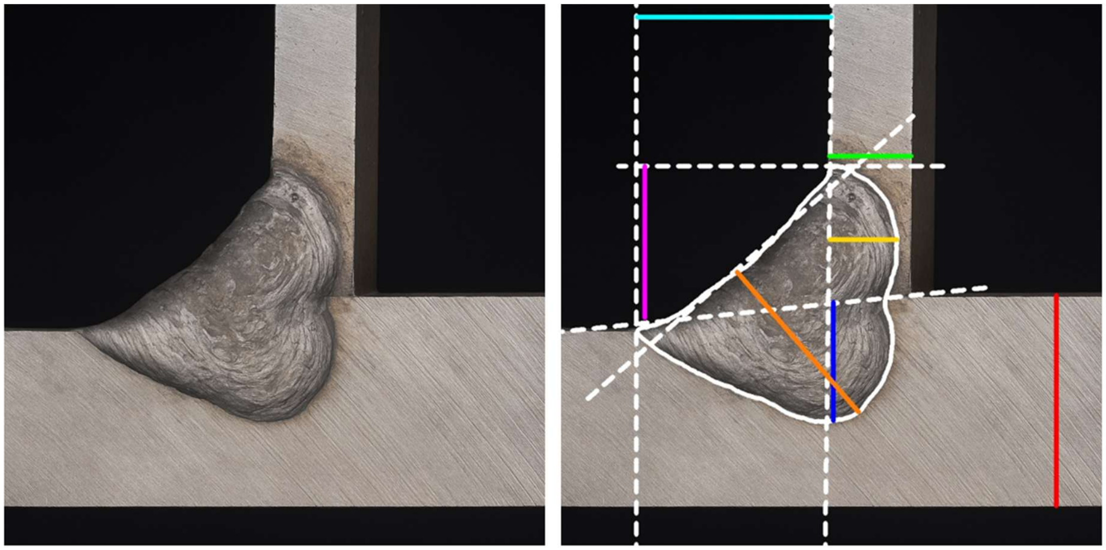


Figure 2. Original weld image and corresponding automated segmentation of the region of interest using image analysis.

Once weld geometry is identified, precise measurements of critical dimensions can be easily extracted. These include throat thickness, leg length, penetration depth, weld width, reinforcement height, and the curvature of the weld face. This automated workflow enables engineers to interpret weld dimensions in accordance with engineering requirements. By automating this analysis, AI provides a consistent and objective evaluation of weld geometry, significantly reducing human error and subjectivity. An example of fillet weld inspection and critical dimensional analysis is shown in Figure 3.



Scale Factor: 0.011135 mm/px
Units: mm

References
[1]
[2]
[3]
[4]
[5]
[6]
[7]

Measurements

Measurement	[1]	[2]	[3]	[4]	[5]	[6]	[7]
(mm)	4.4539	1.7482	2.5165	1.4364	3.9228	4.1087	3.2068
PASS/FAIL	FAIL	PASS	FAIL	PASS	FAIL	FAIL	FAIL

Figure 3. Automated critical dimension and simulated PASS/FAIL analysis of a fillet weld.

Deriving Throat Thickness from Leg Size in Fillet Welds

In fillet weld inspection, standard geometric formulas are used to relate leg size (Z) and throat thickness (a), allowing one dimension to be derived from the other when needed. Specifically, $a = 0.707 \times Z$ and $Z = 1.414 \times a$ describe this relationship. It is important to note that these formulas apply only when both legs of the fillet weld are equal in length, ensuring accurate interpretation of the weld geometry.

This calculation process can be fully automated in MIPAR using Customer Measurements. These custom measurements allow for user-defined formulas and mapping to existing image features. Once weld geometry is detected and key dimensions are measured, the formulas can be applied automatically, with the resulting values seamlessly included in inspection reports.

Weld Quality Evaluation and Defect Detection

Automated weld inspection systems do more than measure dimensions—they also evaluate whether a weld meets pass/fail criteria derived from engineering design and industry standards. Deviations from these thresholds may indicate potential performance issues, such as reduced load-bearing capacity, increased stress concentration, or decreased fatigue resistance.

In addition to dimensional evaluation, AI image analysis systems can detect and classify common weld defects, including porosity, cracks, lack of fusion, undercut, and overlap. By combining dimensional analysis with defect detection, engineers obtain a comprehensive assessment of weld quality, an objective and detailed evaluation that would be difficult to achieve manually.

Reporting and Data Integration

One of the key advantages of AI-driven weld analysis is its ability to generate automated reports. These reports can include measured dimensions, cross-sectional analysis results, pass/fail evaluations, detected defects, and statistical trends across production batches. Integration with quality management systems and digital manufacturing platforms enables full traceability for each weld, supports faster decision-making, and facilitates continuous improvement in production processes. Customizable reporting formats also allow engineers to efficiently meet certification, auditing, and process optimization requirements.

Implementation and Conclusion

Implementing automated weld analysis requires a combination of imaging systems and AI image analysis software. These systems support both surface and cross-sectional evaluation, providing a complete assessment of weld integrity. By embedding engineering principles into automated workflows, modern systems ensure that critical weld dimensions are measured accurately, quality is assessed consistently, and compliance with standards is maintained.

In conclusion, AI-driven weld dimensional analysis represents a major advancement in manufacturing quality control. By automating measurement, defect detection, and reporting, engineers can achieve higher productivity, improved consistency, and greater confidence in weld performance. This approach ensures that every weld meets the required dimensional, structural, and quality criteria, ultimately enhancing both safety and efficiency in production environments.

References

1. International Organization for Standardization (ISO). *ISO 5817:2014 – Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections.* Geneva: ISO, 2014.

2. International Organization for Standardization (ISO). *ISO 17639:2013 – Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds.* Geneva: ISO, 2013.
3. American Welding Society. *AWS D1.1/D1.1M:2020 – Structural Welding Code — Steel.* Miami, FL: American Welding Society, 2020.