The evolution of cosmetic inspection

From human supremacy to hybrid intelligence

Artificial intelligence (AI) has dramatically evolved across various industries, from gaming to manufacturing. A striking example is chess, where AI transitioned from rudimentary programs weaker than humans in the 1950's to AlphaZero's unprecedented dominance in 2017. This evolution mirrors the progress in cosmetic inspection of ophthalmic lenses, where machines are moving from simple assistance to eventual full automation. *By Dr. François Van Lishout*

Today, the industry stands in the second era, where machines outperform humans in detecting certain defects but still require human oversight. This article explores how hybrid-AI strategies can optimize today's processes while paving the way for full automation.

Automation in lens manufacturing is not just about efficiency; it also impacts quality control, cost reduction, and scalability. The push towards automation originates from the growing demand for precision and consistency in lens production.

Optical laboratories and manufacturers are increasingly relying on intelligent systems to reduce human intervention while maintaining high accuracy. Understanding the different phases of AI's evolution in this sector provides a roadmap for future developments.

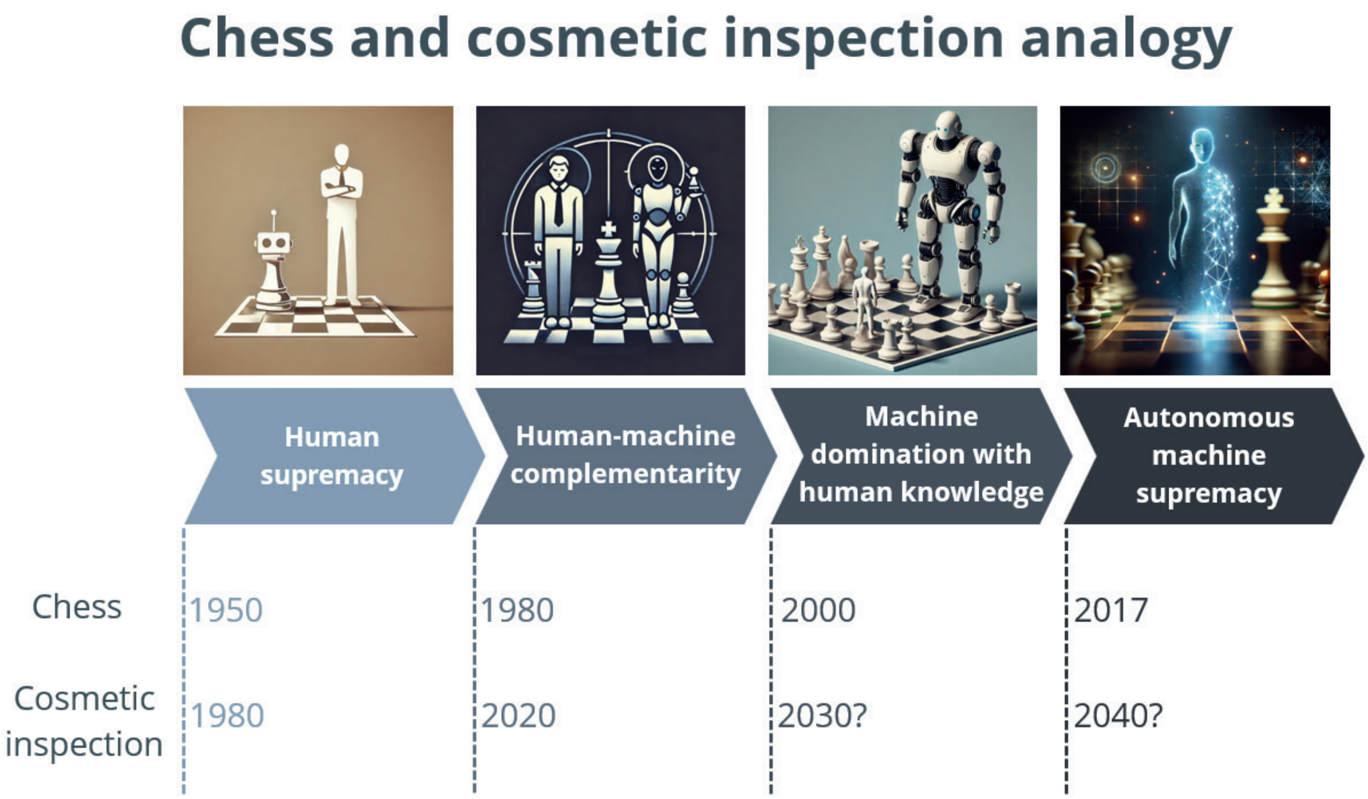

Fig.1 : *AI evolution in chess and cosmetic inspection.*

The evolution of AI: from chess to cosmetic inspection

AI evolution can be understood through four distinct eras, as illustrated in figure 1.

Human supremacy
(1950s in chess, 1980s in cosmetic inspection)
In the early days of chess AI, human players vastly outperformed machines. Similarly, in the 1980s, machines for cosmetic inspection existed but were far too inaccurate for real-world production. Human inspectors remained the only viable solution for detecting lens defects.

Human-machine complementarity
(1980s in chess, 2020s in cosmetic inspection)
By the 1980s, chess programs had become competitive in certain areas, such as calculating deep tactical combinations, while still lagging in overall strategic understanding. The same trend is now occurring in cosmetic inspection. Machines can detect certain types of defects more consistently than humans, but human expertise is still required to verify complex cases.

Machine domination with human knowledge
(2000s in chess, future of cosmetic inspection ~2030?)
In the early 2000s, chess engines like Deep Blue and Stockfish dominated human players but still relied on human-engineered evaluation functions. Similarly, by 2030, machines may surpass humans in all aspects of cosmetic defect detection but still use rules and models shaped by human expertise.

Autonomous machine supremacy
(2017 in chess, future of cosmetic inspection ~2040?)
In 2017, AlphaZero revolutionized chess by learning entirely on its own, without relying on human knowledge. The future of cosmetic inspection could follow the same trajectory, where AI systems optimize decision-making based on vast datasets, predictive maintenance, and customer feedback, eliminating human intervention altogether.

Hybrid-AI strategy

To bridge the gap between human expertise and machine automation, a hybrid-AI approach is essential. Our goal is to provide a solution that maximizes today's machine capabilities while enabling the transition towards full automation.

A purely AI-based approach, where an AI model is trained on human decisions, presents several challenges. It requires extensive retraining when production changes, lacks transparency, and inherits human errors, preventing it from exceeding human performance.

A black-box AI system with limited interpretability poses risks in production settings, where understanding the decision-making process is crucial for quality assurance.

In contrast, our hybrid-AI strategy leverages both image processing techniques and AI, but primarily relies on a rule-based approach for defects.

The defect detection library was developed by our provider IOT, while Automation & Robotics was responsible for all other aspects, including the machine itself, the decision rules, and the optimization of acquisitions to maximize defect visibility.

This approach ensures adaptability through simple parameter adjustments rather than time-consuming AI retraining. It also provides explainability, allowing quality teams to understand and improve the system over time. The method is grounded in expert-defined defect criteria, making it a structured and verifiable solution with the potential to evolve into full automation.

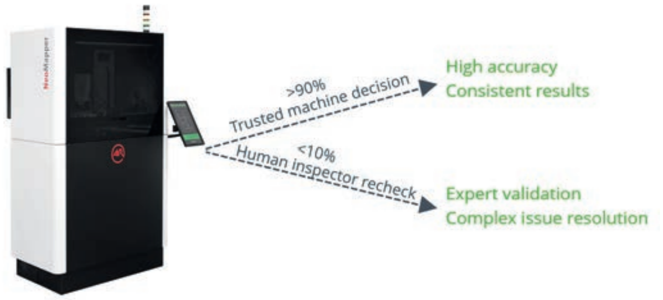

Fig. 2: *Diagram illustrating the hybrid-AI decision process in lens inspection. The majority of decisions (>90%) are made automatically with high accuracy and consistency, while complex cases (<10%) are reviewed by human inspectors for expert validation.*

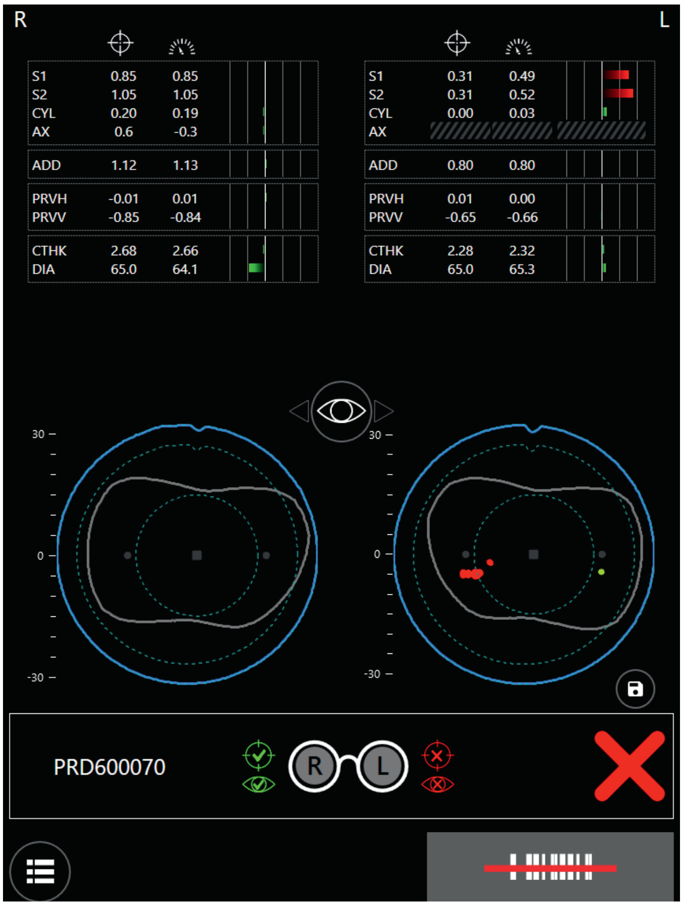

Fig. 3 : *Full lens inspection. Metrology results displayed at the top, cosmetic inspection in the middle, and a summary of the decisions at the bottom. Blue represents the lens edge, grey indicates the cut lens edge, red marks rejecting defects, and green denotes non-rejecting defects.*

Implementing hybrid-AI in practice

The implementation of hybrid-AI follows a two-phase approach. The first phase involves a tuning period, where quality managers validate machine decisions over a short period of time. This allows for fine-tuning parameters to match production requirements.

During this phase, the system does not replace human inspectors but acts as an advisor. The feedback loop created between the machine and inspectors is essential in refining the machine's decision-making process. The more interactions the machine undergoes, the better it becomes at distinguishing acceptable lenses from defective ones.

The second phase transitions to automated inspection, where machines make definitive decisions for at least 90% of lenses. The exact figure depends on the prevalence of the lab. The remaining cases are reviewed by human inspectors, ensuring accuracy while minimizing human workload. At this stage, reliance on human intervention is greatly reduced, leading to increased efficiency and reliability in defect detection.

For enhanced inspection, full lens inspection can be used. This approach combines both metrological and cosmetic inspection within the same machine, ensuring a comprehensive evaluation of each lens. The metrological inspection assesses lens parameters such as curvature, thickness, prism, addition, shape, mapping, polarization axis, and optical power, while the cosmetic inspection detects surface defects that could impact lens quality.

Figure 3 illustrates how the system processes the lens, identifying rejecting defects (red), non-rejecting defects (green), and areas where specific decision thresholds apply. This integrated approach enhances consistency, minimizes subjectivity, and allows manufacturers to maintain high-quality standards with a single automated solution.

Experimental validation

A real-world study conducted at a UK client facility demonstrated the impact of machine-assisted inspection. Without assistance, human inspectors rejected 1.6% of lenses. With machine support, this rate increased to 3.5%, aligning closely with the estimated defect prevalence of 3.7%. This suggests that machine-assisted inspection doubled the accuracy of defect detection, leading to a 50% reduction in defective lenses reaching customers.

Further testing was conducted with two prototypes deployed in German and UK facilities. To objectively assess the performance of the hybrid-AI system, we used six key metrics:

True positive rate (TPR): Measures the proportion of actual defects correctly identified by the system. A high TPR indicates that the system effectively detects defective lenses.

True negative rate (TNR): Reflects the proportion of non-defective lenses correctly classified as defect-free. A high TNR ensures that good lenses are not mistakenly rejected.

Defect prevalence: Represents the estimated proportion of defective lenses in a batch, providing context for interpreting detection performance.

False omission rate (FOR): Indicates how often defective lenses are incorrectly classified as defect-free. A low FOR is crucial to minimizing the number of defective lenses reaching customers.
Yield: The percentage of lenses passing inspection. A higher yield indicates fewer false rejections and efficient screening.
Human review rate: The proportion of lenses requiring manual validation. Lower values reflect a more autonomous and reliable AI system.

Metric	Prototype 1	Prototype 2
True positive rate	90.0%	89.2%
Ture negative rate	94.4%	99.8%
Defect prevalence	5.0%	3.7%
False omission rate	0.6%	0.4%
Yield	90.1%	96.5%
Human review rate	9.9%	3.5%

The results demonstrated significant improvements in defect detection accuracy, yielding high true positive and true negative rates while maintaining low false omission rates. The number of defective lenses reaching customers was reduced by a factor of 10 compared to an unassisted process, highlighting the effectiveness of hybrid-AI. The table above summarizes the performance of two prototype systems tested in Germany and the UK.

The high true positive and true negative rates demonstrate the effectiveness of hybrid-AI in accurately classifying both defective and non-defective lenses. The low false omission rate ensures that very few defective lenses go undetected, improving product quality. The significant reduction in human review rates, particularly in prototype 2, highlights how the system minimizes manual workload while maintaining high precision.

Conclusion

The integration of hybrid-AI in cosmetic inspection has successfully addressed industry needs, improving defect detection accuracy while maintaining operational efficiency. The combination of human expertise and machine analysis has proven to be a powerful approach, reducing the number of rechecks and significantly minimizing defective lenses reaching customers.
As the technology evolves, the potential for reducing human intervention further increases. The transition to fully autonomous inspection systems will require continued research. Nonetheless, hybrid-AI serves as a critical stepping stone, providing immediate benefits and setting the foundation for future advancements in ophthalmic lens inspection. Manufacturers that embrace hybrid-AI now will be well-positioned for the next wave of automation, ensuring both quality and efficiency in an increasingly competitive market. ◆

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