The Mining Eye at the Scale of the Invisible: Challenges of Artificial Vision and Deep Industrial Inference

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In highly complex process engineering, the transferability of intelligence is redefining the frontier of automation. For decades, industry operated under the assumption that scale-related problems were isolated hardware challenges, assuming -for example- that detecting millimeter-scale impurities in iodine and recognizing massive metal objects in copper did not share the same technical DNA.

A study developed by Raymi Vásquez, Technology Manager at STGI Mining, as part of his doctoral research in the Department of Mechanical Engineering at the University of Chile, addresses the use of vision and explainable artificial intelligence for the continuous monitoring of mining processes. The central challenge is to expand operational observation capabilities through camera- and AI-based systems capable of monitoring hard-to-access points, highly complex areas, or processes where permanent human supervision is limited.

In these environments, AI enables continuous detection of visual anomalies, even under adverse conditions such as dust, vibrations, lighting changes, and motion blur, where the human eye is no longer a sufficient metric for ensuring operational certainty.

Automation as an Imperative for Safety and Industrial Impact

A critical question arises in the current debate on underground mining: Why is automation becoming vital today? The answer goes beyond operational efficiency. According to reports from institutions such as Sernageomin, 2025 recorded a 60 percent increase in fatalities compared with the previous year, concentrated in high-exposure areas. Faced with complex geomechanical phenomena such as "planchoneo" (rock slab falls) or rockbursts, Codelco strategic documents emphasize autonomous monitoring as a means of removing personnel from risk zones.

From an engineering perspective, the industrial motivation for automating these processes is critical: anomalous objects can compromise final product quality, reduce operational continuity, and cause catastrophic damage to critical equipment. Vásquez's research addresses this issue through two case studies selected to evaluate technological transferability: Case A, which detects anomalies on an iodine packaging line, and Case B, which identifies large metal objects at the discharge of a bucket-wheel reclaimer. Both demonstrate that, although scales and backgrounds differ, the industrial detection problem can be addressed within a common framework.

Enabling Conditions: Methodology and the End of the Black Box

To address the challenges described above, Vásquez proposes an algorithm structured as a workflow. Success depends on a reproducible workflow based on YOLO (real-time visual detection) and executed through Edge AI (AI running on site, close to the process). The key lies in camera geometry, effective spatial resolution, and the definition of the region of interest (ROI), designed according to the expected trajectory of the anomaly.

The technical process involves acquiring industrial RGB images to train a YOLO detector that analyzes the stream frame by frame. Scale management is essential: cropping and tiling are used for small targets, while inference with a global field of view is used for large targets. To ensure system reliability, a persistence filter is applied: an alert is triggered only when the artificial intelligence is highly confident in what it detects and the image remains stable across several consecutive video frames.

The Value of Integration and Results Analysis

The technical response to the integration challenge lies in Predictive Maintenance (PdM). Reports from iSE-Academy and Gerens highlight that artificial intelligence now acts as a brain

capable of processing up to 5.4 TB of data per day. For technical decision-makers, real value is consolidated through Explainable Artificial Intelligence (XAI), where the operator can audit model confidence and event persistence.

The operational evaluation of these systems combines precise engineering metrics: precision to quantify selectivity and prevent false alarms, recall to ensure sensitivity to critical failures, and latency to measure the real-time response between capture and alert. The results of this study confirm that transferability is feasible when the detection objective is preserved and only the image configuration and scale management are adapted, allowing the same model to be effective across completely opposite visual regimes.

From Concept to Implementation: The STGI Mining Approach

This scientific vision has been validated by STGI Mining in the field at operations of leading companies in the Chilean mining industry, addressing real challenges involving complex industrial assets and processes. STGI Mining is a technology innovation company that does not sell software or sensors separately: it develops complete end-to-end operational intelligence solutions.

Our methodology covers the entire project life cycle: from the initial design of sensing and custom optics, through the implementation of IP67 industrial hardware and advanced AI models, to continuous predictive monitoring through real-time dashboards.

By integrating hardware, software, and explainable predictive inference (XAI), STGI Mining designs technological ecosystems that make it possible to anticipate failures, reduce unplanned downtime, and improve operational safety. Only through this integrated engineering approach is it possible to ensure that the mining eye never blinks before the invisible, transforming risk into the certainty of operational continuity.

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