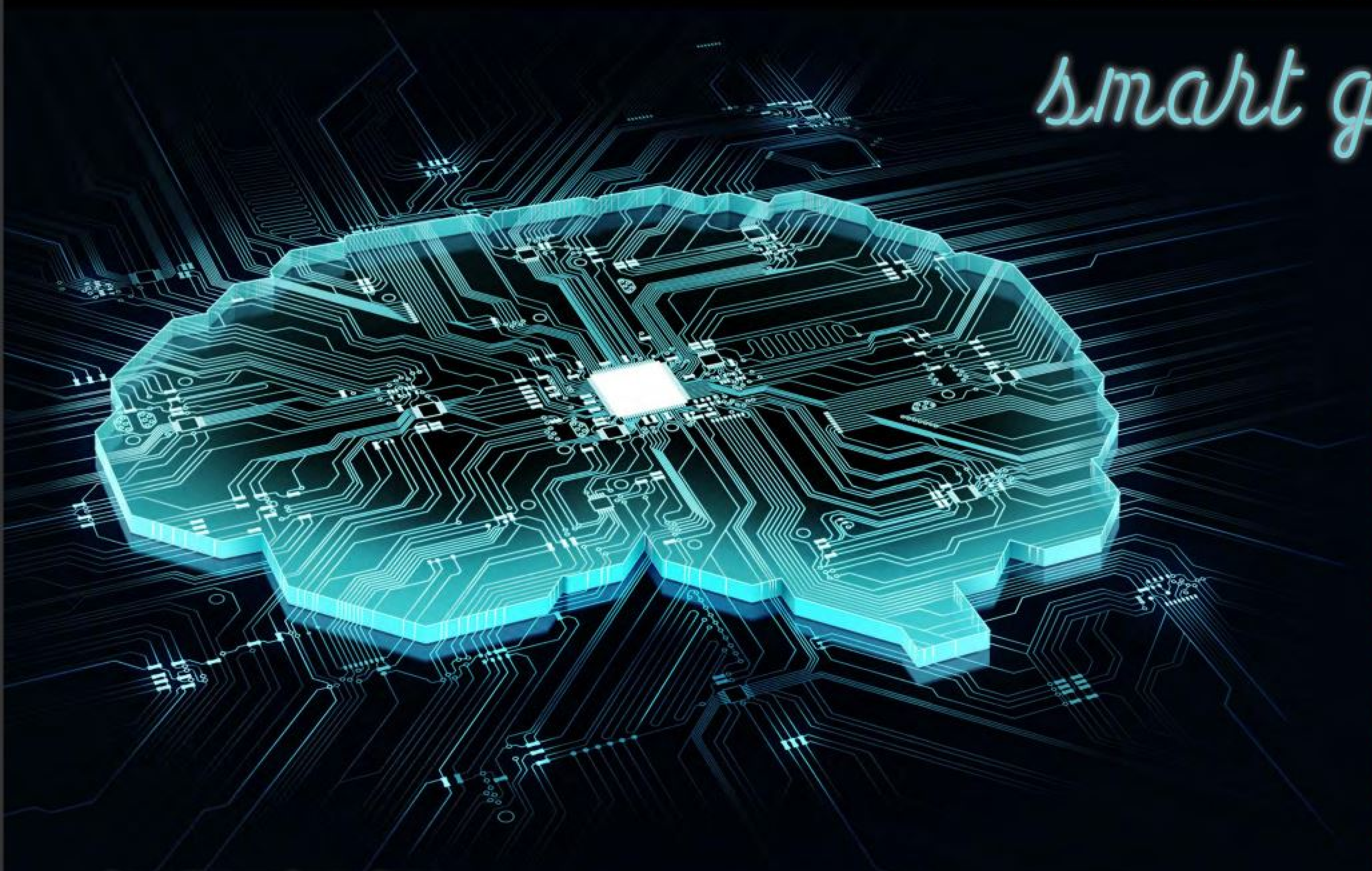
Smart thinking, smart grinding



Rupert Kirchner, Cemtec-Digital, explains how data science is being harnessed to unleash the potential of smart grinding solutions.

A network of increasingly complex difficulties and opportunities sits at the heart of the mineral raw materials processing sector. Navigating this landscape entails overcoming numerous obstacles, such as the rapid growth of market regulations. With new standards and demands appearing on a regular basis, businesses must remain adaptable to keep up with these changes. Falling behind is not an option. It is a path that will eventually lead to irrelevance and extinction.

The growing scarcity of trained workers complicates this dynamic. Companies need people who can oversee complex production processes, people who can balance efficiency and quality against the backdrop of a continuously changing landscape, now more than ever. As if that was not challenging enough, these professionals also need to handle a constant deluge of operational data.

Faced with a vast sea of information, even the most seasoned operators can feel overwhelmed. This reality often forces them to adopt higher operational safety margins, a decision with a double-edged impact. While it ensures the continuity of plant operation, it can lead to significant fluctuations in product quality and a marked reduction in plant performance. Safety, while necessary, comes at the expense of efficiency.

Layered onto these internal challenges are external pressures. The global focus on environmental sustainability is increasing, and businesses are expected to modify their processes in response. Reduced carbon footprints and more energy-efficient operations have become a non-negotiable requirement rather than a value-add. To navigate these various layers of complexity, both invention and resilience are required.

In this challenging landscape, the potential of smart grinding emerges, offering a beacon of hope. With its promise to transform traditional methods through the application of data science and machine learning, smart grinding is a novel approach for controlling dry grinding and sifting circuits.

Harnessing data science for intelligent control

Cemtec-Digital, which was launched in 2022 by the Cemtec Group to provide a central contact point for digital solutions, tackles industry challenges with an approach rooted in the belief that data is not just a by-product of operations, but a valuable resource. Leveraging data science and machine learning, this approach is changing the way dry grinding circuits are controlled and managed.

A digital twin – a virtual version of a real-world grinding plant – was created as part of this data-driven strategy. Serving as a safe simulation ground, this digital twin enables the testing of various operational scenarios, outcome analyses, and impact forecasting without interfering with real-world operations.

However, the potential of a digital twin is increased when it is combined with cutting-edge machine learning techniques such as reinforcement learning. This technique is akin to training a pet, in that positive behaviours are reinforced while negative habits are penalised. Over time, the pet learns to maximise positive actions and minimise negative ones.

Similarly, a reinforcement learning algorithm functioning within the digital twin's environment is trained through an action-feedback loop. Depending on the outcome of the actions taken, the algorithm receives rewards or penalties. This iterative process allows the algorithm to learn and adapt over time, gradually recognising the actions that yield the most positive results.

The power of adaptability

The key to unlocking the full potential of a digital twin lies in the design of the models used. The aim is to create universally applicable models that can seamlessly adapt to various plant conditions.

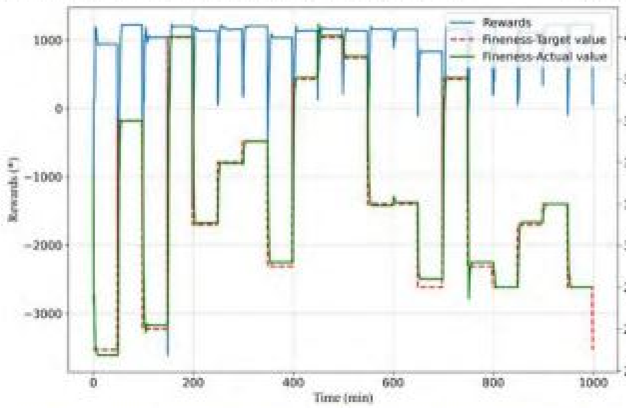


Figure 1. Dynamic reward curve and regulation quality for the Smart Grinding Controller – a testament to real-world adaptability and efficiency.

To realise this, universally applicable input features – measurable characteristics or properties – are utilised. These include the feed material's recipe, the mill's drawn power, the target and actual particle distribution of the product, and the quantity of reject material recycled into the grinding process.

Cemtec-Digital's reinforcement-learning algorithm uses these inputs to optimise plant performance, adjusting in real-time to maintain operational efficiency. With each operational cycle, this learning controller undergoes continuous improvement, effectively reducing energy consumption and maximising product quality.

The output features, which are the control variables that the model is designed to influence, encompass the feed rate of the fresh material to the mill, the speed of the mill's dedusting fan, and the separator setpoints.

The ability to adjust these variables in response to the changing conditions within the plant underscores the commitment to adaptive, efficient, and high-quality plant operations.

Adaptive and efficient control through data-driven algorithms

The Smart Grinding Controller is not just a theoretical concept – it is a proven, effective system for real-world cement grinding operations. Built on a solid foundation of data science and machine learning, the controller was rigorously trained using historical data from a client in the cement industry.

Real-world adaptability and efficiency

The controller was put to the test in a dynamic, high-stakes environment. Using a customised digital-twin-based simulation, its performance was assessed under varying operational conditions. New setpoints for material mixture and target particle size were triggered every 50 minutes. The controller swiftly adapted to these changes, optimising plant control parameters to meet the new conditions (Figure 1).

Results

In a plant with a maximum feed rate of 30 tph, the highest theoretically achievable reward of the reinforcement environment is 1400 points. A deviation as slight as 1 µm from the product fineness can drop the potential reward down to 400 points. During testing, the controller not only maintained a minimum of 800 points but also averaged over 1000 points. This level of performance showcases the controller's effectiveness and capability to maintain optimal grinding operations even under shifting conditions in the simulation environment.

Controller dynamics and adaptability

While theoretical models are compelling, the true test of the Smart Grinding Controller's effectiveness lies in its performance under real-world operational challenges. With this in mind, the Cemtec-Digital team carried out a comprehensive set of simulations, mirroring a wide array of operational scenarios, to assess the robustness, adaptability, and resilience of the derived reinforcement learning policies.

A case study in dynamic adaptability

One noteworthy instance that exemplifies the controller's adaptability involved a recipe change with a drastic shift in target product fineness – from 35 µm to 25 µm (Figure 2). Utilising the reinforcement learning policy, the controller adapted swiftly. Within a short timeframe, it managed to stabilise the new setpoints, aligning closely with what would be expected in a real-world industrial context. The controller also promptly adjusted other key operational parameters such as the feedrate and the speed of the mill's main fan to achieve optimised operational levels.

Operational insights

The recirculating load increased from 55% to 120% during this change, aligning with both theoretical expectations and practical observations. The controller also judiciously modulated the rate of fresh material fed to the mill, striving to operate as close as possible to the circuit's maximum capacity of 120 tph. Such nuanced control fulfils auxiliary goals, such as elevating the plant's performance to peak levels of efficiency and sustainability.

A promise for future application

The encouraging results from these rigorous simulations solidify Cemtec-Digital's confidence that the Smart Grinding Controller is more than capable of meeting the stringent requirements of a real-world, industrial-scale environment.

From simulations to real-world application

Adapting a new behaviour involves starting in a controlled environment before testing in real-world scenarios. The reinforcement learning algorithm's training is initially conducted within the controlled environment of the digital twin. By simulating an array of operational scenarios, the learning algorithm refines its understanding of the grinding circuit and the influences of its actions on the system.

However, the ultimate test is found outside of the digital twin. The purpose of the first industrial test is to demonstrate how a machine learning-based method can increase operational efficiency and sustainability in real-world grinding circuits.

Conclusion: embracing the future of the processing industry

Navigating the challenges and opportunities in the processing industry requires more than resilience and adaptability. It necessitates a commitment to innovation and the courage to challenge the status quo. Cemtec-Digital believes that its data-driven approach represents this commitment.

In combining digital twin technology with advanced machine learning methods like reinforcement learning, the boundaries of what is possible in cement grinding are being pushed. This is resulting in the development of intelligent, self-adapting systems capable of increasing operational efficiency, reducing energy consumption, and driving sustainability. ■

About the author

Rupert Kirchner holds a Master's degree in Mineral Processing from Montanuniversität Leoben and in Business Administration from LIMAK. With extensive experience in mineral processing, Rupert has a strong focus on developing emerging technologies for the industry. He is currently at the forefront of innovation at Cemtec-Digital, a specialised hub within the Cemtec group, dedicated exclusively to the research and development of emerging technologies for the mineral industry, founded just a year ago.

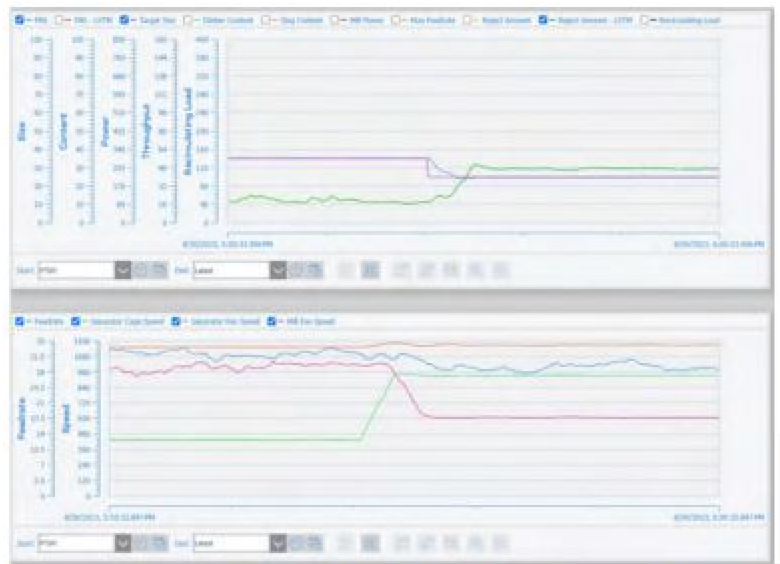


Figure 2. Trends showcasing changes in recirculating load and other operational parameters during a shift in target product fineness.