Artificial Intelligence Applications in Aggregate Quarries: A Reality

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***Abstract*—**The development of Artificial Intelligence services in mining processes, specifically in aggregate quarries, is facilitating automation and improving numerous aspects of operations. Ultimately, AI is transforming the mining industry by improving efficiency, safety and sustainability. With the ability to analyze large amounts of data and make autonomous decisions, AI offers great opportunities to optimize mining operations and maximize the economic and social benefits of this vital industry. Within the framework of the European DIGIECOQUARRY project, various services were developed for the identification of material quality, production estimation, detection of anomalies and prediction of consumption and production automatically with good results.

***Keywords*—**Aggregates, artificial intelligence, automatization, mining operations.

I. Introduction

DIGITALIZATION and artificial intelligence are two tools that are transforming society, especially production processes. In this sense, its application in mining is essential for the best efficiency of the exploration, extraction and treatment of raw materials, which will result in numerous aspects, such as the optimization of work, reduction of energy costs, improvement of safety, etc.

In the last years, research has been developed related to the digitalization of aggregate extraction and treatment processes. A coordinated approach was undertaken with the ultimate goal of reducing the EU's dependence on external supply as well as leading efficient use of resources. The research developed systems, technology and processes for integrated digitalization and real-time automation process control, which was implemented in five quarries of various characteristics. The development of an innovative smart extraction system is increasing the sustainable supply of minerals for the construction sector and enabling the sustainable extraction of the mineral resources in new and existing quarries.

In this regard we designed, developed and validated an Innovative Quarry System (IQS) comprising sensors, processes, tools and methods for data capture, processing and exchange to provide digitalized, automatic and real-time integrated process control for aggregate quarries. This results in:

1. Improving the safety, health and protection conditions of workers, avoiding their exposure to dangerous operations through automated and controlled processes.
2. Improving the selectivity and efficiency of aggregate quarries, thus increasing the profitability of extraction processes, ensuring long-term operational sustainability.
3. Maximizing sustainability and resource efficiency in quarry operations by reducing emissions, improving water management and encouraging a sustainable supply of raw materials to feed new and existing value chains, closing mineral cycles and guaranteeing long-lasting production.
4. Improving social acceptance through communication with policy makers, citizens and relevant actors to involve them in the value chain. Likewise, international cooperation is being worked on within the EU, but also outside it, to share knowledge and best practices and improve the general perception of the quarrying industry.

The new technologies were developed in five quarries with different characteristics to ensure that the results are representative and transferable, with a market-oriented approach. It should be noted that they are covering all key processes in the exploitation of a quarry, from the preparation and exploitation of the material, through extraction and processing to environmental and business management, preserving the circular economy and social innovation approaches.

With all this, the aim was to lead the improvement of process efficiency by maximizing quarry resources and the sustainable management of water, energy emissions, minimizing environmental impact and expanding the construction and aggregates business. The combination of artificial intelligence approaches with cyber-physical systems and the concept of the Internet of Things makes the Industry 4.0 approach possible and the smart and sustainable extractive site a reality. Artificial intelligence was used to close the circle around the optimization of a digital quarry, allowing information to be an asset in economic, environmental or human terms since it will automatically evolve and improve over time.

II. Development of Artificial Intelligence Services

For the development of artificial intelligence (AI) services,

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meetings were held with the companies responsible for the exploitations to identify needs and expectations. Formal descriptions were presented and the opinions and requirements of the different actors were collected. Based on the feedback, updated definitions of AI services were designed and agreed upon in order to better adapt to the real needs of the quarries with respect to the objective of improving the different processes using AI technologies. These AI services that were being developed included: 1.-Quality determination of aggregates by colorimetry; 2.-Determination of grain size; 3.-Calculation of the volume of exploited material; 4.-Prediction of mechanical anomalies; 5.-NLP Information and Document Search Engine (MetaQuarry); 6.-Prediction of consumption and production. A detailed overview of AI services was provided, including the main applications and objectives of each service and how they improve the efficiency of quarry operations, including reducing energy costs, increasing profits, improving health and safety and emissions reduction.

A. Evaluation of the Quality of the Material by Colorimetry

This service aims to estimate the quality of aggregates (composition) on the production line using visual information captured by cameras, together with other external data, such as weather information. The system is non-intrusive and allow maximizing the execution of the mining process [1], [2], improving plant planning and controlling the grinding process. It also supports push notifications and maintain a historical log to further analyze the data. The information is collected and processed to keep the mine in production, promoting direct actions on operations.

The main application of this AI service is focused on limestone quarries in which the presence of clay represents a problem. Since, in general, the color and composition of both lithologies is different, the automatic identification through the use of fixed cameras of the percentage of limestone and clay was used to solve this important problem (Fig. 1).

Previously, samples of different lithologies were analyzed using X-ray diffraction and spectrophotometry to determine the most appropriate characteristics that the cameras should have, as well as the parameters that served to identify the lithologies more clearly.

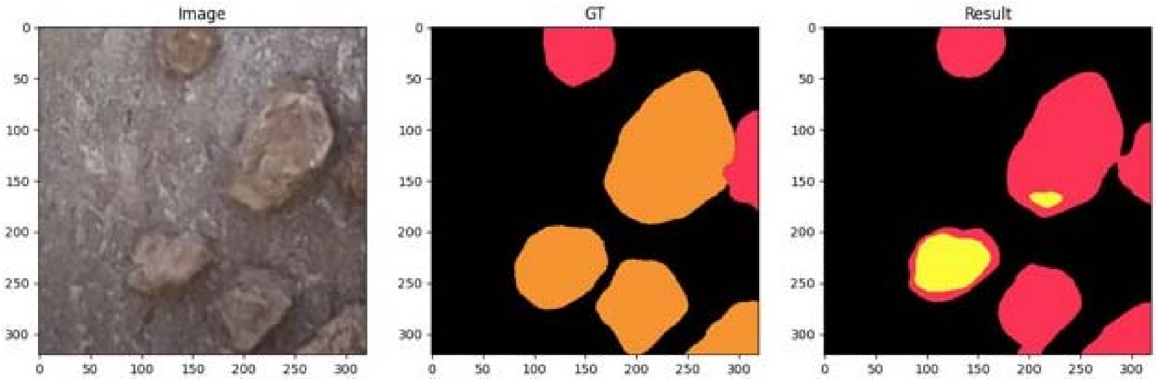

Fig. 1 Detection of the quality of the material based on colorimetry: segmentation and classification of the algorithm process

B. Grain Size Determination by Computer Vision

The grain size determination service aims to analyze visual information to estimate the size of rock fragments [3] extracted from quarries. The system measures the granulometric distribution as it passes through the conveyor belts once processing has finished with the aim of detecting oversized material and evaluating the uniformity of the grain (Fig. 2), which, in turn, reduces damage in the crushing process, maximizes the efficiency of the mining process, and improve the quality of the final product, without interfering with the routinary mining operations.

In brief, this AI service automatizes the process of determining whether the treated material meets technical specifications. By analyzing the screening efficiency, it can quickly identify any issues with the screening process. This allows for timely repairs or replacements of screens, ensuring the proper functioning of material treatment processes. For this purpose, computer vision techniques were used by installing cameras in the conveyor belts located after some screens.

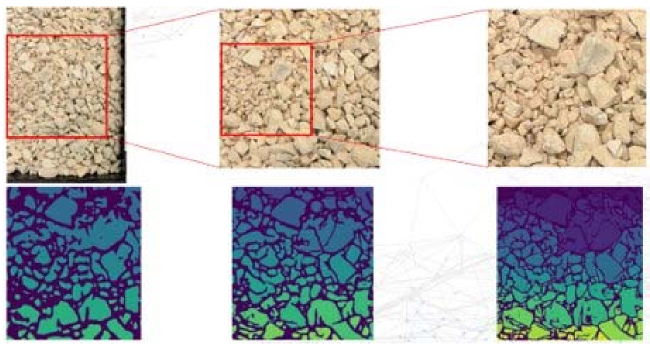

Fig. 2 Determination of grain size using visual data taken by cameras.

C. Stock Pile Volume Calculation

This service aims to integrate visual and data inputs to estimate the volume of material in the different piles of the plants [4], allowing operators to keep track of the stock available throughout the quarry. This knowledge also helps the optimization of production based on stock level and provides insights to other advanced AI services. The stock volume aims not only to obtain a static result but also to track the current volume and its evolution. This means that the estimate is a single numerical value from an independent run that describes a time series showing the evolution of the stock.

To evaluate the best methodology and its cost, the volume of the piles was calculated using three different data sources: drone flights, multi-camera images of the piles and satellite images. The three approaches were compared and evaluated in terms of accuracy and other variables, such as cost and speed of data acquisition, taking into account the needs and conditions of the sites.

Drone flights are considered a fast and low-cost way, offering high precision in the results [5] and were used as a reference to compare with measurements with the other methods (Fig. 3). At the same time, videos were recorded using three cameras located 30 m from the piles (Fig. 4). Also, videos were taken with a mobile phone developing a specific app. In addition, satellite images of the quarries provided by the European Space Agency were used to assess the volume of reserves and compare it with the other approaches.

All of these processes required advanced computer vision capabilities to reconstruct volumes, something that was recently considered for the first time in the scientific literature [6]. The best and easy solution was to use mobile phones for taking the videos, with the volume calculation obtained in just few minutes (Fig. 5).

Fig. 3 Reconstruction of the volume of the stockpiles using images taken by drones

Fig. 4 Calculation of the volume of stockpiles automatically through the use of cameras

D. Anomalies Detection

The detection of malfunction of machinery in industrial processes using acoustic anomalies is a well-known task in order to optimize the predictive maintenance of machinery [6]-[9].

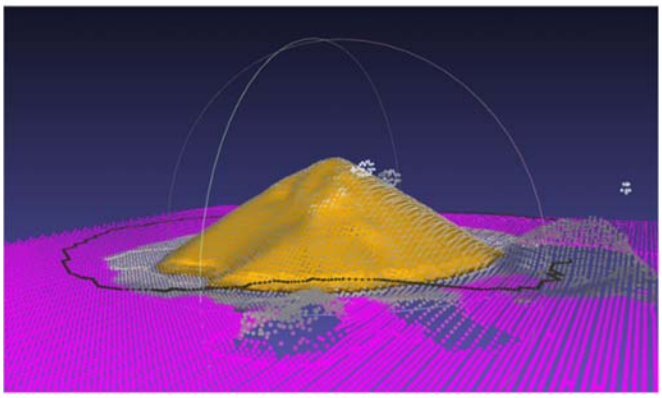

Fig. 5 Example of automatically volume calculation using a mobile phone using the app developed for this purpose

The anomaly detection service uses various types of devices (microphones and sensors) to monitor the behavior of the production line in the quarry to detect and prevent malfunction or anomaly of the machinery involved in the process. This service allows to implement a preventive maintenance system that, in turn, helps reduce production costs. Thus, this service focused on identifying acoustic anomalies to detect and prevent malfunctioning of quarry machinery. To do this, sound and vibrations were recorded using microphones installed on conveyor belts (Fig. 6), screens (Fig. 7) and crushers. The data recorded continuously were used for the direct characterization of the different operating conditions of machinery of the treatment plant, being able to distinguished their malfunctioning at the first stages and prevent total breakage.

Fig. 6 Sound and vibrations recorded on conveyor belts using microphones and accelerometers

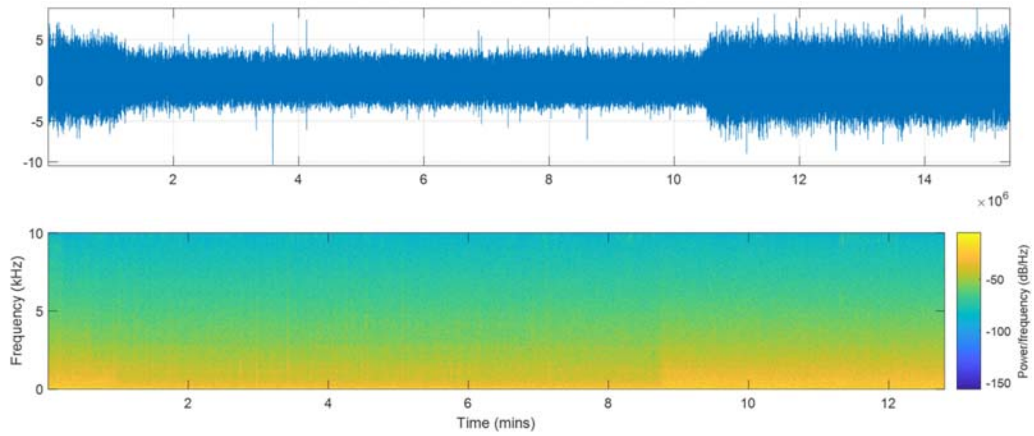

Fig. 7 Example of recording sound and vibrations in a screen using microphones and accelerometers: the central part represent a normal behavior, while at the right part, a malfunction of the screen was detected

E. Consumption and Product Forecasting

Attempts to model and forecast aggregates demand were performed in recent years using data from the Spanish market between 1995 and 2016 [10]. Here, the consumption and production prediction service analyzes the operational information of the quarry to determine the real cost of production and the volume of material produced in order to optimize production, reduce energy consumption (electricity, fuel, explosives) with the aim to increase the profits of the quarry. The service also uses these estimates to produce some recommendations on how the operation can be adjusted to optimize production. To develop the AI algorithms for this service, internal data from the quarries were used, including: monthly water consumption, energy consumption (electricity, fuel, explosives), energy costs and production in recent years. At the same time, meteorological data were used.

Regarding the optimization of water consumption, the analysis of the results of the fitting algorithm indicates that the algorithm can predict a monthly water consumption, using the average temperature, the average wind speed, the number of rainy days and the production of the quarry on a month.

In addition, an AI algorithm related to the estimation of production for the coming days, as a function of weather conditions and past production history, and also considering the costs history and costs associated to water consumption and energy was developed, which allowed to optimize working hours and reduce energy consumption.

III. Conclusions

The mining industry is experiencing numerous advances in recent decades, and one of the most disruptive is the integration of AI into operations. AI refers to the ability of machines to learn and make decisions autonomously using algorithms and statistical models.

The development of AI tools applied to aggregate exploitation has proved to be especially useful to improve efficiency, safety and sustainability at all stages of the mining process, from exploration and planning to extraction and processing.

In brief, within the framework of the DIGIECOQUARRY project, various AI services were developed for the identification of material quality, granulometry, volume calculation, detection of anomalies and prediction of consumption and production automatically with results that are automating these processes.

Acknowledgment

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