VisioRock, an integrated vision technology for advanced control of aggregate circuits

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1. Introduction

Automated vision systems are becoming widely spread in mineral processing plants. This evolution is not surprising in an industry that for many years used to rely almost solely on operators visual observations. This technology can offer the aggregate industry similar advantages considering the importance of product specifications – size and shape.

Closed Circuit TV (CCTV) cameras relaying images from various stages of the crushing and screening circuit to the control or operator room are common. On-line image analysis is less common, although it is already used in many processing plants, in a more or less primitive format, for measuring particle size or flotation froth properties and behavior.

A vision system in the mineral industry consists of a number of cameras installed at critical points of the process, which communicate with one or more computers. These computers then analyze the camera images and generate valuable information. Historically the first systems were characterized by a small number of cameras and low data throughput. The technology was restricted by technical and economical limitations, such as computing time needed for image processing, lack of suitable image analysis algorithms, cost of hardware for systems with many cameras, and lack of integration of the vision system with advanced control systems. Recent technological progress has eliminated these restrictions.

VisioRock is a new vision technology for determining rock size distribution, shape and other rock properties online, typically on a conveyor belt. Although it may be used as a single camera measurement device, the VisioRock technology is designed to be part of large, multi-camera, intelligent systems, with a wide range of possible applications in the mining and metallurgical industries.

Figure 1: VisioRock installation on a conveyor belt
2. The VisioRock technology

A vision system consists of hardware and software components. Each vision system is normally engineered to perform a well-defined function.

2.1. VisioRock functions

VisioRock may be used either as a standalone instrument, or as a component of an integrated advanced control system. The later concept is described more at length at section 3. As a standalone instrument VisioRock is designed for numerous applications where rock size (or more generally material size) matters.

Many applications involve evaluation of rock size distribution on conveyor belts, the most common locations being at:
- Crusher feed and product, as a sensor for setting the crusher gap.
- Screen undersize, as an oversize detector, for detecting holes in the screen or abnormal operation.
- Feed to critical equipment, as an abnormal material detector, for detecting wood logs or other unwanted objects on the conveyor belt that may damage equipment or disturb production.
- SAG or AG mill feed, since measurement of the feed size allows for more optimized operation of the mill.

Contrary to former generations of image analysis systems, VisioRock is well suited not only for size and shape determination but also for the detection of abnormal objects on a fast moving belt. This is due to its ability to fully process 15 to 30 images per second. VisioRock does not sample and process a limited number of images from the conveyor belt. This speed advantage allows VisioRock to observe each particle or object on the belt. This gives a more representative size and shape distribution as well as eliminating the risk of missing a critically sized particles (oversize or undesirable objects).

VisioRock can also be used as an Rock Type Sensor. VisioRock combines various types of information derived from the video images to infer ore type. This capability is addressed with more details hereafter, since it is typically a benefit from the integrated nature of the technology.

VisioTruck is a variant of VisioRock and it is designed to analyse the discharge of trucks into the primary crusher, in order to assess the size and shape distributions of the material generated during the blasting process, and possibly check other properties of the feed.

2.2. VisioRock Hardware

The hardware for a vision system typically comprises:
- One or more cameras,
- Lighting systems associated with the cameras,
- Communication hardware between the cameras and the computer(s)
- One or more computers.
From a hardware standpoint VisioRock is similar but not identical to VisioFroth, the froth vision technology launched at the end of 2001 and industrially applied at more than 20 sites already.

**Cameras**

VisioRock systems may be hybrid and combine cameras of different types. However, it is convenient to have one type of camera in a plant, in order to facilitate maintenance. Similar to VisioFroth, VisioRock is typically based on industrially hardened USB cameras, which are characterized by:

- IP68 enclosure which protects them from the harsh environment of most mining sites. Generally these cameras do not need extra protection, although special protections are provided for very dusty areas. This type of camera is well suited to open air installation.
- 640x480 pixel resolution. This resolution is well adapted to most applications. Higher resolutions are available for special applications, but in most cases the 640x480 images are sharp enough to see all the objects of practical interest while higher resolutions would needlessly increase computation time.
- High-speed shutter (up to 1/5000 sec although 1/1000 sec often suffices). With a 1/5000 sec shutter opening, a 5 m/s conveyor belt moves approximately 1 mm while the image is taken. This type of camera does not need a lot of light compared with other technologies, and therefore high-speed shutters may be used even with relatively low power lights.
- High frame rate (30 frames per second being typical). This is important with our systems because the computation time (15 to 30 images per second) is relatively short, while other systems tend to be limited by the computing time rather than by the camera itself.
- Low cost, and simple installation.

![Figure 2: Typical IP 68 USB Camera used for VisioRock and VisioFroth systems](image)

**Lighting systems**

VisioRock frequently observes objects on a fast moving conveyor belt. This requires shorter exposure times for each image and consequently more powerful lighting. It was found that a powerful lighting system allows better performance at night. A typical design involves four sets of dual high frequency fluorescent tubes.

In order to limit the difference between day and night it is recommended to protect the measurement zone from direct sun light. There is no strict need however to completely cover the area, since the system is quite tolerant to substantial variations in light intensity.
Communication hardware

On the computer side, the usage of the USB technology makes it possible to eliminate the need for a frame grabber card. Only USB controllers are required. The cameras are connected to field USB hubs, installed in protective cabinets, with one to four cameras per field hub. These field USB hubs are linked to USB extenders, which are located near the computer(s), through fiber optic cables, which may be either multimode or single mode. With single mode fiber optic cables, the cameras may be located several kilometers away from the computer(s).

Computer(s)

VisioRock uses PC computers or workstations, obviously the most powerful available in order to achieve maximum performance, with the Windows® XP Professional operating system. The number of computers for a given project is determined when the system is engineered.

VisioRock systems tend to be designed with few cameras per computer, especially for systems with a high safety component when "sampling" the belt can not be tolerated, so as to make sure that every single rock or object on the top of the belt is seen several times.

For process control oriented applications in crushing, screening and milling circuits, 20 VisioRock cameras per computer would be a realistic number.

Figure 3: Typical multi computer arrangement for an OCS© based vision system
2.3. Vision software

The VisioRock vision software is the vision module of the OCS© software. Any VisioRock system is delivered with all OCS© modules, the usage of which is only restricted by the license. The OCS© vision module embeds numerous image-processing algorithms. For each given application, some algorithms are selectively activated.

In general, the criteria to select the algorithms suitable for an application include:
- Nature of measurements required,
- Soundness of the results generated,
- Compatibility with computation time requirements.

For standard VisioRock applications, the algorithms involved to analyze each image include:
- Filtering. This step eliminates the consequences of a possible lack of homogeneity of the original image,
- Contrast enhancement, of particular importance for grayish material,
- Segmentation, where the rocks are individualized,
- Background rejection. VisioRock is able to automatically detect and reject the areas where the belt is empty,
- Fines identification. VisioRock detects the areas of the image where fines are,
- 2D particle size distribution, with user’s defined size classes,
- 2D-3D unfolding,
- Texture recognition per size class.

The user however does not face the computational complexity in the background and can focus on what matters for the operation of the plant. The raw image from the camera is displayed on a computer screen. Another image with artificial colors displays the particles identified by the algorithms. The artificial colors can be configured, but they reflect particle size: the particles above a critical size being red, etc.

Figures 4 and 5 show typical VisioRock screens. However, by far, the figures do not illustrate the dynamics of the system. The full particle size distribution is computed for each image (15 to 30 times per second), and averaged over cycles. The raw image, the “false color” image, and the instant particle size distribution (curve and histograms) are also updated 15 to 30 times per second.

![Figure 4: A typical VisioRock screen](image-url)
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Figure 5: At this iron ore operation, VisioRock determines the full rock size distribution and detects oversize material 15 times per second

VisioRock software features:
- High speed algorithm with many images processed per second per camera,
- Up to several tens of cameras per computer,
- The high speed algorithm allows continuous observation of the belt (no sampling, no scanning), provided however that the number of cameras per computer is limited,
- Video display function (the conveyor belt image is displayed on the computer screen),
- Display of cumulative size distribution graphs,
- Display of individual size histograms,
- Automatic selection of active camera and camera scan sequence,
- Remote selection (mouse driven) of the measurement zone (both position and rotation) and adjustment of camera settings (gain, saturation, contrast, etc) from the PC computer,
- Background (conveyor belt) elimination algorithm,
- Fines identification algorithm,
- Ability to run live image or replay .avi format files on the fly within the application,
- Ability to scale image with simple comparison method and height and width adjustable parameters within software,
- Ability to gather still frames (.jpg) and video (.avi) files manually or automatically based on conditions using Expert system rules,
- Ability to capture .jpg files automatically (triggered by rules in Expert module),
- Benefits from all OCS® advanced capabilities, expert system, fuzzy logic, easy configuration, statistics and graphical interface, etc. (subject to terms of license),
- Communication with plant PLC/DCS via OPC or DDE,
- Main calculated variables:
  - Complete particle size distribution (cumulative and individual)
  - Color (RGB and HSV) measurement for each size class
  - Texture characterization for each size class
  - Numerous other image properties and statistical functions
- Typically activated OCS smart strategy:
  - Generate tailored smart alarms through configuration of OCS expert system,
  - Optimize the sequence and the frequency of observation of each conveyor belt from within the OCS expert system module.
3. An integrated technology

Although it has been successfully used independently as an instrument, it can be also integrated into advanced control of crushing and screening circuits.

In general, images need to be interpreted and combined with knowledge before they become useful. Human beings continuously, although not consciously, supplement the information perceived by their eyes with broad knowledge, in order to generate new knowledge and actions. Humans act not on the basis of the raw image transmitted by their eyes, but on the basis of a 3D environment reconstructed by their brain and interpreted with identified objects. Each of these objects being characterized by numerous properties. People can see a powerful, expensive new car in an advertisement where, in fact, there is only a set of grayish pixels.

The simple ambition behind VisioRock is to combine artificial vision and artificial intelligence so that mineral processing plants can be operated by systems that are capable of understanding whatever may be seen in the plant. Integrate the eyes and the brain.

This ambition is reflected first by embedding the VisioRock algorithms in the OCS© software, and secondly by orienting R&D efforts pragmatically toward that direction.

3.1. Integration within OCS©

About OCS© software

As was explained previously, the vision algorithms of VisioRock pertain to the OCS© vision module, which itself is embedded in the OCS© software.

OCS© is specifically designed for implementing optimizing control systems in the process industries. OCS© was developed from the ground up for advanced process control. Its design simplifies configuration of the system, reduces software size and speeds up code execution.

When optimization algorithms or vision algorithms were previously tested or used in an environment which was not specially designed for fast on-line applications, it was found that the OCS© options for programming are 10 times or more faster.

What does OCS© do? As illustrated in Figure 6 below, in plant operations OCS© typically supplements conventional DCS (Distributed Control Systems) or PLC (Programmable Logic Controllers) controls. OCS© automatically reads information from the PLC or the DCS data base, and uses various advanced techniques to determine new set points, typically several times per minute. The set points are generally automatically applied at PLC or DCS level, usually without necessitating any action from the operators.

These set points continuously pursue strategic objectives. They maintain a required product quality while targeting a technical and economical objective. This typically results in an increase in capacity, product quality and value and/or a decrease in production costs.

Optimizing control systems are an integral part of modern mineral processing plants and quality systems. They have become an industry standard and many green-field plants are now specified with such systems. This new situation is justified by economic considerations. OCS© systems typically have pay back times in the range of a few weeks only, with an annual Return On Investment typically exceeding 100% even when installed in a small plant.

The OCS© software structure makes the applications both powerful and easy to maintain. Our implementation methodology involves operators and other plant personnel extensively and therefore generates very realistic control strategies and allows an excellent acceptance of the systems.
OCS© Overview

OCS© software embeds in a single structure numerous modules valuable for optimally controlling a mineral processing plant. An OCS© application may involve some or all of the following modules:

- a Process Display module, which is easily configured for each application in order to provide one or several user interface(s), such as flow diagrams, animated flowcharts, data entry forms. The user may animate and develop new interfaces in Visual Basic,
- a Fuzzy Expert module: in fact a real time expert system, with an inference engine, built-in crisp and fuzzy logic reasoning and a knowledge base, which is the core of any OCS© application,
- a Soft Sensor module with one (or several) adaptive predictive model(s), which comprise adaptive dynamic process models, a filter estimator for on-line self-tuning of the models and may be supplemented by an optimizer. The user may develop new models in Visual Basic.
- an Optimizer module, with a powerful constrained SQP algorithm,
- a Neural Network module,
- A Vision Module which already embeds numerous algorithms: VisioFroth for froth flotation plants, VisioRock for SAG and AG milling or crushing and screening plants, VisioPellet for pelletizing plants, and VisioBall to count grinding balls added to a SAG mill,
- a Tag Statistics module, which generates on-line statistical information about the process, and may be used for evaluation of plant performance,
- a Generic module, which allows seamless addition of specific algorithms when required.

Both the soft sensor modeling module(s) and the neural network module(s) are "learning" modules, which continuously and automatically adapt their behavior on the basis of new plant data.

OCS© is a modular, yet fully integrated software. It comes with all modules listed above, OPC, ODBC, DDE or DAO communication, setup and runtime functions in one single package. There are no separate add-ons such as separate data base engines, run-time version or development version, etc.
All modules can exchange input and output data, within a given project and between different projects. There is no set limit to the number of tags and rules manipulated (only limited by computer memory and speed).

![Diagram of OCS© Software Structure]

**Figure 7: OCS© Software Structure**

### 3.2. Benefits resulting from the integration

The benefits resulting from the integration of VisioRock in OCS© are real both at the conceptual level (functionality, control strategy, system design and architecture), and at the implementation and maintenance level.

#### 3.2.1. At the conceptual level

The underlying concept is that in a comminution circuit, crushing and screening or grinding circuit, at every location where the operator’s eyes may have something to observe, there is or should be a VisioRock camera and logic in OCS© to interpret the images. VisioRock technology now allows this.

The ability to seamlessly combine the numerous signals generated by the cameras (size distribution, color, texture) directly with OCS© Fuzzy Expert, Soft Sensor or Neural Network modules opens an infinite number of control possibilities. When engineering an advanced control system, the designer no longer needs to exercise any restraint within OCS©, combining several types of knowledge, empirical, heuristics, and insights (physics and chemistry of the process formatted in process models) is common practice. The neural network may be used to try to uncover relationships between vision tags and other tags, beyond initial knowledge.

#### 3.2.1.1. Feed forward strategies

VisioRock provides an unprecedented ability to automatically detect changes of ore type. Figure 8 shows five different ore types (namely hard oxide, sulfide, laterite, saprolite and soft sulfide) that the system is configured to automatically identify at a gold plant. Ore type identification is based on the simultaneous observation of size distribution, color, texture and requires expert logic. At this point it requires software able to characterize color and texture for each size class separately. Color and texture if averaged over the whole image would not provide fine enough information.
In this particular case, fine identification of ore types is critical because it makes it possible to detect changes in ore hardness before the ore enters the mills. This would not be possible if only particle size information was available, because for instance lateritic ore often appears as big rocks, which in reality are very brittle and break easily.

In this same case, OCS© manipulates mill rotation speed, and when changes in ore hardness are foreseen by the system, OCS© starts to increase or decrease mill speed accordingly. This is particularly useful since for mechanical reasons mill speed changes cannot be abrupt. In other cases, automatic detection of ore type may be used for adapting the entire process (reagent additions, grind size target, etc.) when the ore changes.

In general, the cameras looking at the feed of the circuit essentially provide information about ore size distribution and ore type. This information is valuable for anticipating adequate changes in settings such as fresh feed rate, mill speed, or reagent addition rates in some cases. Optimizing control may be combined with emergency procedures if cameras detect abnormal material before it enters the circuit. All actions that can be classified as “feed forward”, no matter how sophisticated or simple is the underlying logic.

3.2.1.2. Feed back strategies

The application of Figure 5 essentially detects anomalies in product size. The product is a final marketed product for which size matters. It is screened and its size distribution must lie within a strictly controlled size range. VisioRock is configured to operate at any time, and react quickly but avoid misinterpreting situations where the conveyor is temporarily partly empty, or partly covered with water. This is achieved by combining information about size, color, texture with outside information from the belt scale for instance, through context sensitive rules coded in the fuzzy logic expert system.

Figure 5 shows one of the OCS© Process Display screens, where the amount of material in each size class is shown in the histogram, the relative proportion of “too coarse” material being shown in red. In normal operation this value stays around 5%. If the relative proportion exceeds this value for a number of seconds, a hole in the upper screen is suspected.

In general, cameras looking at final and intermediate products provide information about the nature and the size distribution of material. Anomalies resulting from foreign material in the circuit, holes in screens or mechanical issues are detected early and addressed appropriately. Crusher settings, feed rates and other manipulated parameters may be adjusted automatically.
3.2.2. Implementation and maintenance

With VisioRock, the full particle size and shape distribution, as well as color and texture information are determined and displayed between 15 and 30 times per second. All the variables associated with this information are averaged over each OCS® cycle. Several different OCS® cycles coexist in a typical OCS® application, with the duration of each cycle being fully configurable. Durations of a few seconds are typical.

The values averaged over a cycle are tags in the OCS® software. These tags and all their attributes are readily available to and accessible by all OCS® modules listed above. The Tag Statistics module makes it possible to work with large numbers of these tags by statistically reducing them. Configuring smart alarms or actions based on absolute values, derivatives over time, stability, or duration of some situations is made easy.

The full software integration greatly facilitates the installation and the configuration. If the system has less than 50 cameras, one computer may suffice to perform all vision and control functions.

Communication with the DCS or other components of the control system does not need to be defined more than once.

Training and evolutionary maintenance are simplified, compared with hybrid systems relying on a combination of several software products. Testing, debugging or modification of the logic is greatly facilitated.

4. Conclusion

VisioRock is a new and innovative vision technology for determining rock size, shape distributions and other rock properties online. Although VisioRock may be used as a single camera measurement device, the VisioRock technology is designed to be part of multi-camera vision and advanced control system, with a wide range of possible applications in the aggregate, mining and metallurgical industries, as listed above.

The authors believe that this new technology is providing added value for the aggregate industry, through:

- Helping to assure and maintain product size and shape specifications,
- Increasing tonnage
- Protecting equipment by avoiding catastrophic situations resulting from oversized or misplaced material on conveyor belts such as wood and large pieces of metal,
- Lower overall hardware, software and installation costs, particularly for large multi-camera systems,
- Enhanced performance, particularly when VisioRock is integrated in advanced control strategies.

The economic value of such benefits is totally dependent on the site (tonnage, value of products, quality specifications, etc.) but all calculations made by the authors indicate pay back times in the range of a few weeks.