A practical system for realtime on-plant flotation froth visual parameter extraction

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Abstract: In plants where froth flotation is utilised to extract minerals from mined ore, the visual interpretation of the froth surface can be used to optimise the flotation process, thus yielding a more efficient extraction. We present a computer-based system that is able to extract a wide range of online static and dynamic visual parameters from the froth surface. The system has been installed in several refineries and performs well in both laboratory and industrial environments.

1. Introduction

The visual appearance of the surface of flotation froth in industrial flotation cells is related to processes occurring in the flotation process. If this visual appearance can be quantified by an automatic system and non-contacting sensors such as industrial cameras, automatic control of the froth flotation process can be performed, as the visual analysis yields information about the true status of the froth process.

This paper details the design and implementation of computational vision algorithms and a software platform for their application in mineral extraction plants.

2. Background

2.1. The froth flotation process

In [1], froth flotation is defined as being the selective separation of solids by artificially modifying the surface hydrophobicity of the particles constituting these solids.

The surface charges of these particles are determined by the pH and therefore anionic or cationic surfactants can be selectively adsorbed. These surfactants render some particles hydrophobic and others hydrophilic. In a mixture of finely milled ore and water, the hydrophobic particles will attach to bubbles which are forced through the mixture. These bubbles float to the surface, with their attached payloads, where they form the surface froth.

In mineral extraction plants the valuable mineral particles are made to be hydrophobic so that these float to the surface, and can thus be more readily extracted from the mixture in froth flotation cells.

2.2. The relationship between visual froth characteristics and process conditions

In order to achieve good froth flotation process performance, several variables pertinent to the process have to be monitored and controlled. For example, flow rates, densities, size distributions and shapes of particles, surface properties and compositions can all change and significantly affect the performance of an extraction plant[2], where performance is rated according to the recovery (i.e. amount) and grade (i.e. quality) of mineral that is extracted.

In [2] it is stated that "the structure of froths developed on the pulp surfaces of industrial scale froth flotation cells has a significant effect on both the grade and recovery of valuable minerals in the concentrate". [3] notices that "in practice the control of industrial flotation plants is often based on the visual appearance of the froth phase, and depends to a large extent on the experience and ability of a human operator".

It is thus an accepted fact that by visually monitoring the froth surface, one can theoretically determine many of the flotation process characteristics. [2], [3] and [4] detail the exact relationship between specific visual froth characteristics and froth process variables.

3. The advantages of a computer vision froth analysis platform

Traditionally plant control is performed by expert froth operators who observe the froth and make decisions based on what they see and their extensive experience.[5]

An automated machine vision analysis platform performs 24 hour plant monitoring, a requirement which can not be made of human froth operators. It is able to monitor several positions in the plant concurrently. Control response on input data is immediate, and all acquired data are meticulously noted for easy recall by the human operator at a later stage. Sensitivity to froth appearance is much higher, as computer vision algorithms can often de-

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tect features in an image which humans aren't able to. In addition to this, sensors are mounted in ideal positions with planned lighting. Froth operators can't always reach these positions for personal inspection.

To add to this, such a system, although evolving to adapt to new plant conditions and human operator input, stays entirely consistent in its judgements. Human opinion is prone to interference by non-related stimuli.

X-ray fluorescence measurements, another method of obtaining information about the froth-process, can be inaccurate.[2] The visual analysis platform attempts to mimic the methods of human froth operators which have proven themselves invaluable on flotation froth plants. Also, utilising non-contacting sensors, the platform affords low maintenance and high reliability.

4. Froth analysis system description

4.1. Algorithms

The froth analyzer performs both a static and a dynamic analysis of acquired froth images. The static analysis yields parameters such as bubble size, bubble perimeter and ellipticity. The dynamic analysis yields motion information pertaining to the froth under inspection.

4.1.1. Static analysis

As is the case in [5] and [6] the static analysis algorithms attempt to segment out each individual bubble and determine per-bubble visual parameters.

Point light sources are used in the image acquisition phase. These light sources cause localised reflection specula on the bubble surfaces. At first glance, these seem to pose a problem in the automatic visual analysis of the froth images, as they can be considered lighting anomalies. However, these localised reflective spots are used in the initial phase of the froth analysis, where a marker for each bubble needs to be found.

A robust morphological filtering technique is used to segment out these markers from an acquired froth image. This marker image is thresholded (in this case a trivial process due to the nature of the marker extraction algorithm) and used to modify the original froth image for watershedding. This modification is called "modification of the gradient homotopy"[7] and ensures that the watershedding algorithm does not oversegment the froth image.

A very fast implementation of the watershed algorithm[7] is performed on this modified image. The watershed algorithm perceives the image as geographical landscape and virtually floods it with water, thus resulting in watershed lines and catchment basins. Intuitively, this algorithm should work well on images of bubbles. Its practical performance satisfies this intuition, and it achieves very satisfactory bubble segmentation. Figure 1 is an example of a watershed-segmented pre-processed froth image.

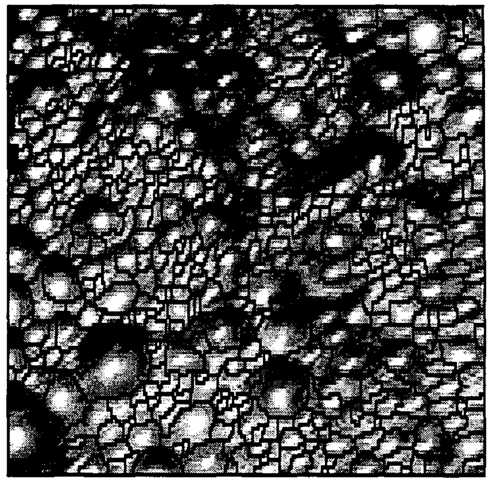

Figure 1. An example of a segmented froth image

After this segmentation, several per-bubble parameters can be extracted. These parameters are: area (size), euclidean perimeter, ellipticity/circularity and orientation angle (i.e. in the case of non-circular bubble, this refers to the orientation angle of the primary elliptical axis).

Naturally, having segmented out each and every bubble, the number of bubbles in a froth image is also reported.

Certain pixel-based parameters are also calculated. These are: red, green, blue and grey levels, which, when summarised by the statistics mentioned at a later stage, are important characteristics of the froth image under inspection.

4.1.2. Dynamic analysis

Froth dynamics can be computed from two images of the froth taken at different times. From these, the motion associated with the froth can be computed. Various approaches can be taken [9], but in this application, we compute motion on a per bubble basis. We take advantage of the fact that the video signal is interlaced. This means that the odd lines (the odd field) in the image are exposed 20ms after the even lines (the even field). This usually results in an undesirable motion artifact but is exploited to good effect here. By extracting homotopic markers for the even and odd fields and, for each bubble, determining how far the marker has

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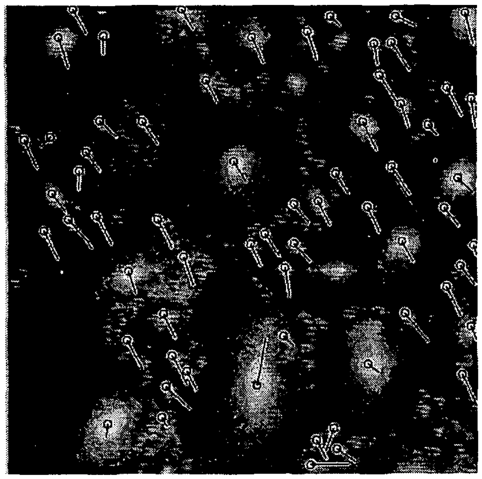

Figure 2. Motion vectors obtained from an interlaced froth image.

moved between fields, we are able to compute the motion vector for that bubble.

4.2. Statistics

In order to utilise the data gathered in decision-making models, some pre-processing has to be performed, mostly by calculating basic statistic features and, more importantly, generating histograms of e.g. the bubble size in a froth image.

This froth analysis system contains functions for extracting values such as the mean, the median and sampled standard deviation from any of the parameter collections. Special attention has to be paid to the angular data statistics, as these differ to a great extent from their linear counterparts [8].

Also, histogram calculations can be generated on a number of the parameters. Figure 3 shows the system's algorithm/histogram configuration functionality. Again, angular data has to be handled specially.

4.3. Software

All the computer vision algorithms are implemented in optimized and portable C++. In fact, the algorithm code was developed on UNIX systems, but runs on Windows NT systems on-plant. A full static and dynamic analysis of two froth images takes five seconds on an Intel Pentium II 233MHz processor. All components of the software were developed in-house.

The froth analysis system graphical user interface was developed in Borland Delphi and enables plant operators to view acquired video sequences, segmented images, images with overlaid motion quivers, and extracted parameters, in both graphed and

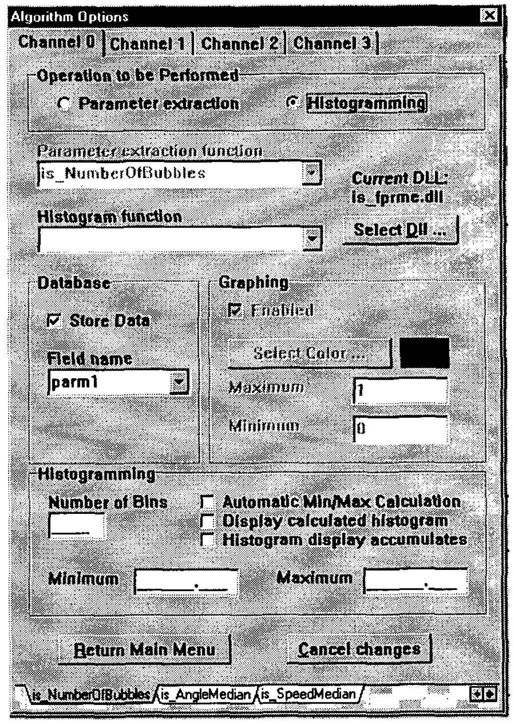

Figure 3. Screenshot of algorithm/histogram dialog box

numerical form. It also enables them to configure the algorithm extraction system. Refer to figure 3 for an example of one of the configuration dialogs. The system is able to run analysis on multiple video input channels.

4.4. Hardware

The froth analysis software system is implemented on the standard PC Architecture, running Windows NT. The video acquisition subsystem employs a commercially available high-end multi-video channel video grabber and commercially available industrial colour video cameras. This makes for an economically viable and readily maintainable hardware platform, as any of the components can be replaced or serviced by normal hardware technicians.

Cameras are mounted at several stages in the flotation process in custom-manufactured metal enclosures above the froth. The enclosures are pyramidal and reach down to near the froth surface. Their purpose is to eliminate as much as possible ambient light interference. Standard spot-lights are mounted next to the cameras, also inside the metal enclosures.

5. System performance

The analysis system has been installed on four cells in South African mineral extraction plants and is very stable. This section details expert feedback that has been received from these extraction plants.

The system fulfils the requirements of an industrial froth analysis system in a manner that robust control can be achieved based on the results of the froth analysis.

It detects deviations from ideal froth characteristics and by implementing control based on expert rules in the plant, the system stabilises the froth appearance and thus stabilises performance of the operation. Benefit is obtained mainly from identifying deviations early. As mentioned earlier, the system standardises the interpretation of the froth appearance where there has traditionally been confusion among the operators. Also, the fact that it operates 24 hours a day is significant in these industrial environments. The system is expected to deliver substantial financial financial benefits to plants that implement it.

6. Future work

6.1. Froth analysis algorithms

The static analysis algorithms are performing well. More research is to be done on cases where the marker extraction algorithm yields more than one marker per bubble in non-standard lighting conditions. This causes over-segmentation.

Clear windows on top of bubbles (i.e. not carrying the valuable mineral) indicate a balance between water and mineral content, and this is normally associated with an ideal froth.[2] Work towards detecting these bubble windows is underway.

Further investigation will be made along the lines of the work done in [9], where motion is estimated from whole segmented bubbles, which differs from the current marker-based method.

The main focus of future work is on more detailed motion analysis. One of the goals of this research is to achieve accurate individual bubble-tracking. This will entail that each bubble is followed from its origin (i.e. first appearance in the vision window) until coalescence, destruction or division. Detailed individual bubble motion vector information will be available at any stage of the bubble's lifetime, as well as changes in its shape.

This information can be used to determine a whole range of new froth characteristics and also to increase the accuracy of parameters that are extracted from the static information.

6.2. Software platform

A distributed processing cross-platform pluggable architecture video acquisition and analysis platform is in its design stages. This will replace the current platform and will permit much more flexible installations on froth flotation plants.

7. Conclusions

It has been established that the visual appearance of the froth surface in flotation cells is related to the froth process characteristics. Thus, if a successful visual analysis of the froth surface can be performed, this information can be used to perform control of the process in order to yield a more efficient extraction.

A stable system that performs such a visual analysis in a fast, accurate and cost-effective way has been implemented. The system is functioning well in the extraction plants where it's being tested, and is expected to yield significant financial benefits to the plants that utilise it.

Future work includes a new more flexible software platform, as well as further development of the image analysis algorithms themselves, especially with respects to full motion video analysis and detailed individual bubble-tracking.

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