Chapter 22

EVALUATION OF A PC IMAGE-BASED ON-LINE COARSE PARTICLE SIZE ANALYZER

C.L. Lin, Y.K. Yen and J.D. Miller

Comminution Center
University of Utah
Salt Lake City, UT 84112

Abstract. A PC image-based, on-line coarse particle size analysis system is being developed for the control of crushing and grinding circuits. Initial results had indicated that the system is accurate when tested with irregularly shaped particles which are stationary and do not overlap with each other. Now the system has been successfully tested in the dynamic mode with a moving belt conveyor. On-line size analysis for actual plant operations is discussed and includes: (1) the video system with respect to lighting and data acquisition requirements for a rapidly moving belt and, (2) image sampling, specifically the number of observations needed for accurate sampling and the total time required to perform the calculations for a representative data set.

INTRODUCTION

On-line determination of crusher product size distributions in the mining and mineral processing industry is necessary for improved energy efficiency and crushing/grinding circuit performance. Many efforts have been made since the 1970's to implement such a real time, on-line, particle size measurement system. Most of the systems, however, have not been able to satisfy the real needs of industry, neither with respect to performance nor with respect to cost.

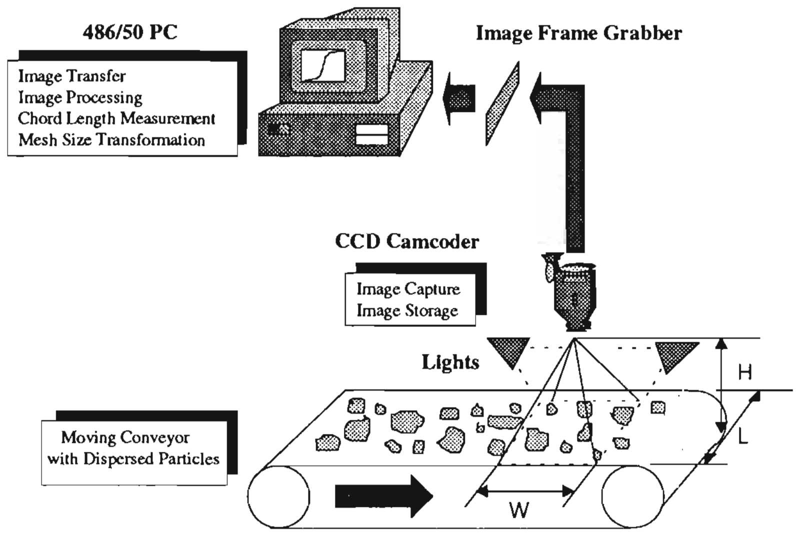
Now, due to the rapid evolution of personal computers (PC) and video technologies, it is possible to overcome certain difficulties that could not be solved only a few years ago and it should be possible to build a fast, economical, and precise system for real-time crusher product size measurement. A detailed discussion of the initial efforts to develop a PC image-based, on-line coarse particle size analyzer was given in a previous paper (Lin and Miller, 1992). Briefly, a PC system has been developed to perform image capture and digital image processing. From stationary particle size measurements, the experimental results show that the stereological model (King, 1982) used to transform linear chord-length data into 3-D mesh size distributions works very well using a special inversion technique (Schneider et al., 1991). This success has now led to the evaluation of the dynamic case, a moving conveyor, in order to understand the differences between the static and the dynamic cases.

Two major areas must be considered for the dynamic case. First the video system must be designed to provide correct illumination and to eliminate image blurring/interlacing as pointed-out by Lange (1988). Such problems require the matching of the conveyor belt speed with the camera speed (shutter speed, digitizing speed, etc.). Second the image sampling size must be considered. At what rate should observations be taken? What is the appropriate number of observations per unit of time? In this regard, the computational time for data analysis and transformation must be compatible with the sampling frequency.

This paper discusses experimental efforts to solve these problems of the dynamic case using an appropriate video system to examine separated particles on a moving belt and specifically designed software for analysis and on-line data transformation. Further, the number of observations needed to represent the entire particle population and the time consumed by each processing step are given in detail.

EXPERIMENTAL METHOD

The experimental arrangement and working conditions are shown in Figure 1. The conveyor belt used for the experiments is 30 cm wide with a fixed speed of 300 mm/sec. It is worthwhile to note that the conveyor belt used is equivalent to an industrial belt, 6 feet wide running at a speed of 6 ft/sec. This equivalence ensures that all the tests



Personal Computer : 486/50 IBM compatible
Image Frame Grabber : 512x512/640x480 per frame, 8 bits res.
CCD Camcoder : Nikon VN-960
Lights : four 45 W incandlescent bulbs

Conveyor speed : 300 mm/sec
W : 317 mm
L : 250 mm
H : 450 mm

Figure 1. Experimental setup for the on-line coarse particle size measurement.

are a reasonable representation of, and simulate, actual plant operations. As mentioned previously, all the problems associated with a dynamic measurement and real time image analysis are due to the speed of the conveyor belt. The first thing that must be done is to determine how the blurring effect and lighting conditions affect the captured images. In other words, we want to control certain measuring parameters in order to minimize the errors caused by the fast motion of the particles and the belt. The second problem that must be considered is to minimize sampling errors during image processing and link those individual processes into a continuous executable routine. Finally, the minimum number of observations and processing time must be determined.

In order to evaluate the dynamic case two groups of samples were prepared from crushed onyx stones. One sample was prepared in a narrow size range from 31.75 mm to 38.10 mm in size and the other sample was prepared with a much broader particle size distribution from 6.3 mm to 50.0 mm in size. The sieve size distribution of the latter sample is given in Table 1. The narrow size sample was used for the comparison of stationary and dynamic images. Image sampling frequency was determined using the polydispersed sample.

Table 1. The measured particle size distribution of the polydispersed onyx stones

Size range (mm)	Weight (g)	Weight (%)	Cumulative Distribution (%)
50.0-37.5	287	0.38	100.00
37.5-31.5	1354	1.73	99.62
31.5-26.5	2008	2.57	97.89
26.5-22.4	15956	20.44	95.32
22.4-16.0	36929	47.31	74.88
16.0-12.5	10305	13.20	27.57
12.5-6.3	11217	14.37	14.37

Video System

Lighting Conditions. Both stationary and dynamic measurements need appropriate lighting which means that the light sources should be sufficient, but not so intense as to over-expose the field. In this regard non-directional illumination is preferred and four 45 W incandescent bulbs were used as illuminating sources to provide uniform distribution of the light.

Blurring Effect. There are three parameters which should be controlled to ensure image quality given the sufficient and uniform lighting condition. These parameters are the conveyor speed, the shutter speed, and the IRIS setting (aperture value) of the video camera. The conveyor belt with a fixed speed (300 mm/sec) was used to carry the onyx stones which were randomly arranged on the belt. Then, different shutter speeds with appropriate IRIS settings were selected to capture the images of the same onyx stones for both stationary and dynamic conditions. In order to make a precise comparison, the particles were actually fixed so that the relative positions did not change from test to test. Next the IRIS setting was varied. The shutter speed was set at 300 (1/300 sec) in accordance with the conveyor speed 300 mm/sec and the effect of the IRIS setting was studied.

Interlaced Effect. The video camera and the image frame grabber belong to the NTSC standard category. Unfortunately, the interlaced problem always occurs for the capture of moving objects with this type of video system (Lange, 1988). Specific details of the interlaced problem are discussed latter. Although, it is not recommended to use such a interlaced video system for dynamic image capture (Lindey, 1991), such a system is much less expensive. In this regard, the system was evaluated to determine the effect of the interlaced phenomena. Specifically, both horizontally and vertically measured chord-length distributions were made to determine the significance of the problem.

Image Sampling

Image Capture. To minimize the total processing time for a large number of observations, it is necessary to determine the minimum image sample size (number of observations) that must be taken from the total number of images (Gy, 1979). Approximately 80 kg of onyx particles (6.3 mm to 50 mm) were spread randomly on the conveyor belt without overlapping. As the conveyor belt moved, the particle images were continuously recorded by a CCD (charge coupled device) camcorder. The camcorder has a capacity of digitizing 30 frames per second, however, based on the equipment setup the time interval for adjacent images is about 1 second which means that at a sample rate of 1 image (frame) per second the whole sample can be analyzed.

Image Processing. The image processing procedures implemented for this experiment are shown in Figure 2. These include an automatic thresholding method for segmentation (hybrid algorithm) (Lin and Miller, 1992), a computer routine for eliminating biased images (labeling and clearing partial particle images at the edges of the frame), and one routine for correcting the interlaced problem based on a morphological method (Overveld, 1992).

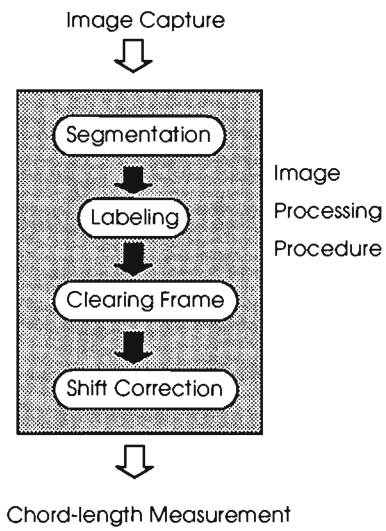
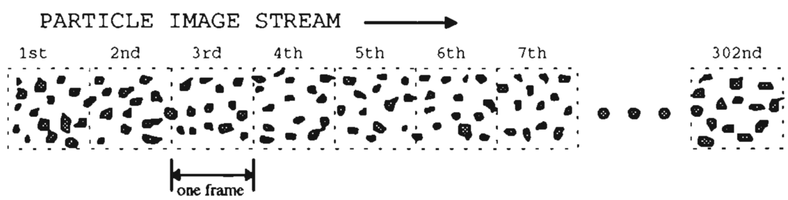


Figure 2. Major steps of the image-processing operation for on-line size analyzer.

Data Analysis. The total particle population which was observed in seven minutes of video tape was converted into 302 individual images (640 x 480 pixels/frame). Note that the image from one frame does not overlap with the image from the next frame. In this way the total particle population is recorded. Chord-length measurements were made for image sample sizes of 2.0%, 3.3%, and 5.0% of the total particle population. Thus of the total 302 images, a sample size of 5.0% means that one out of every 20 images is analyzed. A concise explanation of the sampling procedure is shown in Figure 3.

Incremental Image Sampling Procedure



Sampling size	Sampling interval	No. of frames per Sample	Total Number of Samples
2.0%	every 50 frames	6	50
3.3%	every 30 frames	10	30
5.0%	every 20 frames	15	20

Figure 3. Illustration of the incremental image sampling procedure for the determination of minimum sample size.

VIDEO SYSTEM

Lighting Conditions

An over-exposed particle image is compared to one appropriately illuminated as shown in Figures 4a and 4b, respectively. By visual observation, there is no problem to distinguish the rocks from the background even in the over-exposed case, but it is a problem for computer software. Figures 4c and 4d are the segmented results for the above images. Apparently over-exposure has ruined the image from the very beginning, and in a similar way, insufficient illumination does also. The other problem experienced is the light source. Common incandescent bulbs provide a simple, cost-effective system and that is what we have used in all of these experiments. Inevitably, this kind of lighting source will produce directional illumination which makes strong shadows and causes problems for image processing. By using symmetrically arranged incandescent bulbs to compensate for shading, the shadowing effect can be minimized and if done properly is of no consequence.

There is one more serious problem associated with the use of incandescent bulbs for illumination when the CCD camera is operated continuously. The infrared radiation emitted by the bulbs tends to wash-out the visual data (Vernon, 1991). Therefore, it is recommended that fluorescent lighting be used for illumination and image capture in industrial applications.

Blurring and Interlaced Effects

The blurring effect caused by the motion of objects is shown by comparison of the chord-length distributions for different shutter speeds in Figure 5. It can be easily calculated that the measured length of a chord, parallel to the moving direction, will be lengthened to different extents depending on the shutter speed. For instance, a shutter speed of 60 will widen the image by 5 mm (shutter speed (1/60 sec) conveyor speed (300 mm/sec)). From Figure 5 it is evident that the effect is small yet the experimental results match this simple calculation. The 300 shutter speed seems to be the closest setting for reproducing the static condition. Nowadays, it is very common that a commercial CCD

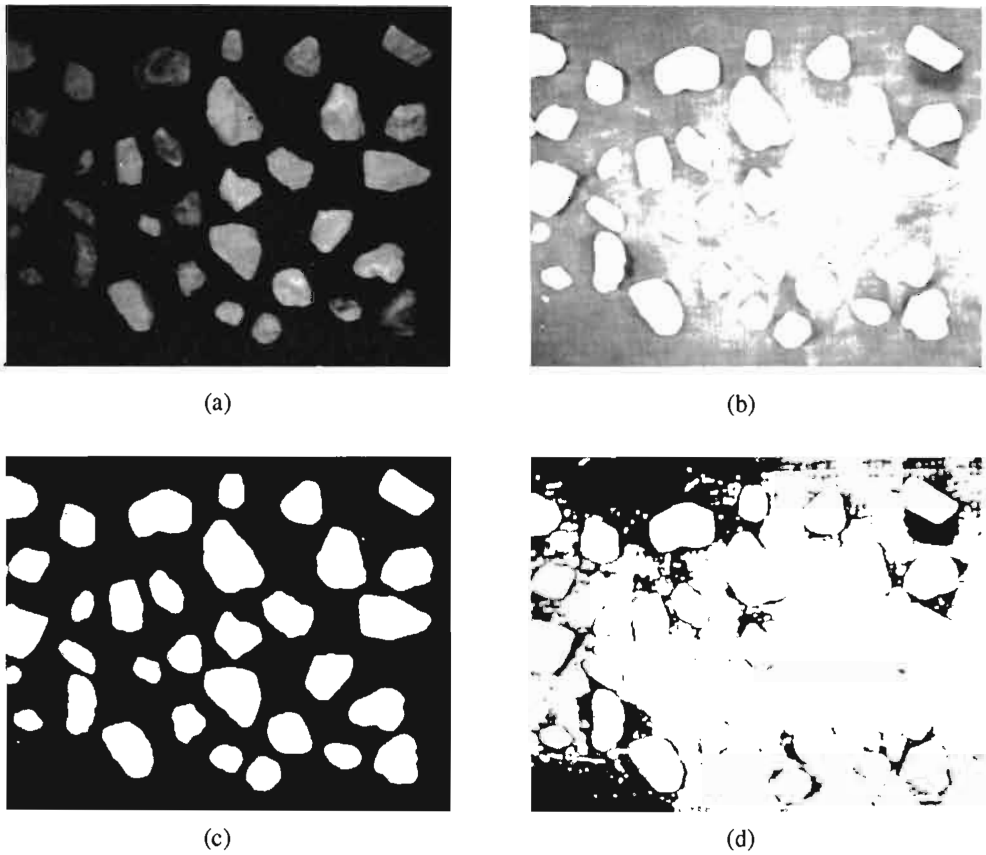


Figure 4. Illustrations of the effect of lighting conditions on image segmentation. (a) original image (normal exposure), (b) original image (over exposure), (c) segmented image (normal exposure), (d) segmented image (over exposure).

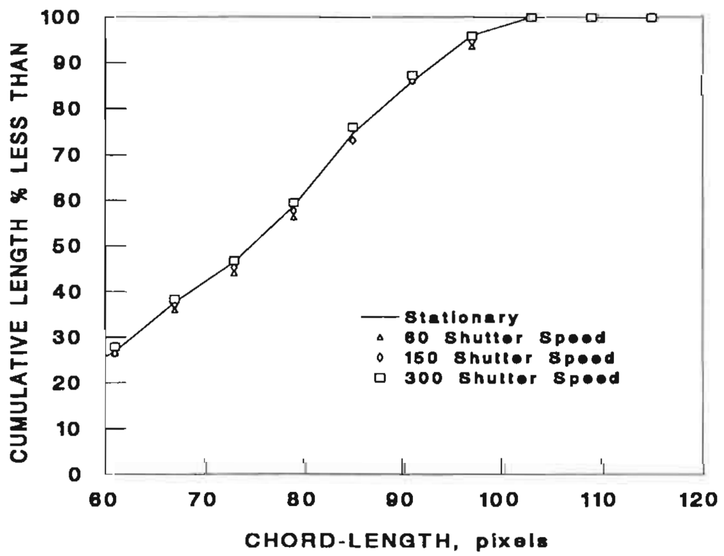


Figure 5. Comparison of dynamic and stationary chord-length distributions at different shutter speed settings.

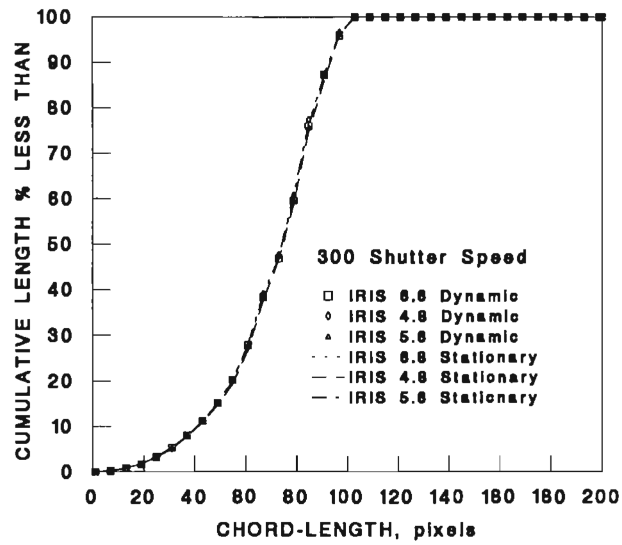
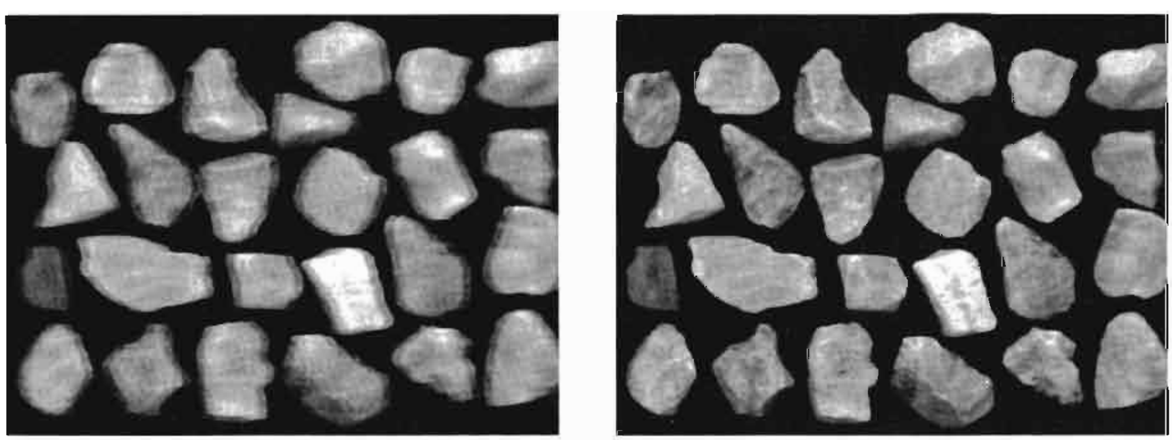


Figure 6. Comparison of dynamic and stationary chord-length distributions for various IRIS settings at a shutter speed of 300.



(a) (b)

Figure 7. Interlaced particle images, (a) original image (interlaced), (b) corrected image.

camcorder can provide a shutter speed ranging from 60 to 10000, which is far beyond our needs even if the conveyor speed exceeds 3 m/sec.

Several IRIS settings have been tested at a fixed shutter speed of 300. Figure 6 shows that there is no significant difference due to the changes of the IRIS. According to these results, it can be concluded that IRIS is not a critical parameter if the shutter speed has been set properly and the appropriate illumination has been provided.

An example of an interlaced image is shown in Figure 7a. For a non-overlapped particle size measurement with enough space between the particles, which is our case, the interlaced images will not cause any problem if the chord-lengths are measured in the same direction as the conveyor motion. But if the measurement is made in a direction perpendicular to the direction of motion, the measurement accuracy will surely be reduced, especially in the small particle size region. To illustrate how the interlaced problem can affect the particle size distribution measurement, chord-lengths were measured both perpendicular and parallel to the direction of motion. The linear chord-length distribution results are shown in Figure 8. It is evident that the measurements perpendicular to the direction of motion are significantly displaced due to the interlaced effect. On the other hand the parallel measurements provide an accurate measure of the chord-length distribution. Nevertheless, the interlaced images can be corrected so that the interlaced problem is of no concern. Using a specially designed algorithm similar to Overveld's technqiue (1992), the interlaced image can be corrected. For example, the images before and after correction can be compared in Figures 7a and 7b. It is clear now that reliable chord-length distribution results can be obtained not only for the static case but also for the dynamic case if the system is appropriately designed.

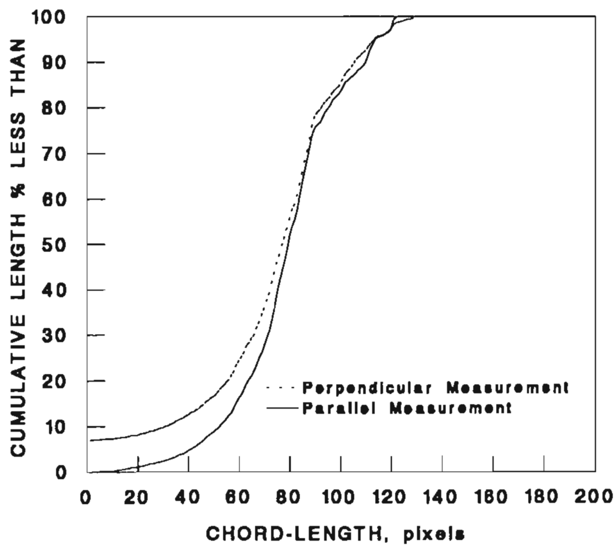


Figure 8. Comparison of the chord-length distributions between perpendicular and parallel measurements (with respect to the direction of conveyor motion) for an interlaced image.

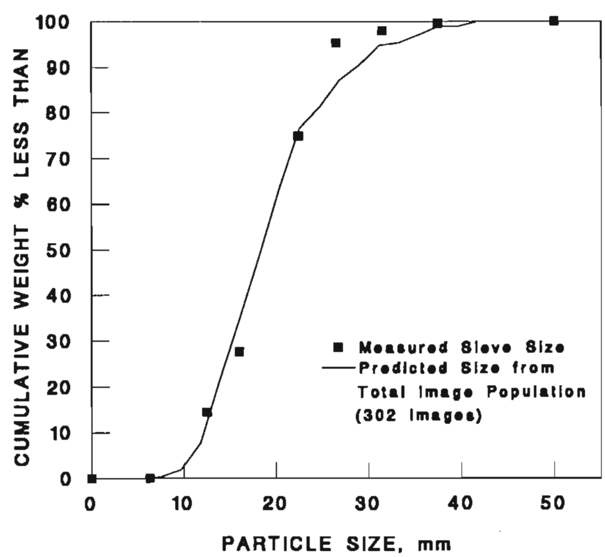


Figure 9. Comparison of the measured sieve size analysis and predicted particle size distribution obtained from the transformation of the chord-length distribution from total image population for the dynamic case.

IMAGE SAMPLING

The mesh size distribution transformed from chord-length measurements (302 total images) is compared to the sieve size distribution for the entire particle population in Figure 9. There are slight deviations observed for the larger and smaller particle sizes, but the transformed distribution for the dynamic case generally predicts the actual distribution very well.

It should be mentioned here that one additional step has been included during analysis. Those particles that are intersected between consecutive images will lead to error in the analysis. In order to avoid this problem all such particle images are removed before the chord-length measurements are made. This processing step ensures that every measured particle image represents a complete particle.

Based on the above procedure, it is reasonable to use the chord-length distribution of the total population as a reference to evaluate the number of observations required for analysis. The image sample sizes of 2.0%, 3.3%, and 5.0% were considered and the results are shown in Figure 10. Clearly the deviations for the 3.3% and 5.0% samples are not large but the results for 2.0% are unacceptable as shown in Figure 11 which shows a comparison of transformed mesh size distributions for the selected image sample sizes. A significant difference is evident in the large particle size range when the sample size is set at 2.0%. In this case, an insufficient image sample size exaggerates the large particle size region of the distribution too much, which makes it inappropriate to reduce the image sample size to such an extent. Fortunately enough, 3.3% seems to be an acceptable image sample size which means only one out of every thirty images needs to be processed. As mentioned previously, each individual image is picked up from approximately 30 consecutive frames, therefore, the maximum available processing time for each image is 30 seconds. In a similar way, the available processing time will be 20 seconds if the sample size is 5.0%.

The time consumed by each step of this particle size analyzer is given in Table 2 and represents a conservative estimate of the entire processing time to be less than 15 seconds. Of course there are always some small variations in time for segmentation and mesh size transformation.

Table 2. Incremental time for each processing step during a real time coarse particle size measurement

Processing Steps	Time Consumed (Sec.)
1. Image Capture	1.93
2. Shift Correction	0.44
3. Segmentation	1.81
4. Labeling	0.88
5. Clearing Partial Particles	0.88
6. Chord-length Measurement	0.27
7. Mesh-size Transformation	6.48
Total	12.69

SUMMARY AND CONCLUSIONS

A PC image-based on-line coarse particle size analyzer has been developed. Dynamic tests with a moving belt conveyor show that it can perform very well for moving objects after solving several critical problems. Moreover, an acceptable image sample size, found to be 3.3% of the total particle population makes the use of the analyzer more probable by industry. Future work on this research problem will consider the particle overlap problem.

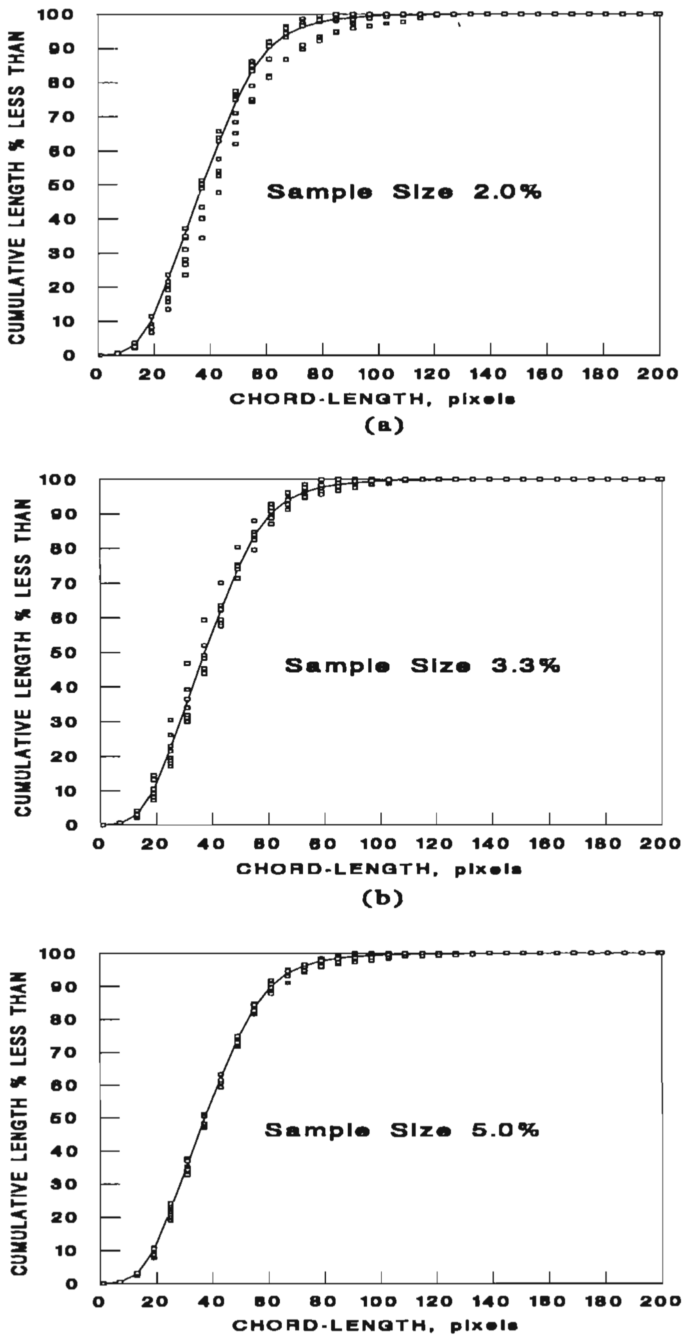


Figure 10. Comparisons of chord-length distributions for different image sample size. (a) 2.0%, (b) 3.3%, (c) 5.0%. Ten different observations for each image sample size are compared with the chord-length distribution from the total image population (solid line).

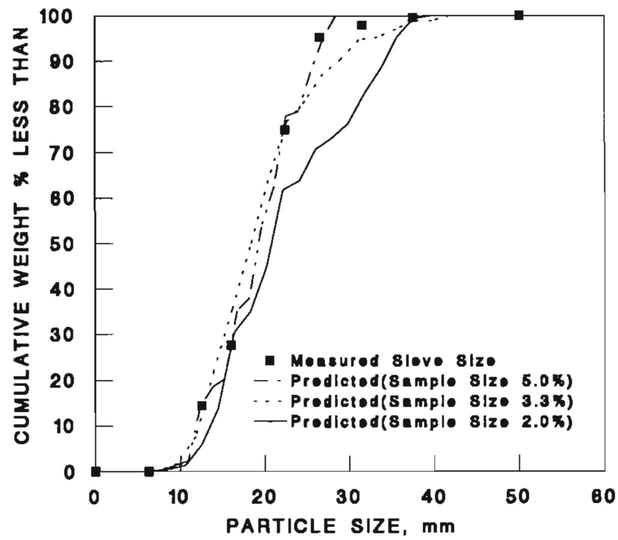


Figure 11. Comparison of the measured sieve size analysis and the predicted size distributions for image sample sizes of 2.0%, 3.3% and 5.0%.

ACKNOWLEDGMENTS

This research has been supported by the Department of the Interior's Mineral Institute program administered by the Bureau of Mines through the Generic Mineral Technology Center for Comminution under grant number G1105149.

REFERENCES

Gy, P.M., 1979, Sampling of Particulate Materials, Theory and Practice, Elsevier, Amsterdam.

King, R.P., 1982, "Determination of the Distribution of Size of Irregularly Shaped Particles from Measurements on Sections or Projected Areas," Powder Technology, Vol. 32, pp. 87-100.

Lange T.B., 1988, "Real-time Measurement of the Size Distribution of Rocks on a Conveyor belt," Applied Measurements in Mineral and Metallurgical Processing, pp. 25-34.

Lin C.L. and J.D. Miller, 1992, "The Development of a PC Image-Based On-line Particle Size Analyzer," Preprint 92-10, SME Annual Meeting, Phoenix, Arizona .

Lindley, C.A., 1991, Practical Image Processing, John Wiley & Sons, Inc., New York.

Overveld, C.W.A.M., 1992, "Application of Morphological Filters to Tackle Discretization Artifacts," The Visual Computer, Vol. 8, pp. 217-232.

Schneider, C.L., Lin, C.L., King, R.P. and Miller, J.D., 1991, "Improved Transformation Technique for the Prediction of Liberation by a Random Fracture Model," Powder Technology, Vol. 67, pp.23-49.

Vernon, D., 1991, Machine Vision, Prentice Hall, Englewood Cliffs, NJ.