Characteristics of sensor-based sorting technology and implementation in mining

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ISBN: 978-3-8440-2498-2
Defence: 13 December 2013

Sensor-based sorting (SBS) is a sustainable processing technology for separation of coarse particles in the size range 10–350 mm. Provided full liberation in coarse particle sizes, SBS is technically applicable for very many aggregate commodities. Through its impacts on all processes in the mineral production chain and the technical options to separate on new separation criteria at relatively low cost, SBS becomes a disruptive technology.[a] SBS is still at the market entry level for many commodities and applications, and far from reaching a technical saturation level; the sensing technology and mechanical platform developments are still developing rapidly. There is an interesting aspect of sampling in SBS, which is explored in this brief PhD summary.

Sensor-based sorting systems

Sensor-based sorting (SBS) is used as an umbrella term for all applications in which particles are detected individually by a relevant sensor technique, to be accepted or rejected by an amplified mechanical, hydraulic or pneumatic process.[1] Figures 1 and 2 display two types of sensor-based sorting equipment, the chute-type and the belt-type. In both cases up to 10,000 particles can be presented to a scanning system *per second*. This translates, depending on the particle size and weight, to a throughput of 10–300 tonnes per hour. The most commonly applied detector systems in today's industrial scale sorting systems are line-scan cameras in combination with LED and laser illumination, NIR spectrometers, UV spectrometers, Vis spectrometers, X-ray-scintillators, radiometric scintillators and AC inductive coils. All these sensor systems must deliver spectral and spatial data at very short integration periods, typically <10 ms. The data is processed in real-time, after which high-speed air jets are activated in case single particles are intended to be ejected from their normal path of flight into the so-called *eject fraction*, while all other pass into the *accept fraction*. In order to minimise energy consumption, a maximum of 50 wt% is ejected with compressed air; a higher reject fraction results in switching the eject/accept logic in the software.

[a]Technology which has a significant impact on productivity improvement and/or cost reduction and/or satisfaction of needs; also referred to as step-change innovation.

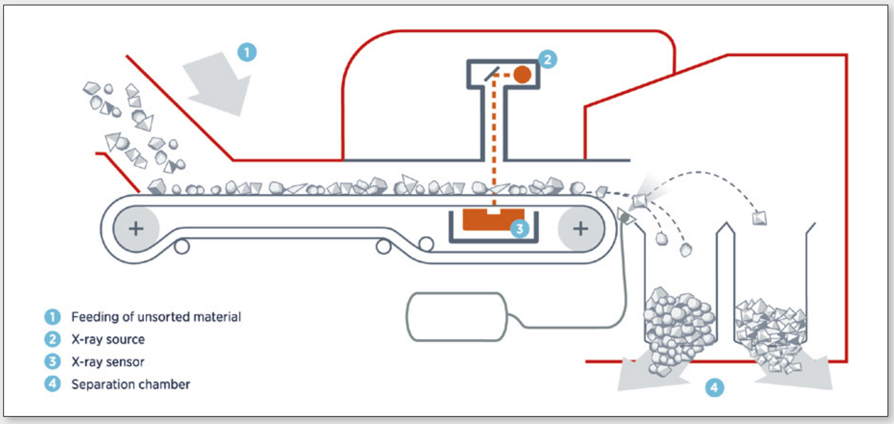

Figure 1. Working principle of belt-type X-ray transmission sensor-baser sorting (SBS) system.

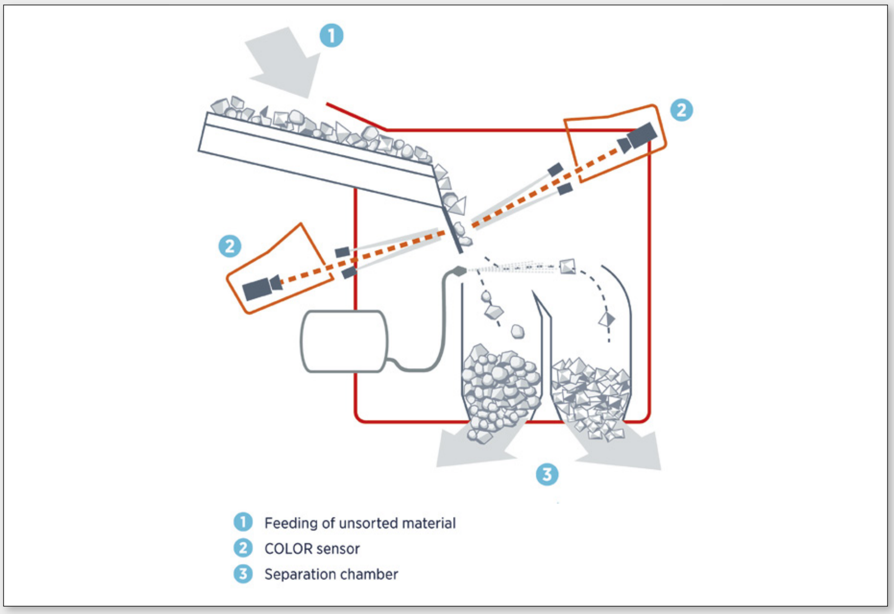

Figure 2. Working principle of chute-type colour-sorter, in this case also a transmission SBS system. Through deployment of double side scanning approx. 70% of the surface can be measured and evaluated.

While the presently presented PhD dissertation is focussed only on mining (where the technology was originally developed in the 1930s for diamond processing), today this technology is also widely applied in the food processing and recycling industries, amongst others.

The impacts of sensor-based sorting on mineral production are discussed using technical–financial scenarios that focus and highlight characteristic effects. The main scenarios offering high economic benefit are, amongst others, sensor-based sorting installations for reduced capital expenditure for downstream plant equipment, or increased productivity through enhanced production capacities by elimination of barren waste, ore type diversion into specialised plant lines. The scenarios treated in the thesis show that sensor-based sorting not only contributes to an environmentally friendly operation through reduced resource consumption and environmental impact, but also significantly decreases production costs. The highest possible economic benefits can be achieved when maximising productivity either through increased feed grade or increased overall recovery.

The impacts of SBS on the total separation efficiency are evaluated using so-called process efficiency functions. These, in combination with the liberation function, constitute a specific four-dimensional process application characterisation, which links recovery to yield, particle size and throughput. This concept shows the full characteristics of sensor-based sorting technology, which allows future analysis of process- and sub-process-efficiency contributions to be performed for different applications. Analogous to these process characteristics, operating cost functions and capital expenditure functions specifically delineate the expenditures in dependence of yield and throughput for stationary and semi-mobile applications.

The PhD study introduces the basic components of a general sensor-based sorting plant and their respective optimality requirements. Both stationary and semi-mobile installations are evaluated and two fully developed semi-mobile plants are described. As semi-mobile installations are relatively compact they allow for flexible application at strategic logistical positions which in many cases can be closer to the mining face with obvious logistic and economic benefits. This endeavour requires careful implementation into the full mining system, especially due to the resulting backfill activities.

SBS and TOS

All investment decisions regarding SBS are made on the basis of pilot experiments or campaigns which further critical data based on sampling and laboratory test procedures. It is prudent that all new materials first are characterised with respect to their sorting feasibility. In this context, the critical issue is, of course, to base this pilot study on a documented representative primary sample of the target material, an issue that will appear trivial to readers of this publication, but may not at all be similarly obvious to clients who often want to supply the test material themselves. This issue constitute sthe first critical success factor before any technicalities regarding the SBS system itself can be meaningfully addressed.

Coarse particle SBS separation introduces significant challenges due to the magnitude of the fundamental sampling error (FSE) involved. The theory of sampling (TOS) offers a proven scientific and practical framework that must be applied in the context of all single particle tests for sensor-selection, calibration and validation and for gaining operational data. Often SBS systems operate in a process environment akin to the process analytical technology (PAT) concept, well-known from many other technological and industrial application sectors, for example Reference 2. SBS and PAT therefore encounter the same issues, for example, also with respect to data fidelity vs chemometric multivariate calibration.

Though sometimes hailed as “sampling-free” techniques, neither PAT nor SBS does in fact eliminate sampling errors. Both PAT and SBS sometimes violate TOS’ fundamental sampling principle (FSP). Depending on the working principle (reflective vs transmitive SBS) and the arrangement of the detection hardware, not all components will always have the same probability of being detected; likewise reflective technologies only observes particle surfaces. And **all** process analytical technologies must be calibrated and validated with respect to *relevant* and *reliable* reference materials/data, which in turn **must be** extracted by representative physical sampling.

The constitutional heterogeneity (CH) and the distributional heterogeneity (DH) of a given test material give an understanding of the grade variation of the lot to be processed (SBS); a proper heterogeneity characterisation is essential in order to ensure that representative training and validation sets are provided for the

Figure 3. On-site containerised, semi-mobile chute-type sorter installation.

Figure 4. Another instance of a system which, like SBS systems, in principle can sample and characterise all individual fragments (individual fish in this case)—comparatively rare occurrences in the domain of TOS.

critically important sorter calibration. But there can never be an automatic guarantee that the specific training set used will also be equally representative for all *future data sets*, for which reason proper validation of multivariate calibration models appears on the agenda.[3,4] As described in the literature, sampling, calibration and validation form a trinity in PAT and thus also SBS applications. Variographic analysis is identified as highly relevant and directly applicable for process efficiency testing and evaluation also for the case of SBS systems.[3]

A rare occasion: CH = DH

Sensor-based sorting systems transform the dimensionality of original 3-D, 2-D or 1-D lots—to a 0-dimensional body, as it is the effective total lot that is sampled (i.e. imaged). In fact, sensor-based sorting systems are intended to scan and characterises **all** single particles in the process stream (**all** lot fragments in the TOS parlance) as they appear in the cross section of the 1-D process lot. Upon reflection it becomes clear that if scanning all particles of a process stream individually can be achieved (all fragments are "sampled" with 100% efficiency), DH *vanishes*! One could alternatively say that the grouping and segregation error (GSE) is completely eliminated in properly designed, installed and maintained transmitive SBS systems. In such a case, FSE can easily be determined empirically as the difference between the nugget effect and sill in a variographic analysis of the sorter's process data—provided that the SBS system operates fully according to its design paradigm such that no incorrect sampling errors (ISE), nor total analytical errors (TAE) crop up in practical operations. There are few systems in which **all** individual fragments are sampled and analysed—but such an SBS system provides another example. One other such system that the author is aware of concerns primary sampling of off-loading streams of industrial fish catches, illustrated in Figure. 4.

Conclusion

This PhD study evaluates the technical and financial characteristics of sensor-based sorting technologies as well as the scenario for its implementation in mining applications. The thesis introduces a technical–economic framework and methodology for project development and evaluation, for implementation, for efficiency testing and optimisation and for future research and development. The Theory of Sampling plays a minor, but far from trivial role in the SBS context.

Acknowledgements

Appreciation goes to Professor K.H. Esbensen, GEUS (external co-supervisor) for introduction to TOS, for illuminating discussions and for revisions of selected parts of the draft thesis.

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