Current Status and Prospects of Mineral Sorting Technology Research at Home and Abroad

Guanglin Qin[1,*], Lianxi Sun[2], Yunzhi Liu[2], Xiaoguang Zhang[1], Xiaolei Jing[2], Qiang Ji[1]

[1]Shandong Gold Mining Technology Co., Ltd. Metallurgical Laboratory Branch, 261400, Shandon Yantaig, China
[2]Chifengshan Jinhongling Nonferrous Mining Co., Ltd. 025463, Neimenggu Chifeng, China

Abstract. With the continuous exploitation of mining resources, the grade of selected ores gradually decreases, and the cost of crushing, grinding, and beneficiation gradually increases. The pre selection and waste disposal of crushed products can improve the utilization rate of resources and the grade of ore entering the mill, reduce the amount of ore entering the mill, improve the economic benefits of enterprises, improve environmental conditions, and extend the service life of tailings ponds in mining enterprises. This article focuses on the development and application research status of color sorting machines, X-ray sorting machines, and artificial intelligence sorting machines, and looks forward to the development direction of intelligent sorting machines.

1.Introduction

Mineral resources, as the foundation of human society's survival and development, play a crucial role in the overall development of the national economy. The overall endowment conditions of mineral resources in China are relatively poor, with typical characteristics of poverty, abundant minerals, fine particle size distribution, and complex co-generation relationships. In recent years, with the continuous overexploitation of mineral resources and the continuous depletion of resources, the reserves of high-grade and easily selected ores have become increasingly scarce, and ore impoverishment has intensified[1,2]. The proportion of low-grade and difficult to select ores has continued to rise, resulting in a significant increase in beneficiation costs. According to statistics, the cumulative stockpile of waste rock in China has exceeded 40 billion tons. Faced with the current situation of selecting ores and storing waste rocks, developing sorting and beneficiation technology can improve resource utilization and ore grade, reduce the amount of ore entering the mill and the production of fine-grained tailings, enhance the economic benefits of enterprises, improve environmental conditions, and extend the service life of mining enterprises[3-5].

2.Development history of intelligent sorting machine

Intelligent sorting technology originated from manual selection, which is based on the identification results of the unique physical characteristics of ores, such as color, particle size, density, radioactivity, transparency, optical properties, etc., or the spectral analysis results of ores based on various types of radiation, to achieve the sorting of valuable ores. The intelligent sorting technology has undergone a development process from optical selection technology to the integration of multiple technologies such as radiation, image, and intelligent algorithms, as shown in Figure 1. In 1905, Austrians were the first to develop a light sorting machine; In 1947, Sortex successfully produced the first photoelectric sorting machine; In 1950,

The Soviet Union developed the APJI X-ray fluorescence sorting machine. In the 1960s and 1970s, due to the development of electronic engineering, photoelectric sorting technology experienced rapid growth in the field of mineral processing; In the 1960s, Sortex collaborated with De Beer to develop the XR series photoelectric sorting equipment for diamond sorting and the 621M photoelectric sorting machine for processing gypsum, dolomite, salt, and other materials. China began developing ore sorting equipment in the 1960s and built its first photoelectric beneficiation workshop in 1969. In 1979, Jiangxi Institute of Metallurgy and Xialong Tungsten Mine jointly developed China's first flat belt polishing machine.

In the 21st century, with the development of computer vision technology, image processing algorithms and pattern recognition technology have been widely applied. Since the emergence of X-ray sorting technology, different companies at home and abroad have developed unique core technologies, especially various equipment developed by domestic related companies. Significant breakthroughs have been made in performance and effectiveness, and it is widely used in major mining enterprises. Among them, X-ray transmission technology (XRT) has become mainstream.

With the rapid development of new sensor technologies and AI, imaging technologies based on optics, X-rays, laser-induced, microwave and other technologies have attracted the attention of mining

*Corresponding author: 49260892@qq.com

enterprises, especially in the field of sorting. Among them, XRT is currently the most widely used sensor information acquisition technology, and has achieved industrial applications in non-ferrous metal mining enterprises such as tungsten, tin, molybdenum, antimony, lead zinc, copper, manganese, platinum, and gold mines.

In actual production, due to the limitations of each detection sensor, most companies will try "sensor fusion" when faced with the selection of complex and difficult materials. For example, Novo Resources uses XRT and electromagnetic induction sensors to sort the Karratha gold mine in Australia. XRT can identify mineral particles with high atomic mass (such as gold), while electromagnetic induction can identify ores charged due to the presence of metal particles; Vista Gold combines XRT and laser sensor technology for ore sorting at the Mt Todd gold mine in Australia. The laser sensor is used to detect quartz in the ore after XRT sorting. Looking at the international ore intelligent sorting market, countries such as the United States and Japan do not have an advantage in the field of ore sorting, while Europe and Australia have been active in technology research and application, and have always been in a leading position.

In terms of current development trends, the pre enrichment stage before ore selection is of crucial importance for the transformation, energy conservation, consumption reduction, and green sustainable development of the entire mining industry. Although Chinese enterprises started relatively late, they have developed rapidly, such as Ganzhou Good Friends Technology, Tianjin Meiteng Technology, Beijing Holisite Technology, and even started to "go global" to explore overseas markets.

3.Intelligent Sorting Technology and Its Significance

Intelligent ore sorting technology can improve the grade of the selected raw ore, reduce the amount of grinding and beneficiation, lower the discharge of fine-grained tailings, and enhance beneficiation efficiency and economic benefits. The decrease in the amount of ore dressing has also led to a reduction in the amount of ore dressing wastewater and fine tailings, thereby reducing the pollution caused by ore dressing wastewater and tailings, and has significant ecological and environmental protection benefits; Pre selection and early disposal of tailings, especially in underground mining sites, can reduce the transportation costs of ore and tailings. Moreover, the tailings particles generated by pre selection and disposal are large, which is beneficial for tailings to be used as raw materials for underground filling, tailings dam construction, construction, and road construction, ultimately providing reliable support for the construction of low tailings and tailless mines; Waste rock, tailings, and other valuable components can be processed using pre selection and tailings disposal technology to reach the boundary grade, and then ore dressing and recycling can reduce the loss of mineral resources and environmental pollution hazards, achieving the transformation of waste into treasure.

4.Intelligent Sorting Technology and Application

4.1. Color selection and tail throwing technology

Color sorter, also known as photoelectric color sorter, is a high-tech product that integrates mechanical, optical, electronic, pneumatic, and control functions. It uses the principle of photoelectric to detect and separate minerals of different colors from a large number of samples. When there is a significant difference in color between gangue and ore, the color sorter can effectively separate them. Typically, color sorting machines are divided into four parts based on their functional structure: feeding system, irradiation and detection system, information processing system, and separation execution system[6]. The principle of photoelectric color sorting is shown in Figure 1.

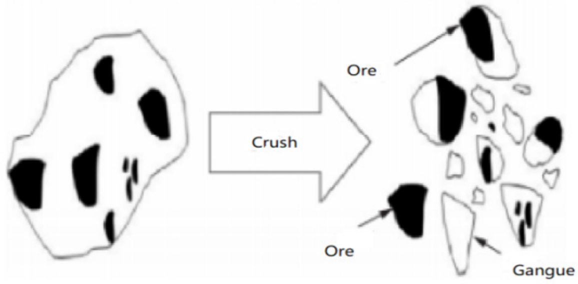

Fig. 1. Principle diagram of photoelectric color sorter sorting

Color selection mainly uses visible light, ultraviolet light, infrared light, etc. to irradiate minerals, and uses detectors to detect surface feature differences such as color, transparency, luster, reflectivity, and absorption rate of different minerals in the ore. Further, through image recognition and sorting, the executing mechanism separates useful minerals from gangue selection. The Hushan Fluorite Mine in Suichang County, Zhejiang Province, has introduced a track type color sorter to solve the problem of difficult manual sorting of 50-10mm particle size fluorite. The sorted concentrate contains about 80% CaF_2 for external sales, and the tailings containing about 50% CaF_2 are sent to a flotation plant for sorting and treatment. Guangxi Coral Tungsten Tin Mine adopts Mogensen Sort Typ AP 1200 color sorter for pre selection and tailings disposal. Compared with manual waste disposal, the waste disposal rate is increased by 14%, and the qualified ore grade is correspondingly increased by 16%, reducing labor costs by about 1.8 million yuan/year and reducing beneficiation processing costs by 2.298 million yuan/year. A gold bearing quartz vein ore in South Africa was pre selected and tailings were thrown using a photoelectric sorting machine, which can increase the gold grade of the ore from 2.5g/t to 6.5g/t for grinding[7].

4.2. X-ray tail throwing technology

In X-ray sorting (XRT) technology, since the characteristic X-rays of each element are unique, X-ray sorting utilizes the characteristic X-rays generated by the excitation of the ore after being irradiated with X-rays. By measuring the energy and intensity of the characteristic X-rays, the corresponding elements and their contents are determined, and useful minerals and gangue are separated through the execution mechanism. The principle of XRT intelligent sorting process is shown in Figure 2.

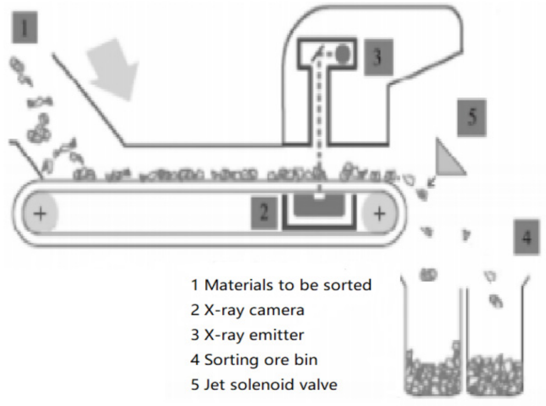

Fig. 2. Schematic diagram of X-ray sorting

The X-ray sorting equipment has high sorting accuracy and has been used for pre selection and tailings disposal of black metal ores, non-ferrous metal ores, precious metal ores, and coal mines. Jiugang Huashugou iron ore adopts XNDT-104 intelligent sorting machine for pre selection and waste disposal, with a waste disposal rate of about 13%. It can achieve indicators such as tailings grade less than 10%, iron recovery rate greater than 96%, and pre selected coarse concentrate iron grade increased by more than 3.6%. A low-grade lead-zinc mine in Zhejiang Province used XNDT-104 intelligent sorting machine for waste sorting, with a waste sorting rate of 27.42%. The waste rock thrown out has a lead+zinc grade of 0.27%, which is lower than the lead+zinc grade of flotation tailings by 0.30%. The lead and zinc recovery rates are 94.59% and 94.20%, respectively. A low-grade tungsten molybdenum mine in Hunan Province was subjected to semi industrial testing using LPPC 1-50 X-ray radiation sorting machine. The comprehensive waste rejection rate of block shaped ores with particle sizes of 40-20mm and 20-10mm reached 39%, and the comprehensive loss rates of molybdenum and WO_3 were 10.67% and 5.78%, respectively.

4.3. Artificial intelligence sorting

Artificial intelligence technology is an emerging and rapidly developing technological science based on statistics, which simulates human thinking and judgment operations through computer programs. Artificial intelligence first inputs a large amount of data for a certain type of problem into an artificial intelligence system for training, enabling it to learn problem-solving strategies. When encountering the same problem, it can solve it through empirical knowledge and accumulate new empirical data[8]. The operation process of the artificial intelligence computer vision system is shown in Figure 3.

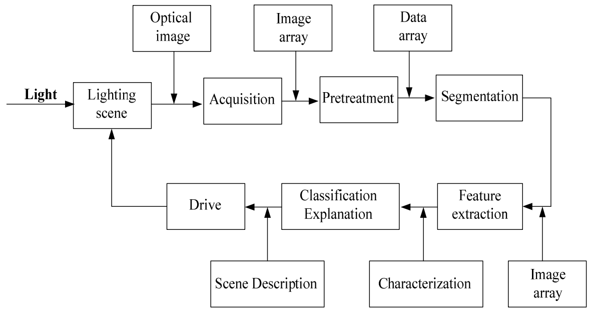

Fig. 3. Typical operation process of computer vision system

As the development and utilization of mineral resources gradually shift towards the direction of "poor, fine, and miscellaneous", traditional mineral processing is difficult to adapt to the current situation of mineral resource development and utilization due to the complexity of the production process. Process parameters, control parameters, and indicators such as final product grade and recovery rate cannot be reflected in mathematical models to reflect their corresponding relationships and decision-making principles. Moreover, the production process relies heavily on manual experience, resulting in a lack of stability and interpretability[9]. For this reason, scholars in mineral processing and related fields have conducted extensive theoretical research and process experiments, among which the combination of artificial intelligence and mineral processing has become an important research direction of concern for domestic and foreign scholars. At present, it is mainly applied in mineral recognition, grinding, flotation and other mineral processing technologies.

4.4. Joint process Throwing Tail

With the gradual depletion of high-grade and easily selectable mineral resources, there are more and more poor, fine, and difficult to select mineral resources. Using a single pre selection and tailings disposal technology often cannot achieve good results. In order to further reduce the cost of pre selection and tailings disposal, improve the technical indicators of pre selection and tailings disposal, and the comprehensive utilization level of mineral resources, the use of combined processes such as photoelectric beneficiation reselection, flotation reselection, and magnetic separation flotation for pre selection and tailings disposal has become an important direction for research and application[10].

4.5. Other Processes

In recent years, with the gradual advancement of technology, some mineral processing workers have gradually expanded the application fields of pre enrichment technology to microwave heating separation and infrared heating separation, but this is only limited to the laboratory research stage and there are no industrial application cases yet. In microwave heating selection, the difference in dielectric constant between metal minerals and gangue minerals is utilized to create a certain temperature difference between gangue minerals and metal minerals. An infrared thermometer is used to eject the gangue minerals from the ore, thereby achieving pre enrichment of the ore. In the field of infrared heating and sorting, the Japan Institute of Physical Engineering has successfully developed a classification and identification instrument that uses the characteristics of near-infrared radiation to produce different intensities of light on plastics for computer classification and storage. By comparing with the computer during the inspection of waste plastics, it is possible to distinguish and classify them, which can be effective for more than 50 circulating types. It may be applied in the field of ore sorting in the future.

5. Conclusion and Prospect

(1) As ore mining continues, the grade of ore selected gradually decreases. Using an intelligent sorting machine to dispose of the selected ore can help improve the ore selection grade, reduce beneficiation costs, and extend the service life of the tailings pond.

(2) In the field of intelligent ore sorting, the main sorting equipment includes colored sorting machines, X-ray sorting machines, and artificial intelligence sorting machines. The color sorter sorts ores based on their surface color, and the greater the color difference, the better the sorting effect. The artificial intelligence sorting machine is based on the characteristics of ore surface texture, color, etc., and still belongs to the category of surface recognition. X-rays can penetrate ore particles, effectively avoiding the occurrence of ore being wrapped by vein stones, which is of great help in improving ore recovery rate. At present, X-ray sorting machines occupy the majority of the market share in the field of ore sorting.

(3) The maturity of domestic intelligent sorting technology and equipment is gradually increasing, but there are also problems such as low processing capacity and further improvement in sorting accuracy. On the one hand, it can be solved through the diversification of detection technologies, such as dual energy XRT technology and X-ray+visible light technology. On the other hand, by improving the performance of sorting equipment and establishing a refined sorting scheme for complex minerals, precise separation of ore and gangue can be achieved.

References

1. TIAN Zhigang. Experimental research of XRT intelligent sorting machine in Fankou lead-zinc mine[J]. Mining Research and Development, 2019, 39(12): 153-156.
2. ZHU Biao. Experimental study on photoelectric pre-selection of a specularite ore [J]. Modern Mine, 2020(12): 114-115.
3. LIU Mingbao,YIN Wanzhong,GAO Ying. Ore sorting by X-ray separation technology [J]. Non-ferrous Metals,2011(S1):177-180.
4. Cai Yazhou, Wang Shaozhong. Application of photoelectric ore sorting technology in Saudi Arabian phosphate mining industry[J]. Industrial Minerals & Processing, 2016(7):63-65.
5. LIU Guangyu. Experiment and research of X-ray separator in pre-selection of moly-bdenum ore[J]. Modern Mining, 2009(10):75-77.
6. LIU Mingbao,YIN Wanzhong,HAN Yuexin,et al. The study on the X-ray separator and its pre-sorting test of the low grade ore of Mo and Ni [J]. Mining and Metallurgy, 2012,21(4): 26-29.
7. WANG Tuanfeng. Study on Online Sorting Method of Gold Ore based on X-ray Fluorescence Technique [D]. Luoyang:Henan University of Science and Technology, 2017.
8. ZHANG Qian, CHEN Chen, WANG Wencai, et al. Experimental study on pre-enrichment of thorium minerals by an X-ray sorter[J]. Mining and Metallurgy, 2021, 30(4): 20-25.
9. CHEN Mingwen, GUO Zhenxu,SONG Ge,et al. Technical analysis of LED light source applied in the feldspar photoelectric configured picker[J]. Zhaoming Gongcheng Xuebao, 2016,27(3): 114-120.
10. Li Baowei, Wang Jianying, Zhang Tiezhu. et al. A process for the si-multaneous efficient recovery of rare earth and precious metal from polymetallic ores[P]. Chinese invention patent, CN103041996, 2013-01-06.