On Sensor-Based Ore Sorting*

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Abstract

The high cost of mineral processing in mining industries keeps rising. Sensor-based ore sorting is key in helping the mining industries to sort out ore to help reduce the processing and production costs. With the implementation of sensor-based ore sorting at the primary stage, it assures of separating larger volumes of the barren gangue from the conveyor-transported ore before excessive handling and mixing occurs. Hence, this paper investigated and evaluated the deployment of the colour camera and the dual energy X-Ray sensors. The successful operation at 2.8 m/s and 3.2 m/s of conveyor speed, and relatively extreme positions of the air jet-based separation mechanism for the sorting proved robustness in separation of barren gangue from the ore feed.

Keywords: Conveyor Speed, Ore Feed, Ore Sorting, Sensors, Separation Mechanism

1 Introduction

Mining is one of the most expensive and capital-intensive businesses. At the initial stage of mining, the grade distribution of every ore body to be mined is determined. From grade control drilling through to the modelling stage helps to know if an ore would be a low grade, a high grade or even a marginal one. But this does not give a full assurance on the efficiency of the feed ore after it has gone through the various processes till crushing. Most mining companies in developing countries hardly sort out ore after crushing has been done but go ahead with ore processing. Hence, after materials are mined from the ground, portions of them that have no beneficial use or value are typically separated or extracted from the portions that have beneficial use or value (Bamber and Houlahan, 2015).

Ore sorting is a mineral concentration process where individual ore particles are separated from the unwanted material based on some physical or chemical property (Strauss, 2016). Ore sorting can be used for pre-concentration or waste rejection, ore-type diversion and concentration to product. Ore sorting implemented after primary crushing assures of separating larger volumes of the barren gangue from the conveyor-transported ore. Before excessive handling and mixing occurs, the ore sorting needs to be conducted in the early stages of the process to increase productivity. This also has the potential to reduce mass of the ore to be processed, water, energy consumption and processing costs (Duffy *et al.*, 2015; Wotruba, 2016). Mining companies in Ghana are yet to bring ore-sorting technology into their operations for enhanced productivity.

Sensor-based ore sorting can be applied to particles and this is known as particle sorting or ore applied to sort bulk materials, which is known as bulk sorting. Sensor-based ore sorting is a technology applied by mining industries to reject barren particles (in a size range between 10 mm and 100 mm) of a heterogeneous ore at an early stage (Kern *et al.*, 2019). The stages of ore sorting include particle preparation, presentation of feed, sensing and processing and particle separation. There are several reasons and possibilities in the output flow sheet of mineral processing for the implementation of sensor-based ore sorting. The technical and financial feasibilities depend primarily on the type of mineralisation as sensor-based ore sorting takes advantage of heterogeneity at relatively large particle sizes. Sensor-based ore sorting results in separation of ore types, decrease in mining cost, and reduction in water consumption, energy and consumables (Strauss, 2016; Wotruba, 2016). Ore separation mechanisms could be electrostatic, use of water jets, pneumatic valves, high pressure air jets, mechanical flaps, and suction nozzles (Anon., 2015; Ciccu, 2019; Kern *et al.*, 2019). However, the reliability and efficiency of sensor-based sorting are highly dependent on the discrimination of physical properties of each particle. Sensor-based ore sorting helps to discriminate and separate enriched ore from the feed ore after crushing. Further processing of the crushed ore involves processing larger volumes of material, which is expensive and energy intensive. In order to reduce energy consumption, sorting needs to be done so that the rejected ones can be sold to the local markets to serve other useful purposes. The process of this separation of barren gangue from the feed ore is termed as pre-concentration. Pre-concentration reduces the total mass which would proceed to the next stage of processing and will be very effective when the right ore sorters are implemented to remove all barren gangue from the ore feed (Duffy *et al.*, 2015).

In recent times, Oladapo *et al.* (2016), and Mazhary (2017) developed sorting machines using different types of sensors to sort low-grade ore and waste to obtain mineralised ores by separation.

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Table 1 Sensors Deployed in Real– time Ore Sorting

SN	Sensor Technology Type	Property Detected	Applicable To
1.	Electromagnetic (EM).	Conductivity and Permeability.	Base metals.
2.	Radiometric (RM).	Natural Gamma Radiations.	Uranium, Precious metals.
3.	X-Ray Fluorescence (XRF).	X-Ray Fluorescent.	Diamonds.
4.	Near Infrared Spectrometry (NIR).	Reflection and Absorption.	Base metals, Industrial minerals.
5.	Colour Camera.	Reflection, Brightness and Transparency.	Base and Precious materials, Industrial minerals, Diamonds.
6.	Magnetic Resonance.	Specific Radio Frequency Spectra Lines	Chalcopyrite.
7.	Dual Energy X-Ray (DE-X-Ray)	Atomic Density	Base and Precious materials, Industrial minerals, Fuel, Diamonds.

Other tests such as hand sorting, bench scale test, sink and float tests with heavy liquids, jig stratification and many others were done by Dumont *et al.* (2017) and Neto *et al.* (2019). The efficiency of sorting on different types of feed was also determined by Strauss (2016). Robben and Wotruba (2019) gave state-of-the-art of sensor-based ore sorting. Phiri *et al.* (2018), and Iyakwari and Glass (2015) used NIR on copper. X-ray Transmission (XRT) sensor was used on some minerals by Neto *et al.* (2017). With the help of an active sensor, Bamber and Houlahan (2015) analysed minerals received within a mining shovel bracket while Kern *et al.* (2019) successfully selected a sensor for sorting. Pingitore Jr *et al*. (2016) visually compared ore peak sizes by way of energy dispersive XRF analysis and Duffy *et al.* (2015) also integrated bulk ore sorting. Robben *et al*. (2020) successfully deployed XRT sensor-based ore sorting, and Wotruba (2016) elucidated the benefits of sensor sorting technology.

Based on review of the literature, it is observed that sensor-based sorting technologies provide potential applications for pre-concentration of ores. XRT, NIR and XRF are currently the dominant sensor technology applications. However, use of the colour camera sensor combined with air jet separation, with sorting at preferred speeds has not been given the due attention.

The objectives of this paper are to utilise the colour camera sensor in gold ore sorting at preferable varying conveyor speeds and air jet separation mechanism position. The rest of the paper is structured as follows: Ore sorting technologies, design concept and simulation models for conveyor speed and separation mechanism are provided as the resources and methods used in Section 2. Section 3 gives the results and discussion, and the conclusion is presented in Section 4.

2 Resources and Methods Used

2.1 Ore Sorting Sensor Technologies

A number of sensor technologies used in ore sorting in real-time are summarised into Table 1. Physical properties of gold ore include having a shiny surface, it is opaque, rich yellow, paling to whitish-yellow in colour, measures 2.5-3 on Mohs hardness scale, exhibits good electrical conductivity, and has a density of 19.3 g/cm^3 (King, 2021).

For a sensor selection, some material information that can be used for identification, classification and sorting are magnetic susceptibility, conductivity, particle size, transparency, colour, fluorescence, brightness, specific gravity and radioactivity. The sensors to be deployed in this system are based on the sensors' ability or reactions to the various properties of the gold ore. In this paper, consideration is given to two sensors, namely, the colour camera and dual-energy X-ray sensors. The colour camera detects the reflectance, brightness and the transparency of ore. Aside, it helps in sorting based on the rich yellow to paling to whitish-yellow colour of gold. The dual-energy X-ray sensor is selected because it measures photon energies in two ranges and determines the average density, which is a property of the gold ore.

2.2 Design Concept

The system is a sensor-based ore sorting system to be used after the crushing stage. The whole system is aimed at using the two different sensors to separate mineralised ore from feed ore. The block diagram illustrating the major components is as shown in Fig. 1.

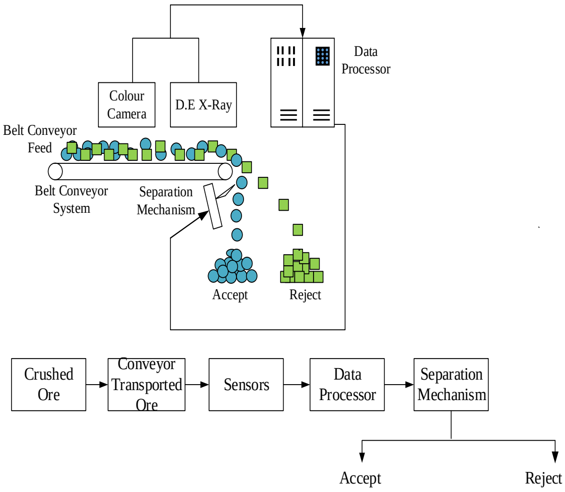

Fig. 1 Functional Diagram of the Proposed Design of Sensor-based Ore Sorting

The jaw-crushed, screened ore is presented to the sensor using vibrating feeders and onto the conveyor belt. The sensors, positioned on top of the conveyor belt, detect the gold ore and the data from the sensor system is then processed by the processor in real-time to make the "yes or no" ejection decision for each particle. The particle to be separated is then selectively ejected by high-pressure air jets (that serve as the separation mechanism) after the processor decision is made.

The data processor is programmed with images of known minerals and ore types. Pixels from these images, which represent characteristic colours of each type are stored in the memory of processor. These data can be viewed as points in a 3-dimensional array with red, green and blue strengths as the axes. The data collected from each ore during the sorter operation are then compared with the representative array to come up with the sorting decision. A flowchart of the separation mechanism is as shown in Fig. 2. The steps of the flowchart are as follows:

Step 1: Start by initialising the system.
Step 2: Find out whether there is ore to be ejected, if no, wait for processor command, if yes, orientate the servomotors.
Step 3: If servomotors are correctly oriented, open valve according to coordinates; if no, orientate the servomotors.
Step 4: When valves are open, wait for 20 secs for ore separation before you close valve; if valves
are not open, go to Step 3.
Step 5: Check to see if valves are closed: If no, go to Step 4, if yes, return the servomotors to home position.
Step 6: End when servomotors are in home position else, go to Step 5.

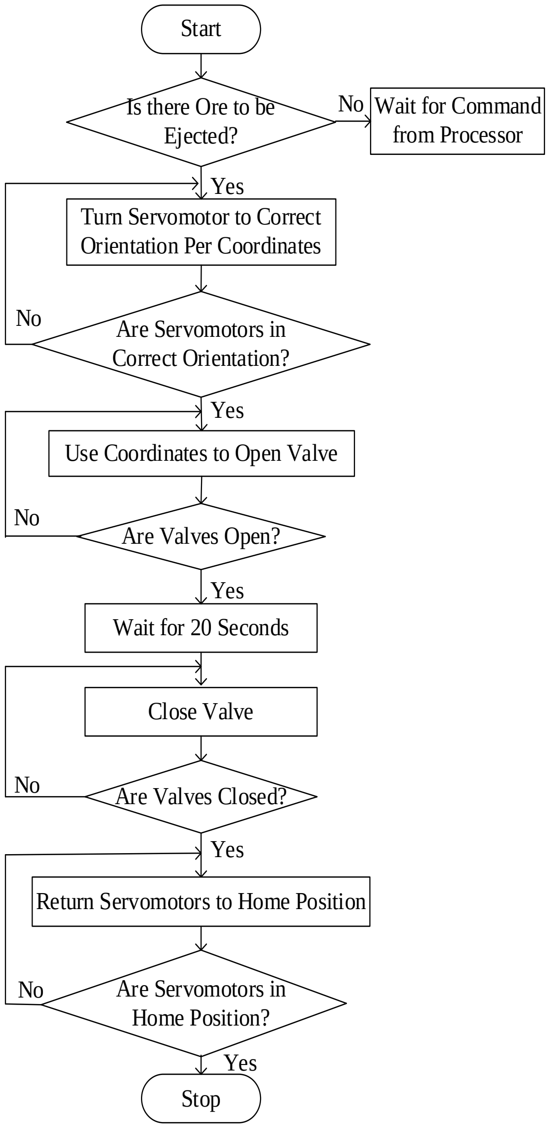

Fig. 2 Flowchart of the Separation Mechanism

2.3 Proteus Design Suite Simulation Model

Models for the simulation of the ore sorting system were created in Proteus Design Suite (PDS) software. Figs. 3 and 4 show simulation models for conveyor speed and separation mechanism, respectively. On the simulation model schematics of Figs. 3 and 4, the various speeds are represented by switches (SPEED 1, SPEED 2, SPEED 3), and the Light Emitting Diodes (LEDs) (D2, D3, D4). The LEDs are used for speed indication. The ejection mechanism, however, is represented by air valves 1, 2, and 3, and the air direction servomotors 1, 2, and 3. The air direction servomotors orientate the air valve through a span of 360° for the effective ejection of ore. The system is programmed such that the various elements aptly communicate with the ATmega microcontroller.

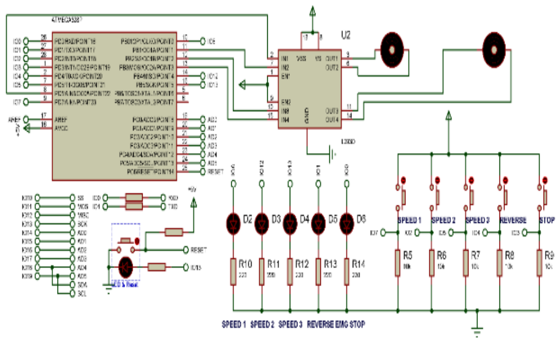

Fig. 3 Proteus Simulation Model for Speed of the Conveyor System

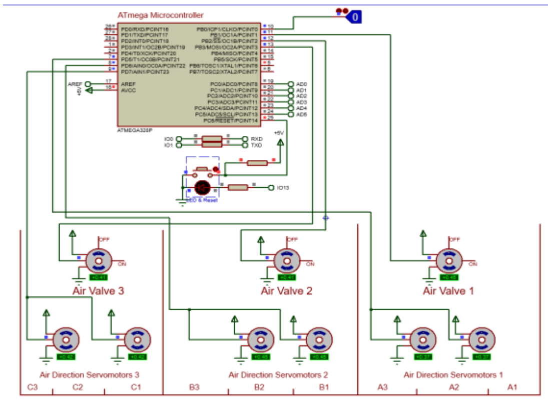

Fig. 4 Proteus Simulation Model for the Separation Mechanism

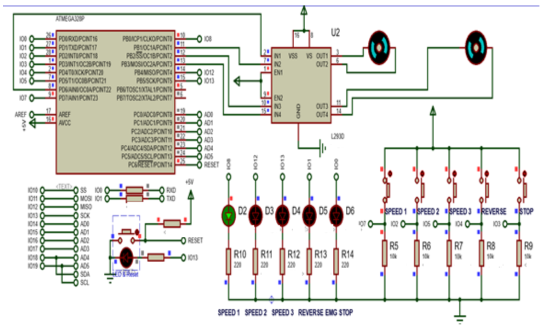

Fig. 5 Conveyor System Operating at Speed 1 of Value 2.8 m/s

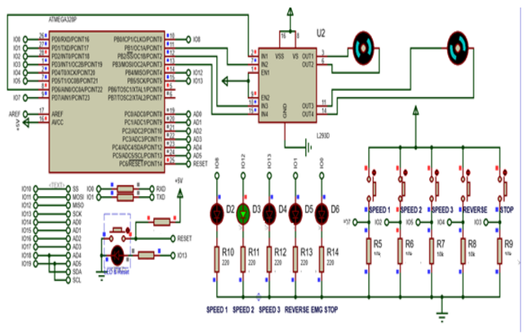

Fig. 6 Conveyor System Operating at Speed 2 of Value 3.2 m/s

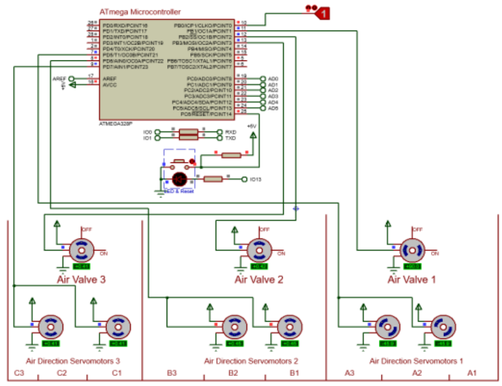

Fig. 7 Ejection by Separation Mechanism at Position A1 at an Angle of Negative 45º

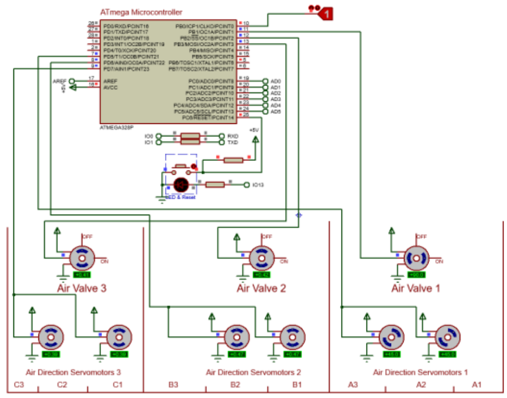

Fig. 8 Ejection by Separation Mechanism at Position A3 at an Angle of 270º

3 Results and Discussion

3.1 Simulation Results

The simulation results are as shown in Figs. 5 to 8. In Figs. 5 and 6, the conveyor system was operated at 2.8 m/s and 3.2 m/s, respectively. In the simulations, the separation mechanism was made to eject at two separate positions namely, at angles of negative 45º and positive 270º, respectively. These two angles, extreme from each other, was meant to demonstrate robustness of the separation mechanism in terms of the ability to correctly orientate the servomotors to open the air valves in order to direct the air jets to equally deal with peripheral positions of the "Accept" and Reject" ores just after their exit from the belt conveyor system. From Fig. 5, it can be seen that, the switch "SPEED 1", and the LED "D2" operated for the desired nominal speed of 2.8 m/s. Commensurate with the hitherto inherent situations of meeting production targets that arise some of the time, prudent increment in speed is required. This situation was simulated as evidenced from Fig. 6, where the switch "SPEED 2", and the LED "D3" went active for an increment in speed of 14.3%, from 2.8 m/s to 3.2 m/s.

3.2 Discussion

The successful simulation of the conveyor system presented the fact that the system can be operated at different speeds based on the user's preference as shown in Figs. 5 and 6. When there is an ore to be ejected at position A1 (-45°) as shown in Fig. 7, the servo motors turn to orientations of the position of ores to be ejected to open the valves to allow ejection to take place, if not, they remain in their original positions. In Fig. 8, the servomotor turned to the position of A3 (270°), as the valves open to allow ejection to take place. The combination of variations in speed and position enhances robustness of the designed sensor-based ore sorting system. The system was designed to sort ores of particle sizes not more than 700 micrometres and assures of at least 80% accuracy in the ejection process.

4. Conclusion

The designed system is capable of operating at specified speeds, and ejects non-mineralised ores at any position on the conveyor belt. The designed sorting system assures of reduction in production cost, energy and water consumption upon field implementation. It is worth recommending that mining companies in Ghana need consider sensor-based ore sorting to achieve further reduction in electric power consumption and processing costs. Our extension of this research will involve prototyping the system as a step towards field implementation in Ghana.

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