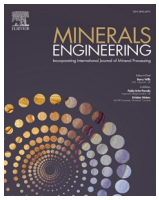
Minerals Engineering 189 (2022) 107884

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng



A critical review of artificial intelligence in mineral concentration

Allan Gomez-Flores [a], Sadia Ilyas [a], Graeme W. Heyes [b], Hyunjung Kim [a,*]

[a] Department of Earth Resources and Environmental Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea
[b] CSIRO, Mineral Resources Division, Clayton, VIC 3169, Australia

ARTICLE INFO

Keywords:
Artificial intelligence
Mineral concentration
Gravity separation
Density separation
Magnetic separation
Sensor–based sorting (SBS)

ABSTRACT

Although various articles have reviewed the application of artificial intelligence (AI) in froth flotation (summarized in this article), other unit operations for mineral concentration in mineral processing have not been reviewed. Thus, this article reviews AI application in various unit operations for mineral concentration. Because unit operations for mineral concentration deal with yields not necessarily linearly correlated with input variables, subsequent yield prediction using AI can add value to their control. The current applications of AI have neglected fundamental variables (e.g., particle agglomeration, particle magnetic susceptibility, particle wettability, particle surface charge, and particle Hamaker constant) as inputs for prediction. Instrumentation and industrial simplicity have hindered the consideration of those variables because validation is required. There are kind learning (repeated patterns and high accuracy measurements) and wicked learning (continuously novel patterns and noise in measurements) environments, which are suitable and challenging for machine learning, respectively. Kind learning environments were largely used for the applications of AI. Furthermore, flow can be captured by AI (e.g., neural networks) to attempt to control drag and mixing using synthetic jet type actuators in equipment (shaking tables, fluidized beds, or vessels). Thus, future applications of AI should consider these points.

1. Introduction

Artificial intelligence (AI) is the ability of machines to imitate human intelligence. Four research approaches describing AI can be found in the literature (Russell and Norvig, 2020). The total Turing test approach describes AI as acting like a human, requiring mental and physical skills. The cognitive modeling approach describes AI as thinking like a human, requiring psychology and brain imaging to develop a theory of the human mind, which is later transcribed into a computer program. The laws of thought approach describes AI following the logic theory used to make a computer program based on the correct inference to solve problems. The rational acting approach describes AI as achieving an objective through knowledge and reasoning even under uncertainty. In other words, a computer program does the right thing to achieve the objective (Russell and Norvig, 2020). To date, human objectives have been provided, and AI has been built to benefit those objectives. This last approach has dominated AI applications and partially overlaps with the total Turing test approach. Thus, in this review, AI is treated following the total Turing test and rational acting approaches.

AI has been applied in medical science (Morley et al., 2020), finance and economics (O'Halloran and Nowaczyk, 2019), astronomy (Yang et al., 2020), environmental science (Goldberg et al., 2015), and other fields to solve problems that are challenging for human intelligence, such as finding patterns or processing large data to model nonlinear correlations. Similarly, the mineral industry has applied AI in mine planning (Noriega and Pourrahimian, 2022), blasting (Ghasemi et al., 2014), mineral processing (McCoy and Auret, 2019), and plant control (Ai et al., 2019; Morimoto and Hashimoto, 2000). Mineral processing subareas include ore handling (transportation, storage, feeding, and washing), analysis (sampling and particle sizing), comminution (crushing and grinding), screening, classification (hydrocyclone, sedimentation classifiers, and hydraulic classifiers), metallurgy, mineral concentration (recovery of valuable minerals), and dewatering. Previous review articles have covered AI application in analysis, comminution, classification, and mineral concentration (Bearman and Milne, 1992; Jovanović and Miljanović, 2015; Jovanović et al., 2015; McCoy and Auret, 2019; Mckee, 1991; Sommer et al., 1992). Besides froth flotation, unit operations in mineral concentration have not been reviewed. Thus, this review focuses on AI application in unit operations for mineral concentration. Fig. 1 shows the principal concept of the review. AI is the bridge between expected added value and unit operations. Moreover,

* Corresponding author.
E-mail address: kshjkim@hanyang.ac.kr (H. Kim).

https://doi.org/10.1016/j.mineng.2022.107884
Received 4 January 2022; Received in revised form 30 August 2022; Accepted 10 October 2022
Available online 25 October 2022