Editorial

Florian Pfaff* and Uwe D. Hanebeck

Sensor-based sorting

https://doi.org/10.1515/auto-2020-0023

In our modern age of globalization, the quantities of raw materials, products, and waste that are sorted, processed, and recycled are steadily increasing. Many products—ranging from grains to minerals—start their life cycle as bulk materials, i. e., material that is transported loosely in large quantities. Furthermore, many products also end up as bulk material in the form of recyclable waste when their current life cycle ends.

In many fields, such as mining, farming, and recycling, the bulk material is not homogeneous but a rather heterogeneous mixture. The utility and value of bulk materials can be increased by separating the mixture into multiple specified fractions. While some sorting techniques, such as magnetic separation or sieving, have been widely used for decades or even centuries, sensor-based sorting is emerging as a new promising technology for more difficult sorting tasks in which sorting based on physical properties is deemed infeasible.

Sensor-based sorters can sort almost arbitrary bulk materials that can be differentiated based on data of an electric sensor, such as a camera. After the particles have been classified based on the sensor data, a separation into multiple fractions is performed in a distinct separation step that involves flaps or air jets. Sensor-based sorters are important in recycling, and thus, they support a sustainable economy. Furthermore, they are used to ensure the quality of food and are important to ensure the affordability of minerals and ores.

While being versatile and flexible, sensor-based sorters are complex machines that come with a variety of challenges. First, suitable sensors and a reliable way to discriminate the particles of the different classes must be determined. A particular challenge is that the classification must be real-time capable and allow for high throughput. Second, a suitable separation mechanism that ensures that the fractions are separated reliably has to be implemented. There are several degrees of freedom (ranging from the design of the sorter to the preparation of the feed) that can be used to ensure the classification and separation are successful. Therefore, developing a sorter for a new mixture of bulk materials is a nontrivial and exiting engineering task.

This special issue of "at – Automatisierungstechnik" provides a broad overview of the topic, innovative ideas, and in-depth information on specific practical applications. We begin with an article that offers a comprehensive overview of the field of sensor-based sorting. The second and third articles present novel methods in the context of sensor-based sorting. The fourth and fifth articles go into detail on specific sorting applications.

The first article "Sensor-based ore sorting in 2020", written by Christopher Robben and Hermann Wotruba, provides an overview and some details on the history of sensor-based sorting. Due to their background in minerals engineering, the authors focus on applications in mining, which is where sensor-based sorting originated. The authors dissect the architecture of sensor-based sorters and lay out all the relevant phases of the sorting process, which include not only the material presentation, detection, and ejection, but also the feed preparation. Moreover, the authors describe which properties can be extracted and used for the classification of the particles. The article also provides details on the sensors and wavelengths that commonly employed in sensor-based ore sorting.

The article "Predictive tracking with improved motion models for optical belt sorting" by Florian Pfaff et al. presents an algorithmic innovation for a previously proposed design of an optical belt sorter that includes an area scan camera. In sensor-based sorting, there is a temporal gap between the detection of the particles and the actual separation. To bridge this gap, predictions are made that are based on assumptions about the particles' motions. The article addresses how an area scan camera can be used to obtain both information about the motion behavior of the bulk material particles in general and particle-specific information such as the velocity of each individual particle. By combining all information with a novel motion model, the authors are able to significantly improve the predictions.

In the article "Characterizing material flow in sensor-based sorting systems using an instrumented particle" by

***Corresponding author: Florian Pfaff,** Intelligent Sensor-Actuator-Systems Laboratory (ISAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, e-mail: florian.pfaff@kit.edu
Uwe D. Hanebeck, Intelligent Sensor-Actuator-Systems Laboratory (ISAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, e-mail: uwe.hanebeck@kit.edu

Georg Maier et al., the authors present a novel way to quantitatively assess the motion behavior of bulk material particles throughout the sorting process. To achieve this, a microcontroller and suitable sensors were tightly packed for integration into an artificial instrumented bulk material particle that resembles other particles in the bulk material stream. The sensor data allow for characterizing the bulk material and extracting material flow properties. As a proof of concept, the authors use sensor data to determine the part of the sorting process in which the particle is.

The article "Near infrared hyperspectral imaging-based approach for end-of-life flat monitors recycling" by Giuseppe Bonifazi et al. addresses the sorting of the milled remains of end-of-life flat monitors. The authors use a cascade to be able to implement the separation into several classes using simple sorters that can only subdivide the bulk material stream into two fractions. All decisions in the four-step cascade are based on hyperspectral images. The authors achieve good classification results and provide ideas how the classification can be further enhanced.

The article "Automated sorting of recycled paper using smart image processing" by Mohammad Osiur Rahman et al. addresses the topic of waste grade classification for paper waste. In paper recycling, higher revenues can be achieved when the paper is sorted according to different waste grades. The authors have previously proposed real-time capable algorithms for waste grade classification based on area scan camera images. The novel approach presented in this article is based on extracting eight regions of interest. By extracting and using features in the RGB or HSI color space, the authors are able to outperform previous approaches in a thorough evaluation involving over 400 objects.

Regardless of whether you are a novice in the field of sensor-based sorting that wants to get an overview or an expert in the field that is interested in the latest trends—we hope you enjoy reading this special issue of "at – Automatisierungstechnik"!

Bionotes

Florian Pfaff
Intelligent Sensor-Actuator-Systems Laboratory (ISAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
florian.pfaff@kit.edu

Florian Pfaff is a postdoctoral researcher at the Intelligent Sensor-Actuator-Systems Laboratory at the Karlsruhe Institute of Technology. He obtained his diploma in 2013 and his Ph.D. in 2018, both with the highest distinction. His research interests include a variety of estimation problems such as filtering on nonlinear manifolds, multitarget tracking, and estimation in the presence of both stochastic and non-stochastic uncertainties.

Uwe D. Hanebeck
Intelligent Sensor-Actuator-Systems Laboratory (ISAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
uwe.hanebeck@kit.edu

Uwe D. Hanebeck is a chaired professor of Computer Science at the Karlsruhe Institute of Technology (KIT) in Germany and director of the Intelligent Sensor-Actuator-Systems Laboratory (ISAS). He obtained his Ph.D. degree in 1997 and his habilitation degree in 2003, both in Electrical Engineering from the Technical University in Munich, Germany. His research interests are in the areas of information fusion, nonlinear state estimation, stochastic modeling, system identification, and control with a strong emphasis on theory-driven approaches based on stochastic system theory and uncertainty models. He is author and coauthor of more than 500 publications in various high-ranking journals and conferences and an IEEE Fellow.