Application of Area-Scan Sensors in Sensor-Based Sorting

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Abstract

In the field of machine vision, sensor-based sorting is an important real-time application that enables the separation of a material feed into different classes. While state-of-the-art systems utilize scanning sensors such as line-scan cameras, advances in sensor technology have made application of area scanning sensors feasible. Provided a sufficiently high frame rate, objects can be observed at multiple points in time. By applying multiobject tracking, information about the objects contained in the material stream can be fused over time. Based on this information, our approach further allows predicting the position of each object for future points in time. While conventional systems typically apply a global, rather simple motion model, our approach includes an individual motion model for each object, which in turn allows estimating the point in time as well as the position when reaching the separation stage. In this contribution, we present results from our collaborative research project and summarize the present advances by discussing the potential of the application of area-scan sensors for sensor-based sorting. Among others, we introduce our simulation-driven approach and present results for physical separation efficiency for simulation-generated data, demonstrate the potential of using motion-based features for material classification and discuss real-time related challenges.

Introduction

Sensor-based sorting provides state-of-the-art solutions to physically separate a material feed into predefined classes. It has found wide application in various industrial contexts, such as food processing, waste management and sorting of industrial minerals. In many cases, solutions are implemented in order to remove low-quality parts from a material stream. Hence, the task can be understood as executing an *accept-or-reject* decision [1]. The sorting process can commonly be subdivided into the tasks of feeding, preparation, presentation, examination, discrimination, and physical separation [2]. Typical setups are opto-pneumatic separators [3]. They consist of optical sensors for perceiving the material and compressed air nozzles for physically separating it. Also, commonly and independent of the spectrum they are operating in, systems utilize scanning sensors, such as line-scan cameras. Due to the movement of the material, scanning sensors allow generating two-dimensional images of objects passing through the field of vision.

With respect to transportation of the material for the presentation phase, the goal is to unscramble the individual objects and achieve ideal flow control [4]. The latter implies that each object contained in the stream is required to move at a defined velocity, along the transport direction. The reason for this requirement is that there exists a temporal gap between the perception and separation of the material. This delay is mainly caused by the time required for data analysis. On basis of the image data, regions of the input image that contain objects are extracted, features for the individual objects are calculated, and they are classified accordingly in order to derive a sorting decision. Consequently, the delay cannot be arbitrarily minimized. It is only information obtained at the point of perception that can be used to determine which air nozzle(s) to trigger at which point in time in order to deflect an object. Obviously, achieving perfect flow control is infeasible for certain products. In order to still reliably remove – potentially dangerous – objects from the feed, the activation time and number of nozzles triggered in order to deflect an object needs to be chosen sufficiently high. In turn, large deflection windows increase loss of the product to be accepted, since more objects are falsely co-deflected during activation.

Recently, we have proposed the application of area-scan cameras in the context of sensor-based sorting [5]. A schematic illustration of a corresponding system is provided in Figure 1. Using a high temporal resolution, multiple measurements of individual objects can be obtained. In order to find the correspondences between objects in consecutive frames, multiobject tracking is used. The parameters of a motion model are updated for each individual particle for each camera frame. This allows us to predict the position and point in time of an object reaching the separation stage based on tracking. Furthermore, information derived from the tracked objects, e.g. their trajectories, can be used for their discrimination. Obviously, our system causes an additional burden with respect to processing time compared with conventional systems. Therefore, we also address the challenge of respecting real-time requirements during multiobject tracking. In this paper, we summarize our approach and advances, thereby demonstrating the success of the method.

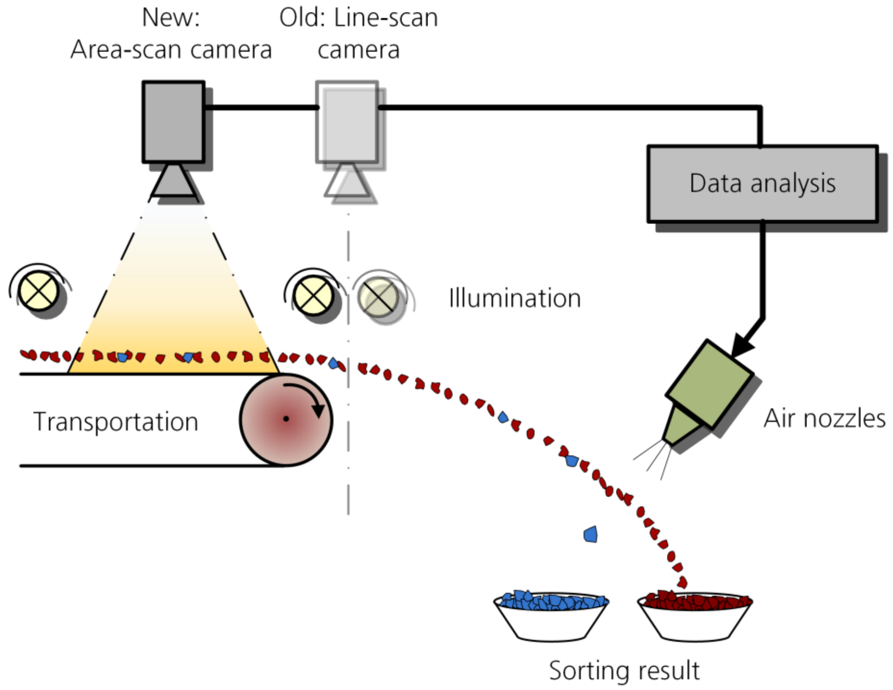

Figure 1: Schematic illustration highlighting the changes in system design.

Multiobject Tracking for Sensor-Based Sorting

As has been mentioned, state-of-the-art sensor-based sorting systems utilize scanning sensors. Hence, activation of the compressed air nozzles is based on the assumption of ideal flow control. More precisely, it is assumed that each object contained in the material stream is moving at the same velocity in transport direction and no velocity perpendicular to transport direction exists. Determination of the nozzles to be activated and the period of activation is entirely based on this assumption. Whether truth holds to these assumptions heavily depends on the system design and the sorting task, i.e. the product, at hand.

In order to break away from these requirements, we have proposed application of multiobject tracking for sensor-based sorting. Our tracking system is provided unlabeled measurements as its input. Those measurements are represented by the centroid of the 2D projection of the objects contained in the material feed, which can be obtained by utilizing image processing (pre-processing, segmentation, and connected component analysis). The tracking system can further be subdivided into the following stages, which are described in detail in the remainder:

- **State estimation** serves the purpose to predict the position at the next time instance for each currently existing track.

- **Gating** can optionally be performed to limit the search space for the subsequent step of association.
- **Association** is performed in order to determine the correspondences between current measurements and predicted actual positions.
- **Internal state management** takes care of updating existing tracks, creating new tracks and deleting tracks that have left the field of view.

For the task of state estimation, we employ a standard Kalman filter with a constant velocity model. Assuming the assignments between the measurements and the tracks are provided, knowledge about the positions of the particles is refined by performing a Kalman filter update step. State variables are given by the x and y coordinate of the centroid of the object as obtained via image processing as well as the velocities parallel and perpendicular to the transport direction, v_x and v_y, respectively. As a result, we predict an approximate position for each individual particle in the next time step (i.e. the next camera frame). Those predictions as well as the measurements of the current frame serve as the input for the gating and the association step. Gating aims at splitting the problem into several, smaller subproblems by partitioning the search space prior to association. During association, correspondences between the current predictions and measurements are identified. This requires solving a linear assignment problem. Various algorithms, varying in terms of computational complexity and quality, exist to solve this kind of problem.

Solving the association problem typically yields a high computational burden. In order to respect firm real-time requirements as existing in sensor-based sorting, we developed two approaches. The first approach is based on the idea of dynamically selecting an algorithm based on the current circumstances in terms of system load [6]. For instance, for frames containing a comparatively low number of objects to be tracked, we select a high quality algorithm with high complexity. In turn, for frames with high load, we switch to an algorithm that is lower in complexity at the cost of lower quality with respect to the associations. The second approach includes an optimized implementation of the *Auction Algorithm* for a GPU [7]. Using data obtained via simulation as described in more detail in the following subsection, we showed that this allows tracking of more than a thousand objects simultaneously with a temporal resolution of 100 fps.

Simulation-Driven Approach

For the development of our multiobject tracking system, we pursue a simulation-driven approach. The Discrete Element Method (DEM) was employed to numerically model the particle–particle and particle–wall interactions within the sorting system. In this context, the precise translational and rotational motion of every particle at a predefined time step is calculated using Newton and Euler’s equations of motion:

$$m_i \frac{d^2\vec{x}_i}{dt^2} = \vec{F}_i^c + \vec{F}_i^g,$$

$$\hat{I}_i \frac{d\vec{W}_i}{dt} + \vec{W}_i \times \left(\hat{I}_i \vec{W}_i\right) = \Lambda_i^{-1} \vec{M}_i,$$

In the translational equation, m_i denotes the particle mass, $d^2\vec{x}_i/dt^2$ the particle acceleration, $\vec{F}_i^c$ the contact force and $\vec{F}_i^g$ is the gravitational force. The angular acceleration $d\vec{W}_i/dt$ is given in the second equation as a function of the angular velocity $\vec{W}_i$, the external moment resulting out of contact forces $\vec{M}_i$, the inertia tensor along the principal axis $\hat{I}_i$, and the rotation matrix converting a vector from the inertial into the body fixed frame Λ_i^{-1}. The contact forces between particles and between particles and walls are separated into a normal and a tangential component, where the normal component is calculated with a linear spring damper model and the tangential contact force with a linear spring limited by the Coulomb condition. Furthermore, the rolling friction of the spherical particles is included in the resulting external moment.

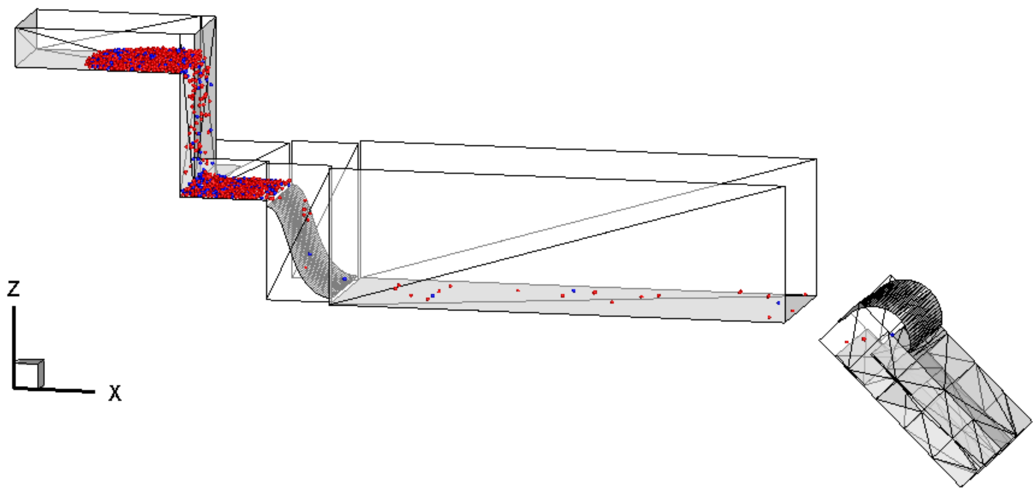

Figure 2: Visual illustration of the model of the sorting system used for simulation.

Utilizing the described methodology, we created a numerical model of the experimental platform that is described below and thoroughly discussed in [8], see Figure 2. Besides other benefits, this model enables the generation of test datasets for different kinds of materials at a very high temporal and spatial resolution.

Experimental Platform

Due to the changes as also highlighted in Figure 1, efficiently adapting the system design in terms of hardware is key to pursue our research goal. With respect to optical sorting systems in industrial dimensions, this is often not the case. Therefore, we created a modular experimental platform that allows fast and easy change of components such as camera and illumination in order to experimentally validate our approach, see Figure 3. It is a table-sized, yet fully equipped sensor-based sorting system that allows significant coverage of the potential parameter space imposed by the choice of components when designing a system.

The key idea behind the design is a back panel that is inspired by a breadboard. Different adapters allow mounting various hardware components on the panel.

For experiments conducted in the course of this research project, we equipped the system with a camera of type Bonito CL-400 that allows frame rates up to approximately 192 fps. With respect to illumination, we use a LED ring light with an inner diameter of 180 mm. The conveyor belt has a total length of 600 mm and width of 160 mm. Separation is performed by an array of 16 air jets whereas air released by a single jet spreads through five neighboring nozzles.

At the time of writing, the described platform was used to acquire image data, which serves as a basis to develop and evaluate our tracking approaches. However, currently, we are conducting sorting experiments including the tracking approach and are planning to publish results soon.

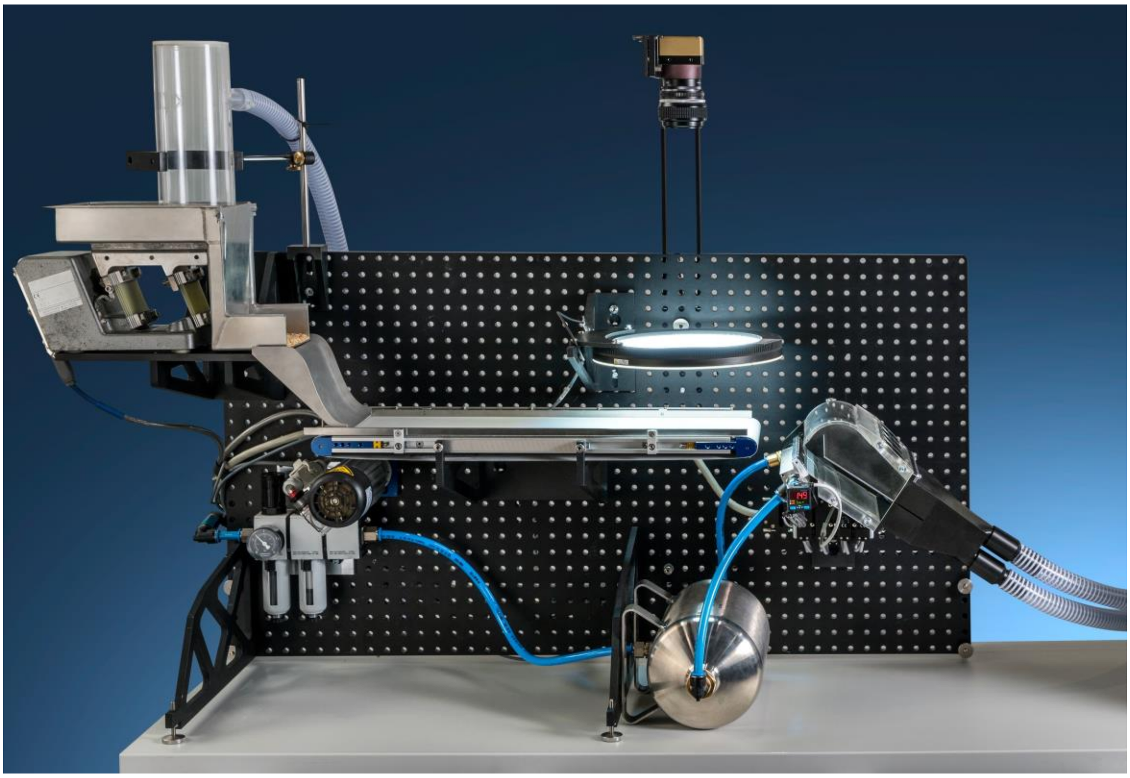

Figure 3: Front view on the experimental platform used in the research project.

Present Results

In order to ensure our simulation results are in line with experiments conducted on actual sorting systems, we performed several studies. Comparisons, among others regarding mass flow, were presented in [8]. Moreover, a DEM–CFD coupled approach was presented in [9] including a comparison between simulation and experiments employing a line-scan camera. From the results, it is concluded that the modelling approach seems promising and suitable for further investigations.

With respect to separation efficiency employing our tracking approach, we have published first results in [10]. Results suggest that spatial and temporal deviation with respect to triggering the compressed air nozzles to deflect an object in the material stream can be reduced utilizing the tracking approach on noise-free data as obtained via simulation. However, it is also shown that noise as present when working with real world image data has a significant impact on the accuracy. Therefore, we continue working on improvements such as more reliable associations [11], more suitable motion models and the precise localization of objects in the image data.

Furthermore, we report that employing the multiobject tracking approach for sensor-based sorting not only has the potential of decreasing the error in physical separation, but also allows for new methods regarding material discrimination. In [12] we showed that a trajectory can be reconstructed from all measurements assigned to a track, which allows deriving integral features such as velocity and acceleration. In particular, we showed that equally sized spheres made of different materials can be distinguished well based on their motion behavior.

Conclusions

In this paper, we provided an overview of the present advances achieved by utilizing area-scan sensors in combination with multiobject tracking for sensor-based sorting. A brief description of the multiobject tracking system as well as the numerical simulation driving our developments was given. Furthermore, we introduced our experimental platform, which allows implementation of a corresponding system. We summarized present results and the curious reader is kindly referred to our referenced works for more details.

With respect to future work, next steps include a thorough study of separation performance when utilizing the multiobject tracking approach both based on numerical simulations as well as empirically. Regarding the latter, we intend using our experimental platform with the aim of providing a quantitative comparison of sorting quality between conventional systems utilizing scanning sensors and our approach.

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