AI and Robotics for waste sorting and recycling

Alberto Bacchin[1], Nicola Carlon[2], Stefano Tonello[2], Alberto Pretto[1] and Emanuele Menegatti[1]

[1]*IAS-Lab, Department of Information Engineering, University of Padova, Italy*
[2]*IT+Robotics srl*

Abstract

A key building block for creating a circular economy is the ability to efficiently recover waste. For recycling to be profitable the purity of the separated fractions must be very high. The aim of the project is to implement a robotised waste sorting system to complement the current commercial solutions. The objective is to improve the quality and quantity of material recovered while limiting costs and labour use. This can be achieved thanks to advanced computer vision and robot manipulation techniques. The system will consist of two main components: (i) a vision system based on Deep Learning (DL) that combines several cameras to achieve high accuracy in material recognition; (ii) a manipulator robot that will sort objects based on feedback from the vision system. Grasp planning will exploit Reinforcement Learning (RL) to learn how to handle complex situations such as singling objects from a stack or disordered flow. The goal of innovation is twofold: to develop Artificial Intelligence techniques to be able to use low-cost sensors and to make system training simple and flexible for high reconfigurability to different types of waste.

Keywords

waste sorting, robotic waste sorting, circular economy

1. Introduction

Waste sorting is a complex problem which is addressed in several stages. First a gross manual separation is performed by the owner of the items before trashing the items into a specific litter box accordingly to the material of the item. Than, specialized sorting companies empty these boxes and process the separated fraction to increase the purity of the different waste fractions. Long chains of machinery are therefore used in waste sorting plants that include mechanical shredders, optical sorters, magnetic separators, rotating drums, vibrating plates and more [1]. Anything that these automatic systems fail to sort (in the case of plastics about 15% of the total) is still sorted by hand by workers forced to perform repetitive work in an unhealthy environment. These plants have a very high economic and human cost. For this reason, several companies have recently started to propose robot systems to accompany or replace the current waste sorting systems.

We aim to develop a robotic system for sorting waste (Robotic Waste Sorting System, RoWSS) to be inserted within the current plants sorting, where manpower is currently used to improve separation some materials. Sorting waste on a conveyor belt is repetitive work, wearing and unhygienic and also has an environmental/economic cost because it is part of the potentially recoverable material (up to 20% in some cases) fails to be recovered.

Industrial robot manipulators are increasingly fitted with exteroceptive sensors and autonomous planning capabilities to modify their motion according to external stimuli. We are developing an AI-powered robot manipulator for waste sorting. The goal is to increase efficiency and lower the cost of waste separation in order to reduce the amount of waste directed to the incinerator. For the recognition of waste, Deep Learning, Self-Supervised Learning and Data Augmentation techniques have been widely used in this project in order to deal with the complexity of collecting large amount of labelled data in real-world industrial settings. Reactive motion planning techniques and markerless human motion tracking techniques are under investigation to achieve an efficient collaboration between humans and robots. Different robot geometries will be investigated for increasing the speed and the efficiency of the sorting process.

The use of an RoWSS allows to reduce or avoid the use of human operators, freeing up the workforce for other more rewarding and value-added functions, and would make it more efficient and economically more sustainable material recovery. Moreover, it can reduce staff turnover which is very high in this sector of the unhealthy work environment. The development of waste sorting robots is not new. However, the products currently available have several limitations. In particular, it is assumed that the objects to be separated are placed on the conveyor belt in a not overlapping situation. This necessity limits the separation yield because it is not always possible to guarantee that condition and it is necessary to put more machinery before it to better distribute the waste

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bacchinalb@dei.unipd.it (A. Bacchin); nicola.carlon@it-robotics.it (N. Carlon); stefano.tonello@it-robotics.it (S. Tonello); alberto.pretto@dei.unipd.it (A. Pretto); emg@dei.unipd.it (E. Menegatti)
0000-0002-2945-8758 (A. Bacchin)

on the belt, which requires other investments to modify the plant line.

In our project, we aim to overcome these limitations by building a system able to manipulate complex and disordered piles of objects. The product is under development (TRL 2). The first prototypes and level installations industry are expected by the end of 2023.

2. Related works

Sorting through automated systems is a technological achievement of several years ago. Today, automation is very present in medium and large plants [1]. At the beginning these machines were built by adapting machines from the mining or agri-food industry, while today producers are increasingly specializing, creating special systems for sorting waste: mechanical sorters, optical-pneumatic sorters, magnets, etc. These are able to handle large flows of materials but have poor accuracy. For these traditional plants, the separated outgoing fractions have a non-optimal recovery level (about 70-80%) [2]. In addition, many of these machines can perform a binary separation or separate the incoming flow into two fractions (the fraction to be recovered and the ”residue”) and are very sensitive to any contaminants that can even block the plant. This is why today human operators are still widely used in sorting plants to buffer the low yields of the machines currently on the market.

There are also some companies producing robot waste sorting systems based on robot manipulators. Only a couple of these company seems to have mature systems[1]. The products they offer, albeit with some differences, use an advanced vision system to guide an industrial robot in a pick & place operation. However, these machines need objects well distributed on the conveyor belt and cannot handle complex and intermingled objects.

3. Methods

The system we are developing is sketched in Fig.2. It is a modular system to be adapted to the current machine in the sorting plant and especially to the conveyor belt. It is designed to work alongside human operators and to perform specific selections. In the first stage we devise to have several installed along the conveyor belt, each one devoted to selecting a specific material. The system is composed of two main blocks: the vision system and the handling system.

The vision system is mainly base on Deep Learning. The first problem to be tackled is the data collection to train the models, then.

We already completed a couple of data acquisition campaigns with different methodologies and in different sorting plants thanks to the collaboration of local companies. Differently from standards, our datasets have been collected with the aim to explore self-supervised and/or weak supervised approaches. The first dataset have been collected in a glass sorting facility. We installed two cameras above the conveyor belt, one before the human operator and one after. By leveraging the difference between the scene before and after the human intervention, we aim to automatically label the contaminants indirectly exploiting the knowledge of an experienced worker. A standard semantic segmentation model trained in this self-supervised settings showed an mIOU of 0.5.

On the other end, we built a second dataset in a paper sorting facility. In this case we targeted a different approach. We collected around 2500 single waste objects from a real plant. Given a uniform background, it is relatively simple to automatically extract object image patches and corresponding semantic labels. We aim to use the obtained patches to generate synthetic cluttered scenes on a conveyor belt, through generative model as Diffusion Models [7].

We also started to record a dataset of RGB-D and hyper-spectral images to starting develop and test the algorithms. Despite the promising preliminary results, we consider the usage of hyper-spectral images as a secondary research line since the high hardware costs would limit the applicability in real-world settings.

The handling system is also very important since it is the main limitation of current commercial solutions which perform just standard pick & place operations common in industrial robotics. We are developing an advanced algorithm for grasping and disentangling in order to be able to pick objects also from complex and intermingled piles of materials. In this direction, Reinforcement Learning and Self-Supervised Learning have shown promising results in laboratory settings [5]. We want to extend these approaches to work in real-world settings, e.g. considering objects with irregular geometries.

Another promising advancement we are going to test in the next months is the use of tossing motion for the robot. After the robot picks the objects, instead to move the end-effector over to the correct container and *place* the object, the robot is is throwing the object into the container to save time in the cycle time. Tossing involves a complex correlation between the shape of the object and the release pose and speed, which are almost impossible to model in a closed form using equations of motion. Deep learning can be used to capture this information citeb13, allowing to compute the right release specifications without an explicit motion model.

[1]https://zenrobotics.com/, https://www.amprobotics.com/

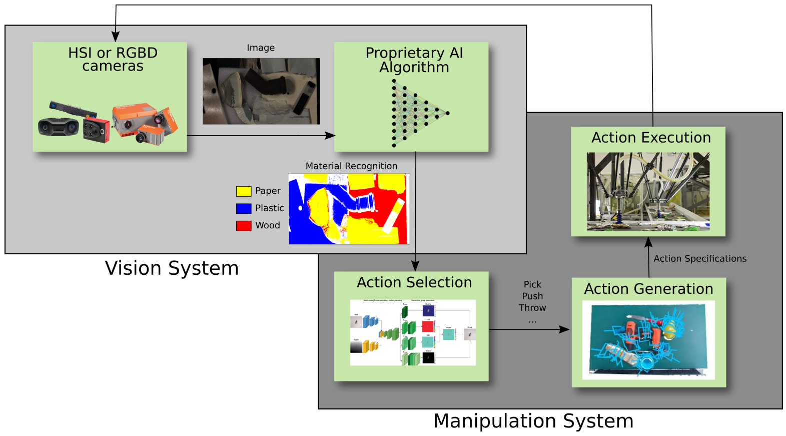

Figure 1: A sketch of the proposed system for robotic waste sorting system based on a robot manipulator and a vision system based on deep'learning.

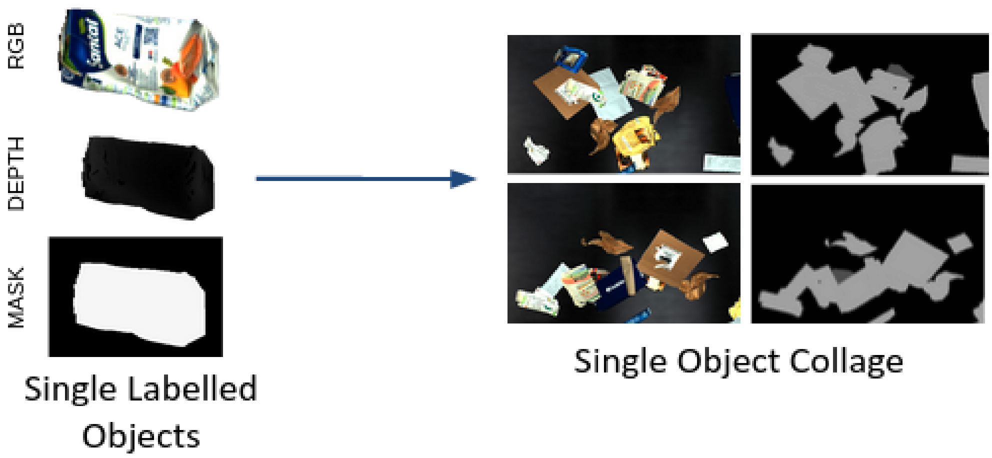

Figure 2: Data Augmentation strategy based on cut and paste patches.

4. Conclusions

We presented an automatic system to process waste to sort the different fractions to be recycled with very high precision. The system is based on a modular solution with a robot manipulator and a vision system. The advanced algorithms we are developing in this project will enable us to overcome the current limitations due to the long cycle time and high costs of the machine vision systems.

We are designing a first prototype for careful and precise sorting of paper, cardboard, and Tetrapack^{TM}. We aim at achieving an accuracy of the sorting of 98% against the 80% of current opto-mechanical-pneumatic sorters.

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