IPSE

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Executive summary

IPSE project aims at improving the efficiency of plastic waste sorting through the integration of artificial intelligence and eco-design. The project focuses on enhancing the detection of impurities on sorting conveyor belts in sorting implants, collaborating with Corepla, Seruso, and WiSort, entities involved in plastic waste management.

Currently, plastic sorting involves both automated systems and manual sorting, with automated systems mainly utilizing Near Infrared (NIR) technology to identify polymers and colors. Given the limitations posed by NIR implementation, manual intervention is still needed. However, manual sorting is labor-intensive and prone to errors. The IPSE project seeks to develop an improved detection system for sorting impurities, integrating cameras and machine learning algorithms for enhanced sorting accuracy in the output flow.

The system is tested at Seruso's sorting facility, where the team installs cameras along sorting belts and employs state-of-the-art machine learning techniques to optimize impurity detection. The goal is to automate and improve the sorting process, thereby reducing errors and optimizing workforce distribution. In addition to technological advancements, the project emphasizes public awareness about proper waste separation to improve sorting accuracy and avoid contamination.

The final goal is to improve sorting performance which is crucial for improving recycling rates inserted in the EU Targets for 2030. Furthermore, improving the purity of the output flows avoids the imposition of monetary sanctions. Economic evaluations predict that the system could reduce costs and enhance efficiency in plastic sorting plants by optimizing human labor and minimizing errors. Ultimately, the project aims to support a circular economy by improving recycling efficiency and sustainability practices through innovation in AI-based sorting technologies.

Key Words

Sustainability, Plastic sorting, Artificial Intelligence, Eco-design

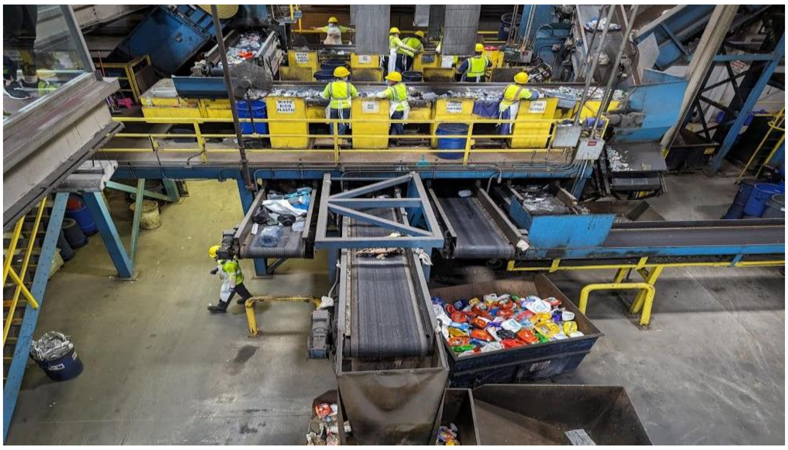
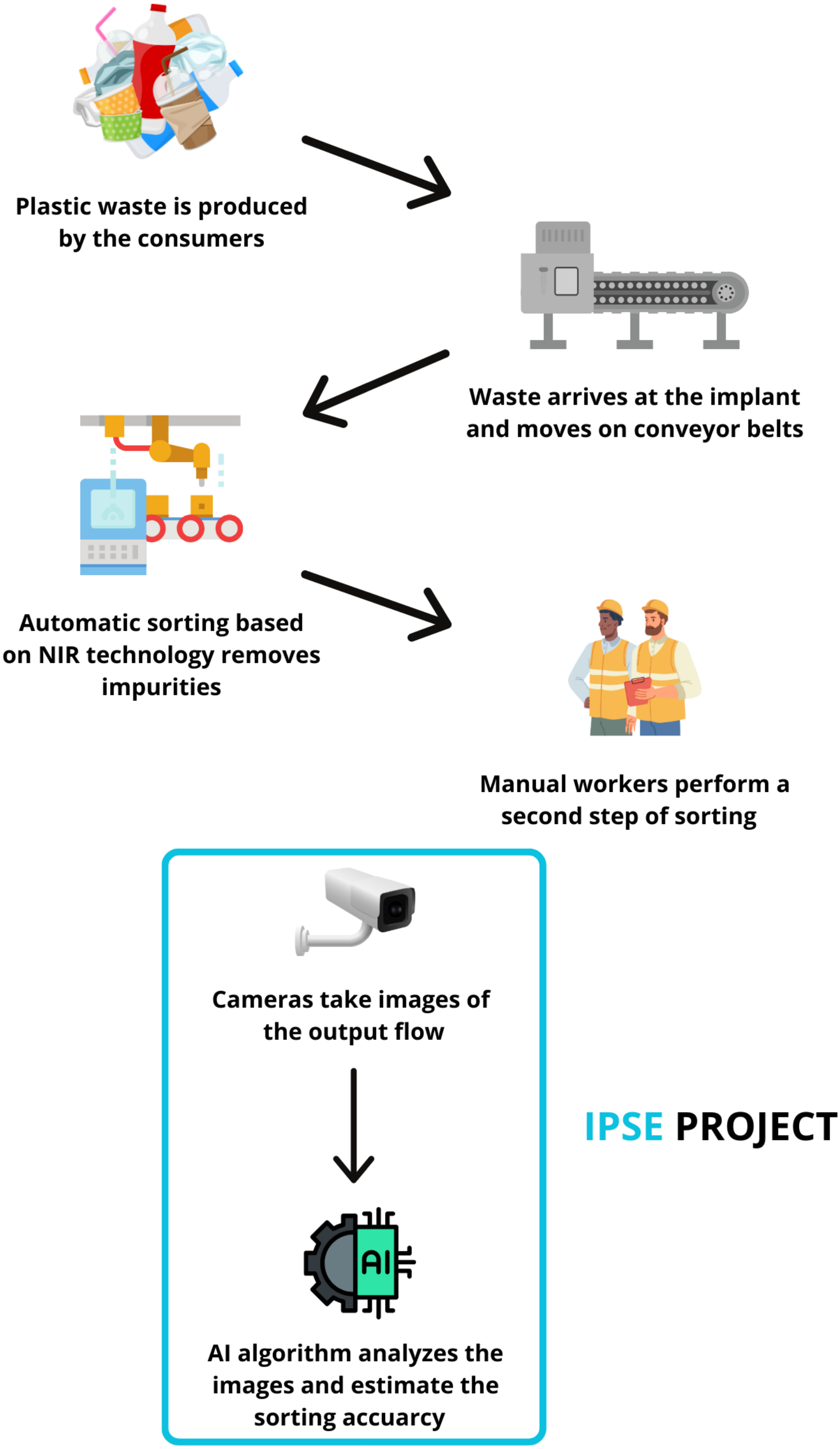


Figure 1: Conveyor belt from the Seruso's sorting implant


Plastic waste is produced by the consumers
Waste arrives at the implant and moves on conveyor belts
Automatic sorting based on NIR technology removes impurities
Manual workers perform a second step of sorting
Cameras take images of the output flow
AI
AI algorithm analyzes the images and estimate the sorting accuarcy
IPSE PROJECT

Project description written by the Principal Academic Tutor

The proper management of the continuously increasing streams of plastics packaging source separated from the municipal waste is posing a challenge to the automated sorting plants. They are currently based on optical sensors operated in the Near Infrared (NIR) sector of the light spectrum, able to detect different polymers and colors, followed by a refining carried out manually by operators. This is a routinely and stressful type of work, that might be replaced by advanced systems based for example on image recognition, artificial intelligence and machine learning. A second challenge is the need for a better analysis of the composition of the different input and output streams, which is now carried out by hand, involving high costs but also high uncertainty due to the poor representativeness of the samples.

Aim of the project is to carry out a comprehensive and multidisciplinary evaluation of the potential to upgrade the plastic sorting plants with such technologies; this will include some preliminary theoretical evaluations, some practical testing on both an experimental facility owned by Corepla and a full-scale sorting plant, an environmental, economic and social assessment, the latter related to the potential loss of work. Finally, the outcome of the work will become inputs for the eco-design of the plastic products that will allow a better sorting and handling at the plants.

Team description by skill

Given the multidisciplinary nature of the project, it is essential to assemble a team with a diverse range of backgrounds, expertise, and experiences. IPSE is not merely about developing an AI algorithm, but rather, it requires a comprehensive approach that involves the collaboration of multiple domains. The successful implementation of this project depends on the integration of various fields, each contributing unique insights to address all the technical, scientific, and strategic requirements.

The team consists of five members with different engineering backgrounds to gather the required skills for completing the project:

- **Leonardo Pesce:** Artificial Intelligence Engineer from Politecnico di Milano. Leonardo has a great passion for AI applications. His research experience makes him a key figure not only in guiding technical decisions and developing the proposed solutions, but also in organizing the work.
- **Alberto Foresti:** Data Science Engineer from Politecnico di Torino. Alberto is specialized in computer vision, generative modeling and machine learning for scientific applications. His expertise in the realm of computer vision is essential for the project's technical execution.
- **Simone Clemente:** Data Science Engineer from Politecnico di Torino. Simone has previous experience in the field of Large Language Models, specifically with transformers architecture. He plays a critical role in analyzing technical requirements and contributing to the development of the final solution.
- **Fabiana Mangano:** Chemical Engineer from Politecnico di Torino, involved in a Double Degree project with Nuclear Engineering. Since plastic sorting involves different kinds of polymers which should be treated in different ways, Fabiana provides the domain knowledge in the chemical field, giving to the team insights into the realm of material analysis and composition.
- **Marco Persico:** Automation Engineer from Politecnico di Milano. Given the industrial application of our research, having an expert in the automation department is an important advantage. Furthermore, Marco’s polyhedric experience with student teams offers a unique advantage in assessing potential real-world applications and the economic implications of the research.

Goal

The primary goal of the IPSE project is to improve the accuracy and efficiency of plastic waste sorting by integrating artificial intelligence into current sorting practices. Current sorting is done exploiting NIR technology in combination with manual intervention from the implants' employees. Given the limitations of NIR in detecting different types of plastic polymers and the errors implied by human sorting, there is a presence of impurities in the output flow. Our algorithm specifically aims at quantifying the level of those impurities: our implementation analyzes the material flows and computes estimates in real-time to gather important metrics about the efficacy of the process. This step is crucial to:

- **Respect the rules** about the composition given by the selection agreement with Corepla avoiding sanctions
- Optimize the **distribution of the workforce** on the sorting belts

Furthermore, this implementation is the starting point for future integration with robotic arms for enhancing the automated sorting capabilities of the implants. New and improved automated sorting techniques could reduce the need for human intervention, avoiding alienating work and at the same time providing better results for the sorting process.

The ultimate objective is to create a solution that not only enhances operational efficiency but also supports the principles of the circular economy by increasing the purity of recycled materials, reducing costs related to fines due to impurity levels, and optimizing human resources in the sorting facilities. Additionally, the project emphasizes raising consumer awareness about proper recycling practices, which is crucial for the successful adoption of improved sorting technologies and the reduction of contamination in the waste stream.

Understanding the problem

The first step taken by the team to reach the final solution is defining the problem and identifying stakeholder needs. During the initial weeks, the team conducts a literature review and interviews specialized workers from Seruso's implant. Through these discussions, we identified key needs related to the sorting process, which enabled us to adapt our solution accordingly.

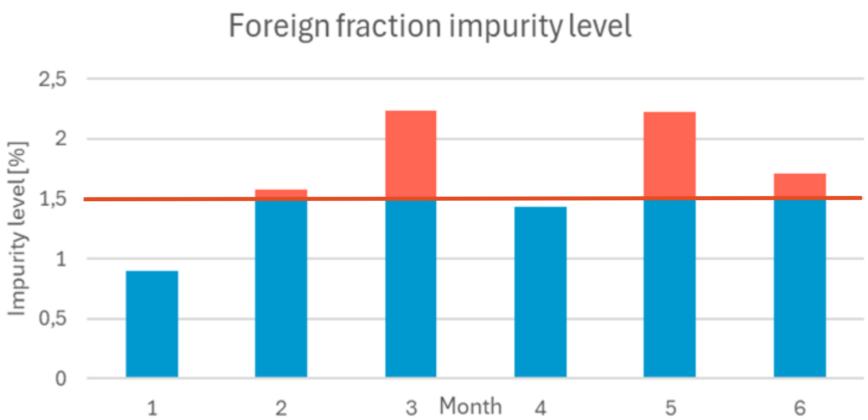


Figure 2: Impurity levels measured in the first semester of 2024. The red component is above the threshold defined by Corepla, and it implies a sanction for the sorting implants.

To begin with, it is crucial to define the two primary metrics that should be considered during the plastic sorting process:

- **Accuracy**: The presence of non-plastic items reduces the quality of recycled materials, increases sorting costs, and introduces safety risks. It is fundamental to keep the highest accuracy possible to obtain an output flow as pure as possible.
- **Throughput**: Achieving high throughput while maintaining sorting accuracy is a major challenge for existing facilities. Current systems struggle to process large volumes of material.

Current implementation mounted at Seruso's implant exploits NIR in combination with manual sorting. Considering the NIR limitations when analyzing plastic polymers that have similar infrared spectra, human effort is crucial for keeping a high accuracy. However, the manual workers underlined some common problems:

- Conveyor belts are often overloaded making it hard to clearly detect and eliminate all the external material.
- The speed of the flow is sometimes too high to maintain a good performance.
- There is a strong presence of different contaminants. Some of them, such as e-waste, can be dangerous to manage during the sorting process.
- The workload across the different flow is not well distributed.

Current implementation makes the manual sorting labor-intensive and introduces inefficiencies in the process. Improvements are needed from the sensors' point of view, to have more effective automatic sorting. The workload should be distributed in a better manner to reduce the stress on the workers and improve their accuracy. Finally, the last step should be taken in terms of consumers awareness: some kinds of contaminants could be removed at the source by instructing better the customer on the correct practices.

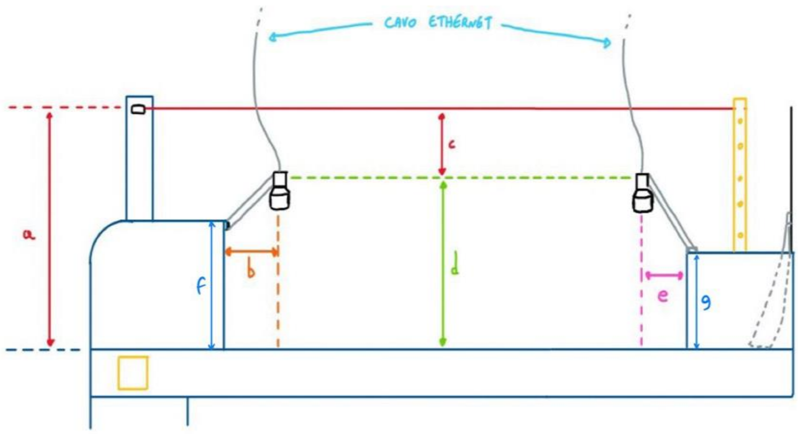


Figure 3: Implementation schema

Exploring the opportunities

When analyzing plastic sorting technologies, it is possible to identify three main categories currently utilized by sorting implants:

- **Mechanical sorting** relies on the physical properties of materials, such as size, shape, and density, to separate different types of waste. Some examples are ballistic separation or air classification. While these methods are straightforward and effective for a wide range of materials, they face significant challenges when dealing with mixed plastic streams and contaminated waste, which can reduce efficiency.

- **Optical sorting**, on the other hand, focuses on the reflective properties of materials. A prominent technique in this category is Near-Infrared (NIR) spectroscopy, which measures the light scattered off and through materials to quickly determine their composition without altering them. Optical sorting is highly precise, allowing for accurate differentiation of materials by type and color. However, its effectiveness decreases when dealing with dirty or dark-colored plastics. Additionally, certain polymers that share similar reflection spectra pose challenges for this method, particularly in complex mixed-stream scenarios where precise identification is required.
- **Sensor-based sorting** employs advanced technologies like cameras and laser-based systems to detect and classify waste based on appearance. This method, enhanced by recent advancements in artificial intelligence and computer vision algorithms, is versatile and capable of handling a broader variety of plastics than the other methods. However, sensor-based sorting can be costly and complex to implement due to its high computational power requirements and the need for large labeled datasets.

Given the specific requirements posed by the sorting implants we opt for a camera-based system which exploits machine learning algorithms to detect impurities.

Generating a solution

To reach the goal we use a computer-vision supervised machine learning approach for performing a semantic segmentation task. Semantic segmentation is the process of classifying each pixel in an image into a predefined category, effectively partitioning the image into meaningful segments based on the objects or regions it contains.

The building process of the proposed pipeline is divided into three main steps: setting up of the camera system to take images from the conveyor belts, creation of a labeled dataset specific for the plastic sorting and training a semantic segmentation model.

The system includes a dual-camera setup designed to optimize sorting and ensure precise quality control. The first camera, located at the start of the sorting line, captures high-resolution images of incoming plastic materials, allowing the algorithm to classify and guide the sorting process. The second camera, positioned at the end of the conveyor, focuses on quality control by analyzing detailed images of materials removed as impurities. This enables the system to evaluate sorting accuracy, identifying any valuable plastics mistakenly discarded. This feedback mechanism is essential for refining the sorting process and enhancing overall efficiency.

Once the camera system has been set up, we need a labeled dataset which can be used for training the algorithm. We start from images taken directly from the conveyor belt and, with the guidance of Seruso's expert and professional labelers provided by WiSort, we generate the masks representing the objects to be removed. The result is a new dataset which can be used for training of models specialized in plastic sorting: this represents a novelty which could be used also by other projects in the future.

For the model selection, we leverage a SegFormer model built upon the transformer architecture: this choice guarantees state-of-the-art performance while keeping feasible computational needs. Thanks to transfer learning, we start from a pre-trained SegFormer model which can be found on HuggingFace and perform fine-tuning on our plastic sorting dataset. The fine-tuned model is tested on a test partition, measuring the performance in terms of IoU, which is a common metric for semantic segmentation. The obtain results are promising for future development.

Once the technical component is completed, we propose new guidelines for both stakeholders and customers, to facilitate the sorting process. While stakeholders should insert new common standards for the sorting process and change some parameters to make manual sorting easier, customers could improve the sorting done in their houses according to sorting needs.

Main bibliographic references

Xie, E., Wang, W., Yu, Z., Anandkumar, A., Alvarez, J. M. and Luo, P. (2021), 'Segformer: Simple and efficient design for semantic segmentation with transformers', *Advances inneural information processing systems 34*, 12077–12090.

Taneepanichskul, N., Purkiss, D. and Miodownik, M. (2022), 'A review of sorting and separating technologies suitable for compostable and biodegradable plastic packaging', *Frontiers in Sustainability 3*.

Geyer, R., Jambeck, J. and Law, K. (2017), 'Production, use, and fate of all plastics ever made', *Science Advances 3*, e1700782.

Bashkirova, D., Abdelfattah, M., Zhu, Z., Akl, J., Alladkani, F., Hu, P., Ablavsky, V., Calli, B., Bargal, S. A. and Saenko, K. (2022), 'Zerowaste dataset: Towards deformable object segmentation in cluttered scenes'.