Portable, Robotic Material Recovery in a Box

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Abstract. In recent times, there has been a growing integration of robotic technology in waste separation, offering a robust solution for managing the continually increasing volume of post-consumer waste. While existing solutions are typically implemented in large-scale Material Recovery Facilities (MRFs) designed for handling substantial waste quantities, the current market offerings for robotic waste sorting systems prove to be less cost-effective for smaller or less accessible areas. However, in contrast to bulk processing, sorting waste close to its source has demonstrated enhanced material recovery in terms of both quality and quantity. To address this disparity, the Horizon Europe RECLAIM project is dedicated to developing a portable, robotic MRF (prMRF) tailored for small-scale waste sorting and material recovery. RECLAIM adopts a modular multi-robot/multi-gripper approach for material recovery and employs an AI-powered computer vision module for material categorization. Additionally, the project introduces an innovative Recycling Data-Game that encourages citizens to actively participate in RTD activities, contributing annotations crucial for training the AI models utilized in material categorization.

Keywords: Portable Robotic MRF, Robotic Waste Sorting, Material Recovery.

1 Introduction

Recent advancements in technology have facilitated the modernization of industrial Material Recovery Facilities (MRFs), now supported by intelligent and autonomous robotic waste treatment equipment [1]. This approach is currently employed by large-scale MRFs typically situated near major urban areas for municipal waste treatment [2]. Despite the high efficiency of these industrial solutions, the transportation of waste to

these large plants incurs high costs and complicates material recovery due to the compression applied to reduce volume before transport.

However, there are instances where this operational model does not efficiently address waste treatment needs. Such scenarios include natural disasters, social, cultural, and athletic events with surges in waste volumes during specific periods, rural or remote areas, and transport hubs. To cater to the recycling needs of these cases, a recent market trend focuses on implementing lightweight, flexible, and portable waste management units that can be swiftly deployed in areas requiring waste treatment, especially the recovery of valuable recyclable waste. Despite the substantial demand for these systems, they currently lack the integration of smart, high-tech solutions that could significantly enhance their productivity. Consequently, waste sorting in these specialized sectors is still carried out manually today.

The RECLAIM project (https://www.reclaim-box.eu/) utilizes established and well-tested AI-driven robotic waste management technologies, currently undergoing refinement and integration into an advanced "portable, robotic Material Recovery Facility" (prMRF). This endeavor aims to substantially elevate local-scale material recovery activities, imparting them with efficiency comparable to industrial standards. Additionally, the project embraces a citizen science approach. Beyond heightening social awareness of the European Green Deal, it facilitates and motivates citizens to engage in project RTD activities by contributing annotations crucial for the deep learning process used in training the AI-based waste categorization module.

2 The Essence of the RECLAIM approach

In pursuit of its objective, the RECLAIM project implements concrete steps to create innovative solutions within four essential technology pillars aimed at facilitating the recovery of valuable materials from post-consumer waste streams. The pertinent pillars are outlined below.

PIL-1: Advanced AI for material localization and categorization (AI-ILC) - Leverage and improve existing AI technologies to create efficient solutions that integrate visual [3] and hyperspectral [4] information, achieving high-performance localization and categorization of recyclable waste. These solutions should be applicable in real and harsh conditions, supporting material recovery efforts in challenging environments.

PIL-2: Modular, low-cost, high performance, multi-robot/multi-gripper recyclable recovery – Advocate for a new modular and easily scalable structure for robotic waste sorting, relying on cost-effective, high-productivity Robotic Recycling Workers RoReWos (see Fig. 1) equipped with diverse grippers tailored for various material types [5]. The RoReWos' simplified architecture reduces implementation costs and doubles the rate of "picks per invested euro". The development of RoReWos is realized by their grouping in teams, in a way that enhances the productivity of the composite system.

PIL-3: Portable robotic Material Recovery Facility (prMRF) - The RECLAIM project strives to integrate waste loading and ferrous material sorting equipment, along with AI-powered robotic waste sorters, within the prMRF container box. The prMRF accomplishes fully automated waste treatment and the efficient recovery of recyclable

materials with a minimal number of human workers undertaking simple supporting tasks. The prMRF container can be easily transported to designated locations and become fully operational within a few hours, ensuring continuous and effective waste sorting for extended periods.

PIL-4: Environmental gaming for social awareness, data collection and annotation- Enhance public awareness of recycling through an innovative Recycling Data-Game (RDG). This game not only sheds light on challenges related to waste treatment but also motivates citizens to engage in project activities using a citizen science approach, contributing data for AI-ILC training [6]. Simultaneously, RDG serves as a platform to communicate the fundamental principles of AI and Data Science to the wider public.

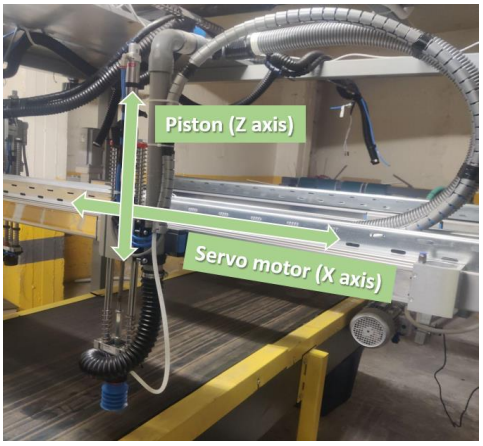

Figure 1. One of the RECLAIM's low-cost Robotic Recycling Workers

The above described implementations advocate for the decentralized processing of recyclable waste, anticipating elevated recovery rates and enhanced material purity. The improved sorting efficiency is further facilitated by the higher quality, freshness, and uncompressed state of the materials presented to the RoReWos.

3 Focused Deployments

The RECLAIM technological advancements will be put into practice and subjected to thorough evaluations through rigorous real material recovery tasks. RECLAIM aims at deploying a prMRF at diverse pilot sites to assess its performance under real and particularly demanding conditions, recovering materials from post-consumer packaging waste.

Specifically, the deployment of prMRF will take place in the Ionian Islands group, Greece, offering an opportunity to evaluate its performance in distinct use-case scenarios. The Ionian group comprises seven main islands, widely recognized as popular tourist destinations. All these islands encounter significant challenges in waste management, particularly during the summer period. However, the relatively small size of these islands and the high seasonality of waste production do not favor investments in a full-size Material Recovery Facility (MRF).

To date, packaging waste generated by residents and tourists is typically compacted and packaged for transportation to the mainland for material recovery. The residue from this waste treatment must either return to the islands for landfilling or remain on the mainland, incurring notably high costs for landfilling. In addition to the increased logistics expenses, particularly in roundtrip transfers (island-mainland-island), the quality of recyclable materials transferred to the mainland for processing often diminishes due

to inadequate temporary storage and compression. This leads to heightened material degradation and entanglement, resulting in increased difficulty in recovery and lower recycling rates. Consequently, valuable recyclables are more likely to end up in landfills instead of being recycled.

Much like the situation in Greece, the utilization of prMRF for the localized processing of fresh, uncompressed, high-quality waste and the recovery/sorting of recyclables in a decentralized fashion is crucial for all rural areas. By enhancing the economic feasibility of decentralized sorting, RECLAIM offers a viable strategy to significantly boost recovery rates for valuable recyclable materials by sorting in close proximity to the source. Th RECLAIM approach also helps in reducing costs and minimizing environmental impact by eliminating the need for back-and-forth transportation of waste.

The geographical setting of the Ionian Islands group offers a distinctive chance to evaluate both the foundational technologies and the business case for the prMRF. RECLAIM is in direct collaboration with partners, holding the responsibility for waste management across all the Ionian islands. This will play a crucial role in investigating how prMRF can effectively address the specific requirements of different islands. Specifically, RECLAIM has outlined three scenarios of particular interest for the Ionian Islands group, as well as for various other regions in Europe encountering similar challenges. The three scenarios are outlined below.

Scenario-1: Material recovery from mixed recyclables streams. The primary recycling method employed in Greece involves citizens collecting mixed post-consumer municipal packaging waste in bins, which is later sorted at material recovery facilities. However, as noted earlier, particularly for the Ionian Islands, this process results in high logistical costs and increased material loss, especially when compression and improper temporary storage occur at transport stations. RECLAIM will evaluate the operation of prMRF in treating mixed recyclable packaging waste streams, with a specific focus on the PMD stream (Plastics, Metals, Drinking cartons). This stream involves the positive separation of multiple material types and represents the most challenging scenario due to the high material complexity examined in the RECLAIM project. Addressing this challenge will be a focal point throughout the entire duration of the project.

Scenario-2: Cleaning of citizen separated, material streams. In a section of Corfu, which is part of the Ionian Islands group, the promotion of recyclable separation by citizens involves the use of dedicated bins for collecting recyclable packaging materials in distinct streams (a recycling approach also embraced by many North European countries). The gathered material streams require further processing to enhance their purity and, consequently, their value in the secondary market. RECLAIM will evaluate the operation of prMRF in treating material-specific streams, employing negative separation to eliminate undesired objects. This scenario will be explored concurrently with Scenario-1, offering the opportunity to adapt prMRF for both positive and negative material selection. By comparing Scenarios 1 and 2, the project aims to assess the advantages and disadvantages of citizen-led separation. While citizen separation is anticipated to yield higher sorting efficiencies, it also incurs higher collection costs.

Scenario-3: Close to the source material recovery. The inherent portability of the prMRF allows for its installation in proximity to areas with high production of packaging waste, such as transportation hubs (e.g., ports, airports), festivals, sporting events,

exhibitions, etc. Unfortunately, until now, the fresh, high-quality waste generated in such areas has been collected with garbage trucks and is commonly mixed with other municipal waste. Consequently, RECLAIM will leverage the portability of the prMRF to investigate the feasibility of local, close-to-source robotic material recovery and sorting, comparing its efficiency with the current practice. This scenario will be explored in the final six months of the project by installing the prMRF at a central location, serving as an open and live demonstrator for EU citizens (residents and tourists), local authorities, governments, circular economy stakeholders, and potential investors.

4 Conclusions

RECLAIM lays the foundation for the adoption of innovative and decentralized waste sorting and management strategies. This is achieved through the creation of low-cost, portable, easily installable, and highly productive prMRFs, designed to facilitate local waste treatment as well as direct and efficient recovery of recyclable materials. Consequently, the prMRF is anticipated to play a crucial role in establishing a global circular economy model that is leakage-free, ensuring complete material recovery from post-consumer waste in any location, even in the most remote areas. This is expected to pave the way for the widespread adoption of prMRF in the market, contributing significantly to Europe's goal of becoming zero-polluting, climate-neutral, sustainable, and globally competitive.

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