Type of Presentation:

Oral: ☐ In-person: ☒

Poster: ☐ Virtual in Zoom: ☐

The same: ☒

Topic: Artificial Intelligence

Autonomous robotic sorting of recyclable waste

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Summary: The use of robots in Material Recovery Facilities (MRFs) can significantly facilitate the treatment of recyclables. Such robots need sophisticated visual and manipulation skills to be able to undertake the extremely heterogeneous, complex and unpredictable waste sorting task in industrial environments. We examine the industrial application of an autonomous robotic system for the categorization and physical sorting of recyclables, according to their material type. In particular, we focus on the development of (i) a low-cost computer vision module that exploits the deep learning technology to identify and categorize recyclables and (ii) a robotic controller for fast and accurate pick-and-place of the recovered materials. The composite system is deployed in a waste processing plant, where it is successfully assessed in recyclable separation in difficult and demanding industrial conditions.

Keywords: Machine Learning, Robotics, Recyclable Material Recovery Application.

1. Introduction

The current trend of environment-friendly 'circular economy' changes the way products are made and consumed. Circular economy is based on the assumption that materials will not end up at landfills but they will be recovered and reused. Traditionally, the recovery of materials from waste streams has been made by humans workers, a solution that suffers from low productivity and increased health risks. The last two decades, the solution of optical sorters has been made popular in Material Recovery Facilities (MRFs). It uses a combination of lights and sensors to illuminate and capture images of the objects. This technology faces difficulties in dealing with heavy items such as semi-full container packages, which are not rare in waste streams [1].

As a means to overcome the limitations of optical sorters, a new trend has appeared the last years, which considers the use of robotic technology for waste recovery and sorting [2]. This approach assumes low integration cost and easy installation to existing MRFs. Robotic waste sorting systems rely on high-cost imaging technology that exploits recent AI advancements to identify and categorize waste [3].

The present work supports the development of low cost computer vision-based waste categorization modules that can be directly applied in the industry. To this end, we exploit the industrial research setup implemented in the MRF unit of the island of Crete, Greece, to collect images of different waste types. The images are further processed in the lab, to develop a rich and well documented recyclable waste dataset that is used to train an AI-powered module for recyclable detection and categorization, applied in the industry.

The computer vision modules provides a robust solution to a three fold problem, that of object identification (bounding box specification), localization (masking) and material type attribution (classification). The simultaneous accomplishment of this triplet makes our solution applicable in industrial conditions where several and potentially overlapping recyclables shown in the very same image, need to be identified, localized and classified. The computer vision module is integrated with a delta robot which perform the picking of recovered materials and their placement into bins dedicated to specific materials. The composite system is tested in demanding industrial conditions with very promising results in material sorting (average success rate 91:8%).

2. Industrial Research Setup

We have implemented an industrial research setup to facilitate data collection, experimentation and system assessment in realistic conditions. The key components deployed to facilitate investigation and experimentation are presented in the following.

Conveyor Belt. We developed an industrial installation of a 22:5m long, 1:0m wide (usable width :8m) belt, that moves with speed up to 0:25m=sec and an encoder system that reports its speed in real-time.

Waste Feeder. A dual waste feeder is used to shed waste in a controlled rate onto the conveyor belt; one with uncontrolled urban waste, and another with a controlled waste-mix, for experimentation purposes.

Camera. A standard stereo full HD ZED camera is used to enable the automated categorization of the recyclable materials. The camera is placed 148cm before the robot (in the conveyor's movement direction), at a height of 75cm above the conveyor belt, looking downwards.

Robot. An ABB IRB360 delta robot has been installed above the conveyor belt, to enable the pick and transfer of the waste to the bins. The robot employed in the present work has a payload of 6Kg being highly appropriate for applications assuming repetitive and fast-executed manipulation tasks.

Vacuum Gripper. To enable the automated pick-n-place of recyclables, a vacuum gripping system is attached to the endeffector of the robot, which consists of a vacuum blower that provides high volume suction to pick and hold the materials. Vacuum technology provides a robust and low-cost solution for material transfer [4].

3. Material Detection and Manipulation

We have implemented an integrated robotic system for recyclable sorting that is composed of two parts, a robotic manipulator for the physical separation of waste to different bins, depending on their material type and a vision-based material detection and categorization module.

Pick-n-Place of Recyclables. An essential part of the autonomous sorting process regards the physical separation of recyclables. We follow a typical pick-n-place approach consisting of the following steps: (i) horizontal translation from the current position to the target-waste position, (ii) vertical translation towards the waste with the pathetic involvement of the shock absorber which ensures good contact of the suction cup with the material surface, and activation of the vacuum to implement gripping, (iii) follow the material transferred on the conveyor belt for a short period of time to improve sealing, (iv) vertical translation upwards, moving away from the conveyor belt, with the requested material grasped by the suction cup, (v) horizontal translation towards the bin that corresponds to the waste material, where vacuum is deactivated for the disposal of the waste.

Vision-based Material Categorization. For the material classification, we adapt the well-known Mask R-CNN to the current classification task, by developing and testing four customized Mask R-CNN implementations that differ in (i) the dataset size, (ii) the number of the learning steps per epoch, (iii) the use or not of additional data augmentation strategies to improve generalization. The synthetic training datasets consists of aluminum cans in flat, crumpled and cylindrical shape, papers and nylons in flat, crumpled and ball shape, PET bottles in flat, arbitrarily crumpled and cylindrical shape with various contents (i.e. with or without liquids). After extensive experimentation we show that: (i) vision based approaches can handle the demanding task of waste-material separation with overlappings, and (ii) the performance of the network Mask-RCNN is sufficiently effective even in multiple-object images that include difficult cases with partially overlapping recyclables, reaching an overall 91.8% accuracy.

4. Industrial Applicarion

The implemented system has been gradually integrated into the operation of the MRF unit to support the treatment of the increased volume of waste that is processed on a daily basis. *The performance of the robotic waste sorter is demonstrated in the following link:*

https://youtu.be/6dV4vg3EeqU.

To further ensure the robustness of the system, the robot treats only the objects that have been recognized with a very high level of confidence (i.e. more than 98%). Moreover, the pump-based vacuum has been very effective in grabbing and transporting objects with a weight of up to 500gr. Overall, the operation of the robot can effectively complement the manual sorting of recyclables, thus having a clearly positive impact on the productivity of the MRF. This is because, the fast, precise and tireless operation of the robot reduces the amount of waste to be treated by workers, thus facilitating the processing of the large volume of waste that arrives daily at the plant.

4. Conclusions

Current solid waste management practices are no longer sustainable. With the exploitation of state of the art computer vision and robotics technology, the promise of finding new innovative ways to attaining sustainable waste management becomes more achievable and realistic. The proposed industrial research setup has crucially supported experimentation towards the development of a robotic waste sorter that is applicable in the real world.

Acknowledgements

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH—CREATE—INNOVATE (project name: ANASA, code:T1EDK-03110).

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