Indexing and Sorting Robot Based on Hyperspectral and Reflectance Information for CDW Recycling

Indexing and Sorting Robot Based on Hyperspectral and Reflectance Information for CDW Recycling

Tommaso Zerbi[1], Roberto Landò[1], Raffaele Vinai[2], Konstantinos Grigoriadis[2], and Marios Soutsos[2]
[1]STAM Srl, Piazza della Vittoria 14/11, Genova, Italy
[2]Queen's University Belfast, School of Natural and Built Environment, 39 Stranmillis Road, Belfast, BT9 5AG, United Kingdom.

ABSTRACT
Research on construction and demolition waste (CDW) has been identified by the European Commission as a priority due to large volumes generated and high potential for reuse and recycling. Around 750 million tons of CDW are generated yearly in Europe, accounting for 25%-30% of the total waste. The average recovery rate for EU27 is below 50%. RE^4 (REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction) is a Horizon 2020 funded project promoting new solutions for the design and development of eco-compatible and cost-effective pre-fabricated building elements with high degree of recycled materials from CDW (up to 65% in weight).
This paper presents preliminary results from the development of a novel CDW robotic sorting system. Data from hyperspectral cameras and reflectance sensors will be combined to produce a 2D heat map for object classification by an algorithm which is under development. A 6 Degrees of Freedom robotic arm will be utilised in handling and sorting the CDW particles. The final goal is to achieve purity higher than 90% for each fraction. Different material classes will be sorted and recycled in prefabricated construction applications. Preliminary results indicate that coupling the hyperspectral information and the robotic technology allow to achieve high-quality sorting of CDW.

Key words: CDW Recycling, CDW Sorting, Recycled Aggregate, Robotics

1. INTRODUCTION

The Waste Framework Directive requires Member States to take any necessary measures to achieve by 2020 a minimum target of 70 % by weight of non-hazardous CDW for reuse, recycling and other material recovery, including backfilling operations (refilling of an excavated area). In Europe around 750 million tons of CDW is generated every year [1]. The average recovery rate for EU27 is below 50% [2]. A negligible percentage is destined to reuse mainly because the majority of the existing buildings was not designed for disassembly and reuse. Recovered materials are typically used for low-grade applications (unbound road base, fill, hard-core). Innovative technologies are needed for increasing the percentage of recycled materials and reused structures from CDW, the technical and economic value of CDW-derived materials and structures, and the building energy efficiency, whilst minimizing future CDW coming from the next generation of buildings.

Prefabrication can significantly reduce the material consumption and the complexity of manufacturing, improve the quality of design and products, reduce production time and create condition for continuous construction during the year. The overall goal of the RE^4 Project is to develop a prefabricated energy-efficient building made up to 65% by weight of CDW-derived materials and structures. Developed building components will be suitable for both new construction and building refurbishment. The consortium, composed by 13 members from Industry, Academia, Research and Civil Society, is industrially driven, focussed on the needs of end-users and products manufacturers, aiming at strengthening their competitiveness and grow perspectives.

2. RECYCLING OF CDW MATERIALS IN BUILDING APPLICATIONS

Recent estimations indicate that the EU27 consumed between 1.200 - 1.800 Million tonnes of construction materials per annum for new buildings and refurbishment between 2003 and 2011. Cement, aggregate materials (sand, gravel and crushed stone) and bricks are estimated to make up to the 90% (by weight) of all materials used [3]. These figures indicate the potential availability of mineral aggregate in CDW on one hand, and the market demand for such product on the other. Recycled mineral aggregate from CDW may present a number of contaminations which can limit its use in structural concrete. Acid soluble sulphate content, chloride content, alkali content and potential for alkali-aggregate reaction, gypsum (leading to delayed ettringite formation) content, and freeze–thaw and sulphate resistance must be checked when using CDW aggregate [4]. Current technology for recovering aggregate from CDW is based on washing, crushing and screening processes, typically coupled with thickener unit and filter press for water recycling. While floating materials and fine fraction are discarded, clean and sorted aggregate sizes (from sand to coarse aggregate) are obtained. However, no sorting based on different mineral materials is made, and this influences the quality of the aggregate in terms of physic, chemical and mechanical properties.

One of the goals of RE4 project is to improve the sorting system by separating the different material fractions in order to (a) increase the purity of each fraction, and (b) find appropriate applications for each fraction. In particular, ceramic materials (bricks and tiles) will be separated from the mineral fraction, thus improving the quality of the aggregate for concrete applications. In order to assess the quality of the “improved” sorted aggregate, a full characterisation campaign will be carried out, testing physical, chemical, mechanical and geometrical properties of aggregates, as well as their durability. Tests will be carried out according to the standards summarised in Table 1.

Table 1. Technical standards used for the characterization of CDW aggregate.

Properties	*Standard*
Petrographic description	EN 932-3:1997
Geometrical properties of aggregates	EN 933 series
Chemical properties of aggregates	EN 1744 series
Carbonate content and alkali-silica reactivity	prEN 12620:2015
Thermal and weathering properties of aggregates	EN 1367 series
Mechanical and physical properties of aggregates	EN 1097 series

This exercise is currently undergoing on currently marketed CDW-derived aggregate, i.e. without the “improved” sorting with material separation, in order to determine a benchmark against which assess benefits from the improved sorting system.

3. INNOVATIVE AUTOMATIC SORTING SYSTEM

One of the objectives of the RE^4 Project is the development of a fully automatic robot-based system to sort CDW by material classes, in order to allow the recycling of CDW in high technical and economic value applications in building industry in a circular economy perspective. The system will separate stones and aggregates, bricks, ceramics, glass, plastic and wood. Sorted material will then be further processed according to the particle size requirements for target applications. Aggregate for concrete will be produced in three fractions: 0/2, 2/8 and 8/16 mm. The sorting system is composed by three elements: a set of sensors, a real-time classification algorithm and a robotic arm with an end-effector.

Sensors: the sensor system aims at detecting the surface features of each CDW particle moving on a conveyor belt. The proposed approach is based on the different spectral response of different materials. The concept design of the system foresees wide spectrum hyperspectral cameras, splitting the output information into visible and Near-Infra Red (NIR) spectra, in order to detect the object position and the NIR wavelength response. A data fusion algorithm will be developed for completing this information with a sensor able to detect ceramic and glass. On this regard, reflectance sensors performances are under investigation. Signals coming from these two different sources will be synchronized and digitalized before entering the real-time classifier. The sensors set will be configured for communication with the logic unit running the classification algorithm.

Classification Algorithm: both geometric and spectral information will be taken into account by a real-time classification algorithm, whose development environment and hardware are under analysis. Conceptually, the centre of gravity of a single CDW part will be detected and identified as the point of the working field on which the robot end effector has to pick the target. On the other hand, the NIR and reflectance data acquired from the same particle will be fused together and elaborated by the algorithm to generate a 2D heat map of the objects on the conveyor belt at a certain time. Taking into account the speed of the belt and the information of the heat map, the algorithm will calculate the Cartesian coordinates of the object at the time when the robot will pick it, and will assign the material class to the object itself.

Robot Controller: a 6 Degrees of Freedom robotic arm will be used to handle each object and move it into the final position, according to the material class assigned by the classification algorithm. The robot will have a low payload (6 kg) due to the small dimensions of the parts to be sorted, being light and flexible enough to be installed on a small-scale prototype line.

4. CONCLUSION

In order to achieve the main goal of RE^4 Project, i.e. to develop a prefabricated building made by up to 65% by weight of CDW-derived materials, an advanced CDW sorting system is under development. Analysis of current CDW recovery systems pointed out the need for improving the purity of sorted aggregate classes.

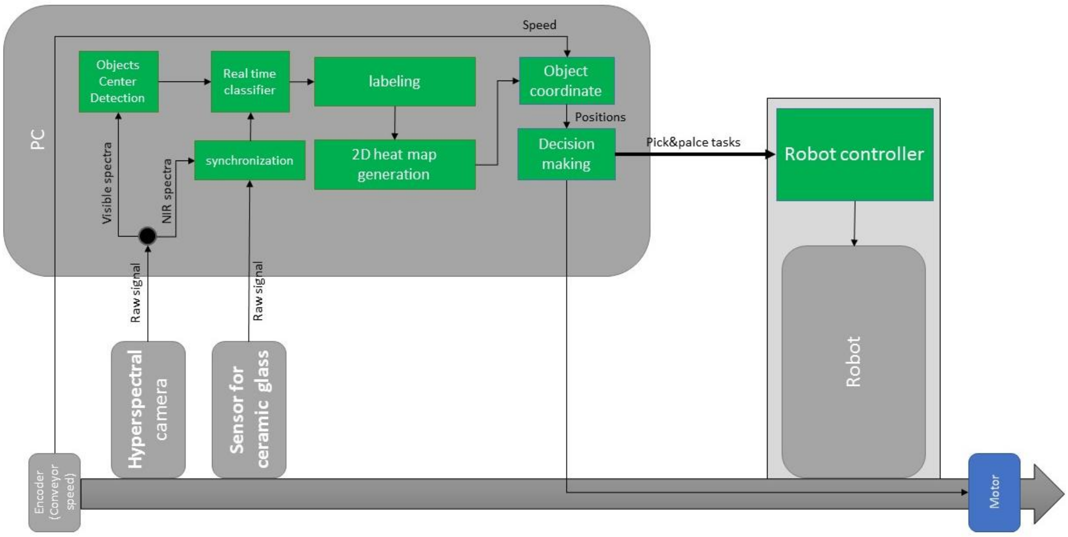

Figure 1 - Sorting system architecture

To this aim, a fully automatic, robot-based sorting system is under development, in order to achieve the complete separation of the coarse fractions of CDW materials, obtaining sorted classes of aggregates, bricks, ceramics, glass, plastics and wood. Hyperspectral analysis of each single particle of crushed CDW will allow to recognize the nature of different materials, and a classifier will be implemented to drive the robot in physical sorting. Preliminary results are expected for September 2017, while the full system integration will be ready by April 2018. The sorting system is expected to achieve a quality performance of maximum 1% by weight of material contamination among the different sorted classes.

ACKNOWLEDGEMENT
This research was carried out in the framework of the RE4 "REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction" project, which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583 (Call EEB-04-2016). Project partners, in particular CETMA Project Coordinator Mr. Alessandro Largo, are kindly acknowledged.

REFERENCES

[1] EUROPEAN COMMISSION ENV.A.2/ETU/2014/0049 - Resource Efficient Use of Mixed Wastes
[2] Implementing EU waste legislation for green growth, DG ENV (2011)
[3] Herczeg, M., McKinnon, D., Milios, L., Bakas, I., Klaassens, E., Svatikova, K. and Widerberg, O., 2014. Resource efficiency in the building sector. *Final report. Prepared for European Commission by ECORYS and Copenhagen Resource Institute, Rotterdam, the Netherlands*.
[4] Soutsos, M.N., Tang, K. and Millard, S.G., 2011. Concrete building blocks made with recycled demolition aggregate. *Construction and Building Materials*, *25*(2), pp.726-735.